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A Collection of Resources for the Study of Educational Reverse Engineering Activities in Engineering Design Education

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Marco Lino Calderón Saldierna

Doctorand

Director de Tesi

Prof. Dr. Ing. Joaquim Lloveras Macià

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DEDICATION

A Dios

A mi familia y amigos por el apoyo incondicional a través de los años

Marco Lino Calderón Saldierna

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Marco Lino Calderón Saldierna

Barcelona, Spain

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ABOUT THE UNIVERSITY

The School of Engineering of Barcelona was created in 1851. In 1971 it merged with other schools of engineering and architecture to form the Universitat Politècnica de Catalunya (UPC) and what is now the School of Industrial Engineering of Barcelona (ETSEIB) which combines its long-standing tradition with its endeavours to bring about renewal and continuous improvement; this has made it one of the best schools of engineering in Spain and it enjoys an excellent reputation on the international stage. The school has close ties with industry, the financial sector and local businesses (e.g. Seat, Nissan, and HP) which contribute towards its efforts to secure international outreach and recognition. The research, technology, and knowledge transfer activities that the school's departments; research centres, and groups carry out have made it a pioneer in many fields of science and technology which in turn has favoured its extensive involvement with the industrial sector.

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ABOUT THE AUTHOR

My name is Marco Lino Calderón Saldierna, I am a Mexican national with a doctoral research grant from Mexico's National Council on Science and Technology (CONACYT); I hold a degree in Electronics Engineering from the San Luis Potosi Institute of Technology in Mexico (ITSLP:2000) and a MBA from the Hochschule für Technik und Wirtschaft Berlin in Germany (HTW Berlin:2005). I've been the recipient of research grants by foreign governments such as (JICA - Japan:2003) and (ITEC India:2004) to attend specialization courses abroad, and I've had industrial working experience in the companies General Electric (GE:2000-2003) and Honeywell (HON:2006), as well as teaching experience at the Polytechnic University of San Luis Potosi in Mexico (UPSLP:2006-2007).

Apart from the contents in this doctoral dissertation, the following five peer-reviewed conference papers were also presented at relevant conferences across Europe:

- Product Visualization Praxis and its Integration to Academic Curricula, [Calderon. 2008]
- Analysis of Existing Products as a Tool for Engineering Design Education, [Calderon. 2009]
- Application of Reverse Engineering Activities in the Teaching of Engineering Design, [Calderon. 2010a]
- A Comparison of Competences Required in Reverse Engineering Exercises Versus Conventional Engineering Exercises and its Relationship to IPMA's Competence Baseline, [Calderon. 2010b]
- The Design Research Methodology as a Framework for the Development of a Tool for Engineering Design Education, [Calderon. 2010c]

Additionally, a work report was submitted to the Engineering Design Department of the Faculty of Mechanical Engineering at the Technical University of Ilmenau in Germany after being accepted for a three-month visiting internship in 2010.

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RESUM

Les Activitats Educatives d'Enginyeria Inversa "AEII" també conegudes com "EREA" pel seu acrònim en anglès ajuden els estudiants d'enginyeria de disseny a: Adquirir i desenvolupar un conjunt d'habilitats que eleven el seu coneixement del procés de disseny; expandir les seves fonts d'inspiració, situar les seves accions dins el cicle de vida d'un producte, i transformar coneixement teòric en pràctic. No obstant això, es va detectar que tot i que aquestes activitats despertaven l' interès dels professors de l'àrea d'enginyeria de disseny elles estaven o absents dels típics programes d'enginyeria de disseny o no explotades en la seva totalitat.

Després d'analitzar les causes d'això i determinar que la creació d'una col·lecció de recursos per a l'estudi de les activitats educatives d'enginyeria de disseny en l'àrea de l'ensenyament de l'enginyeria de disseny era la millor manera d'accedir a un grup geogràficament dispers i així començar a intentar canviar la situació de recerca existent , el desenvolupament d'aquests recursos va començar amb la meta d'atendre tantes inquietuds com fos possible, de les trobades sempre que s'intentava implementar "AEII" en programes existents d'enginyeria de disseny.

Els continguts seleccionats per a formar part de la col·lecció de recursos, van ser definits en base a converses inicials d'exploració amb experts en l'acadèmia i la indústria; sobre la base de la retroalimentació rebuda dels articles en conferència avaluats per parells procedents d'aquesta recerca doctoral, i de la presentació de resultats als revisors preliminars d'aquest projecte; per tals raons, la informació presentada en els diferents recursos està dirigida a instructors per primera vegada (o principiants) d'activitats d'enginyeria inversa i prenen en compte no només les consideracions tècniques sinó també les pedagògiques i administratives involucrades en l'estudi d'activitats acadèmiques i la seva potencial incorporació a un programa existent en enginyeria de disseny.

Atès que certa informació rellevant al tema de recerca ja existia però estava dispersa entre diverses àrees del coneixement; en comptes de desenvolupar tots els temes des de zero novament, es va realitzar un esforç conscient per examinar la literatura existent i consultar amb experts en el tema per així integrar i contextualitzar tota la informació disponible en un estudi coherent que pogués ser complementat amb els resultats originals produïts per aquesta investigació.

Les seccions principals que comprenen la col·lecció de recursos s'enumera a continuació:

• Recurs 1: Fonaments de les Activitats Educatives d'Enginyeria Inversa

• Recurs 2: Enginyeria Inversa i Aprenentatge

• Recurs 3: Interpretacions equívoques sobre l'Enginyeria Inversa

• Recurs 4: Beneficis de l'Enginyeria Inversa

• Recurs 5: Una Proposta de Metodologia per Utilitzar Anàlisi d'Enginyeria Inversa a l'Ensenyament de l'Enginyeria de Disseny

• Recurs 6: Una Proposta de Pedagogia per a l'Ensenyament d'Activitats Educatives d'Enginyeria Inversa

• Recurs 7: Exemple d'una Activitat Educativa d'Enginyeria Inversa en una càmera fotogràfica d'un sol ús

• Recurs 8: Conclusions i Apunts Finals

• Recurs 9: Recursos Diversos per a l'Estudi de l'Enginyeria Inversa

Els recursos van ser escrits utilitzant la metodologia "DRM" per a la investigació en l'àrea d'enginyeria de disseny i es va contactar a diverses institucions acadèmiques per saber del seu interès en aquests recursos, al final 12 institucions al Regne Unit; Irlanda, França, Dinamarca i Alemanya van mostrar el seu interès en el projecte i van accedir a rebre el document, ajudant així a complir una de les metes principals d'aquesta investigació que va ser difondre els resultats entre estudiosos de l'enginyeria inversa educativa. 5 articles en conferència també poden ser comptats com a resultat d'aquesta investigació.

Paraules Clau: Activitats educatives d'Enginyeria Inversa; ensenyament de l'enginyeria de disseny, habilitats de l'estudiant, materials d'ensenyament.

Codis UNESCO: 580101, 580103, 580107, 61042

ABSTRACT

Educational Reverse Engineering Activities referred to as the acronym "EREA" help engineering design students to: Acquire and develop a set of abilities that raise their awareness of the design process; expand their sources of inspiration, position their actions within the lifecycle of a product, and transform theoretical knowledge into practice. However, it was detected that although such activities sparked interest among engineering design educators, they were either absent from typical engineering design curricula or were not fully exploited.

After analysing the causes for it and determining that the creation of a collection of resources for the study of educational reverse engineering activities in the area of engineering design education was the best way to reach a geographically dispersed community and thus start trying to change the existing research situation, the development of such resources began with the goal to address as many of the concerns as possible found whenever trying to implement EREA into existing engineering design curricula.

The contents selected for inclusion in the collection of resources then, were derived based on initial exploratory discussions with experts in academia and industry; from the feedback received from peer reviewed conference papers stemming from this doctoral research, and from the presentation of intermediate results to early reviewers of this project; for such reasons, the information presented in the different resources target first time (or novice) instructors of reverse engineering activities and takes into account not only the technical but also the pedagogical and administrative considerations implicated in the study of academic activities and their potential introduction into an existing engineering design curriculum.

Given that some relevant information about the topic already existed but it was dispersed across different areas of knowledge; rather than developing all topics from scratch again, a conscious effort was made to examine published literature and to consult with domain experts to integrate and contextualise all existing information into a coherent body that could be complemented with the original results originating from this project.

The major sections comprising the collection of resources then, are listed below:

• Resource 1: Fundamentals of Educational Reverse Engineering Activities

• Resource 2: Reverse Engineering and Learning

• Resource 3: Misconceptions about Reverse Engineering

• Resource 4: Benefits of Reverse Engineering

• Resource 5: A Proposed Methodology for Reverse Engineering Analysis in Engineering Design Education

• Resource 6: A Suggested Pedagogy for the Teaching of Educational Reverse Engineering Activities

• Resource 7: Integrated Example of an Educational Reverse Engineering Activity on a Disposable Camera

• Resource 8: Conclusions and Final Remarks

• Resource 9: Miscellaneous Resources for the Study of Reverse Engineering

The abovementioned resources were of a self-contained nature, could be read either individually or sequentially, and were written using the "DRM" framework for research in the area of engineering design. Once finished, a number of academic institutions were contacted to measure their interest in the resources and in the end 12 different ones in the United Kingdom, Ireland, France, Denmark and Germany showed their interest in the research project and agreed to receive the document for reading thus helping fulfil one of the main goals of this research which was to disseminate the results from it. Other results from this project include five peer-reviewed conference papers, and a report presented at the Technical University of Ilmenau in Germany after spending a visiting internship abroad to learn about similar approaches to the research into reverse engineering by other schools and traditions of design.

Keywords: Educational reverse engineering activities; engineering design education, student's abilities, instructional materials.

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RESUMEN

Las Actividades Educativas de Ingeniería Inversa “AEII” o conocidas como “EREA” por su acrónimo en inglés ayudan a los estudiantes de ingeniería de diseño a: Adquirir y desarrollar un conjunto de habilidades que elevan su conocimiento del proceso de diseño; expandir sus fuentes de inspiración, situar sus acciones dentro del ciclo de vida de un producto, y transformar conocimiento teórico en practico. Sin embargo, se detectó que a pesar de que tales actividades despertaban el interés de los profesores del área de ingeniería de diseño ellas estaban o ausentes de los típicos programas de ingeniería de diseño o no explotadas en su totalidad.

Después de analizar las causas de ello y determinar que la creación de una colección de recursos para el estudio de las actividades educativas de ingeniería de diseño en el área de la enseñanza de la ingeniería de diseño era la mejor forma de acceder a un grupo geográficamente disperso y así empezar a intentar cambiar la situación de investigación existente, el desarrollo de tales recursos empezó con la meta de atender tantas inquietudes como fuera posible, de las encontradas siempre que se intentaba implementar “AEII” en programas existentes de ingeniería de diseño.

Los contenidos seleccionados para formar parte de la colección de recursos, fueron definidos en base a conversaciones iniciales de exploración con expertos en la academia y la industria; en base a la retroalimentación recibida de los artículos en conferencia evaluados por pares procedentes de esta investigación doctoral, y de la presentación de resultados preliminares a los revisores preliminares de este proyecto; por tales razones, la información presentada en los diferentes recursos están dirigidos a instructores por primera vez (o principiantes) de actividades de ingeniería inversa y toman en cuenta no solo las consideraciones técnicas sino también las pedagógicas y administrativas involucradas en el estudio de actividades académicas y su potencial incorporación a un programa existente en ingeniería de diseño.

Dado que cierta información relevante al tema de investigación ya existía pero estaba dispersa entre varias áreas del conocimiento; en vez de desarrollar todos los temas desde cero nuevamente, se realizó un esfuerzo consciente para examinar la literatura existente y consultar con expertos en el tema para así integrar y contextualizar toda la información disponible en un estudio coherente que pudiera ser complementado con los resultados originales producidos por esta investigación.

Las secciones principales que comprenden la colección de recursos se enumera a continuación:

- Recurso 1: Fundamentos de las Actividades Educativas de Ingeniería Inversa
- Recurso 2: Ingeniería Inversa y Aprendizaje
- Recurso 3: Interpretaciones Equívocas acerca de la Ingeniería Inversa
- Recurso 4: Beneficios de la Ingeniería Inversa
- Recurso 5: Una Propuesta de Metodología para Utilizar Análisis de Ingeniería Inversa en la Enseñanza de la Ingeniería de Diseño
- Recurso 6: Una Propuesta de Pedagogía para la Enseñanza de Actividades Educativas de Ingeniería Inversa
- Recurso 7: Ejemplo de una Actividad Educativa de Ingeniería Inversa en una Cámara Desechable
- Recurso 8: Conclusiones y Apuntes Finales
- Recurso 9: Recursos Diversos para el Estudio de la Ingeniería Inversa

Los recursos fueron escritos utilizando la metodología "DRM" para la investigación en el área de ingeniería de diseño y se contactó a diversas instituciones académicas para saber de su interés en tales recursos, al final 12 instituciones en el Reino Unido; Irlanda, Francia, Dinamarca y Alemania mostraron su interés en el proyecto y accedieron a recibir el documento, ayudando así a cumplir una de las metas principales de esta investigación que fue difundir sus resultados entre estudiosos de la ingeniería inversa educativa. Entre los resultado adicionales a esta tesis doctoral también se incluyen cinco artículos en conferencia revisados por pares, y un informe de trabajo presentado en la Universidad Técnica de Ilmenau en Alemania después de ser aceptado como investigador doctoral visitante para aprender sobre los diferente enfoques hacia la investigación de la ingeniería inversa por parte de otras escuelas y tradiciones de diseño.

Palabras Clave: Actividades educativas de Ingeniería Inversa; enseñanza de la ingeniería de diseño, habilidades del estudiante, materiales de enseñanza.

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***Unless otherwise stated all Tables / Figures were created by the author**

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GLOSSARY

The following is a list of terms used throughout this document next to the definitions best suited to convey the context and ideas presented herein, namely:

- **Ability:** The power or competence to perform an observable behaviour or an activity that results in an observable product
- **Capability:** The ability to perform actions
- **Competence:** A measure of the ability to perform a specific task, action or function successfully, so if capabilities are used with success they become a competence
- **Curriculum (Plural: Curricula):** A collection of courses
- **Effectiveness:** The capacity of producing a desired effect
- **Engineering Design:** The process of devising a system, component, or process to meet desired needs to end up in specifications and implementations
- **EREA:** Educational Reverse Engineering Activity (Plural: Activities), a term introduced in this project to describe a kind of hands-on activities that assist in the teaching of engineering design
- **Essential:** Said of anything indispensable to the attainment of a goal
- **Hands-On:** It refers to the human interaction with technology that implies an active participation in a direct and practical way
- **Instructional materials:** The discrete physical components of a curriculum e.g. textbooks, software, kits
- **Knowledge:** An organized body of information (i.e. Factual or procedural) applied directly to the performance of a function and that can be considered the lowest level of a learning outcome
- **Programme:** A curriculum taught progressively over the full length of career studies
- **Reverse Engineering:** An approach to developing an understanding of the functional relationships of a product without a priori knowledge.
- **Skills:** The proficient competence to perform a learned psychomotor act such as a manual, verbal, or mental manipulation of data or things
- **Structured:** Said of an approach having an organised, arranged form
- **Subject System:** The result of a development process and usually the object of the reverse engineering analysis. After: [Chikofsky & Cross. 1990]
- **Syllabus:** The schedule of a course
- **Systematic / Systematised:** Said of an approach that is carefully planned; methodical, organized, or arranged according to a system.

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PREFACE

Reverse engineering in education has been used for more than twenty years so far and several benefits from it have been documented already, e.g:

- To help students reduce the gap between theory and practice, [Sheppard. 1992a]
- To be an aid in expanding students' base knowledge of solutions and design possibilities, [Hyman. 2003]
- To elicit transfer (the ability to apply or adapt prior knowledge to solve new problems or develop novel solutions) in students, [Dalrymple. 2009]

However, back in 2010 while still exploring the definite research line to investigate, I found that whenever I mentioned educational reverse engineering as a research idea it was being met with curiosity and with a load of unrelated questions that quickly made me realize that a number of myths and misconceptions about educational reverse engineering activities "EREA" and about their role in engineering design were still floating around. After exploratory discussions with experts in academia and industry to see how extended these misconceptions actually were, I found that an interest in this type of educational activities to support the teaching of engineering design existed, but their level of understanding, credibility and integration to existing educational curricula was not homogeneous.

Based on such findings, the need arose to provide credible evidence about the benefits of EREA in design education and to help others integrate them into their existing teaching curricula, for example by providing examples and guided instructions that could ease the entry barriers to those potential adopters of EREA in the field of engineering design education. In the end, six research questions and two hypotheses were investigated following the Design Research Methodology by authors [Blessing & Chakrabarti. 2009] to try to come up with scientifically valid results that could be shown in a scholarly way.

This dissertation then, describes the experiences and impressions about the work done to understand; document, and help disseminate EREA via the creation of an assimilable, and readily applicable collection of resources for the systematic preparation; execution, evaluation and follow-up of such activities to support the teaching of engineering design.

Hoping that the information presented in this document proves useful for the attainment of your teaching goals.

Yours Truly: Marco Lino Calderón.

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I hear and I forget; I see and I remember; I do and I understand

Confucius, 551 BC – 479 BC

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CHAPTER 1 INTRODUCTION

1.1 Introduction to the Research Topic

Educational reverse engineering can be understood as the methodological analysis of a subject system (e.g. A consumer product) done by students in an academic setting and through hands-on activities that help discover the technological and non-technological principles of the system under analysis.

Educational reverse engineering entails the investigation of the structure; function and operation of a subject system by taking it apart and analyzing its workings in detail, to try to recapture the abstract and functional top level specifications envisioned by the original designers during the Product Design Specification (PDS) stage of the engineering design process, in a orderly sequence of steps that helps engineering design students not only to understand and compare against their own knowledge the design rationale and tradeoffs the original designers faced to go from multiple design solutions initially available down to the delimited solution boundaries featured in a final existing product, but also to asses a product's fulfilment of customer requirements and the reasons for its eventual market failure or success.

"Reverse Engineering" is a generic concept spanning several disciplines, but for a specific design education context it is theoretically founded on the product tear down analyses conducted in 1972 by Yoshihiko Sato, [Sato & Kaufman. 2005]; on the reverse engineering for product design methodology proposed by authors Otto and Wood, [Otto & Wood. 2001], and on Kolb's model of learning, [Kolb 1984] which states that concrete and practical experience can be obtained through product dissection activities, which in turn help reduce the gap between theory and practice in experimental learning environments.

The term "Reverse Engineering" has been traced back by author [Tilton. 2004] to at least 1960 in connection with hardware, when it meant an attempt to fathom and reconstruct the circuitry inside a potted electronic module, the first quotable definition of reverse engineering though, was given until 1985 by author [Rekoff. 1985] as "The process of developing a set of specifications for a complex hardware system by an orderly examination of specimens of that system"; other names for "Reverse Engineering" in the design education context include "Mechanical Dissection"; "Product Dissection", "D/A/A (Disassemble, Analyse, Assemble) Activities", and "Product Archaeology"; whereas similar engineering methods that share the concept of disassembling a subject system to further analyze it are called depending on their ultimate goal "Tear down analyses";

“Analysis of known solutions”, “Weak points analysis”, “Value engineering”, “Forensic engineering” and the German term “Konstruktionskritik” – roughly translated as – critique of designs. However, they are all traditionally associated to formal studies of design itself and are typically oriented to systems analysis or commercial, industrial applications that neither fully focus on the pedagogical value of the hands-on activities themselves nor on the non-technical aspects defining a system under analysis.

The first full scale implementation of educational reverse engineering activities in engineering design education then, can be traced back to Prof. Sheppard’s course “ME99 Mechanical Dissection”, [Sheppard. 1992a] offered at Stanford University in the USA in 1991, whose course’s objective was to give mechanical engineering students an understanding of mechanical artifacts by answering the question, “How did others solve a particular problem?”, such course marked the birth of the systematic study of dissection and reverse engineering activities in engineering education and proved the pedagogical viability of them.

For the purposes of this doctoral dissertation “Educational Reverse Engineering Activities” (EREA) is a term that describes an educational exercise which essentially follows the ideas and approaches of systems engineering, to analyse and understand a subject system (cf. a consumer product) through a combination of cognitive processes; engineering tests, and analyses of published data. If they are focused on the student’s acquisition of practice-related abilities rather than on their numerical exactness, such activities can indeed contribute to the overall fulfilment of the educational requirements of an engineering design student.

Note: A thorough analysis about the state of the art and fundamentals of educational reverse engineering activities that discusses among other topics:

- The principles of educational reverse engineering
- Similar approaches to reverse engineering
- Characteristics of subject systems
- The historical development of reverse engineering
- The drawbacks of the practice of reverse engineering
- The validity of reverse engineering as an academic subject in design education

is not shown here, but it can be found in Chapter 1 of annex A which is a self contained document titled “Resources for the Study of Educational Reverse Engineering Activities in Engineering Design Education” and it’s found at the end of the main body of this dissertation.

1.2 Research Specifics

1.2.1 Research Problem Statement

Educational reverse engineering activities, are in general, highly regarded hands-on activities cf. [Sheppard 1992a]; [Lamancusa et al.1996] and [Dalrymple. 2009] that help students bridge the gap between theory and practice in the safety of an educational environment; they can be included in any engineering design curriculum to help students increase their awareness and understanding of the design process, and to show through real-life examples, what worked for other designers and what didn't. However, as useful as they may sound, their understanding, credibility, and integration into existing engineering design curricula has been unequal, cf. [Calderon. 2010a], with a good level of integration found in design programs in the United States of America, the United Kingdom, and Germany for example, but with an irregular, rather low integration of them found anywhere else.

1.2.1.1 Research Situation

Initial, exploratory studies conducted as part of this research (e.g. Mentored colloquia during the first two years of the doctoral studies, discussions with experts and stakeholders in academia and practice, etc.) showed that the low integration of educational reverse engineering activities into existing teaching curricula in the area of engineering design could be associated to:

- The limited awareness about their educational benefits, especially in relation to their potential contribution to the expected competences of an engineering design student at the time of graduation
- The lack of a standardized guideline on how to actually prepare; deliver, and evaluate these activities to make the most out of them
- The perception that the existing resources for the study of EREA were either dispersed or unsuitable as a tutorial (i.e. Self-directed learning)
- The idea that current literature on the topic required a re-contextualization in light of progressing technologies now available in education
- A number of misconceptions about educational reverse engineering activities, mostly concerning their lawfulness and ethics.

And thus, the opportunity to improve the existing situation by investigating and developing solutions for the abovementioned issues was acknowledged.

1.2.2 Research Approach

This research was about the promotion of the use of reverse engineering activities in engineering design education by trying to increase in the engineering design community the awareness of their benefits and credibility as a teaching tool. To achieve this, there were two possible ways, one of them was to develop a new theory about the area of educational reverse engineering to come up with alternate concepts to the existing ones and then go to the field to conduct the required tests to evaluate the associated hypotheses and finally present the results to the academic community. In the author's opinion, this approach to the research and confirmation of the benefits and effectiveness of reverse engineering in education has been covered several times already by pioneer authors such as [Lamancusa et al. 1996] or [Otto et al. 1998] and more recently by authors such as [Dalrymple et al. 2011], but since the understanding and actual inclusion of this type of exercises in engineering design curricula still remained somewhat unequal, [Calderon. 2010] a second approach to promote the use of reverse engineering activities in engineering design education was devised as part of this doctoral project which dealt with analysing the status quo and why reverse engineering activities were not fully integrated into engineering design curricula, and then through tangible actions create a support tool, that could change the research situation (e.g. by addressing the most relevant barriers for the adoption and growth of reverse engineering activities in existing engineering design curricula).

Existing approaches to the study of methodologies for educational reverse engineering activities such as those by [Otto & Wood. 2001] or [Ogot & Kremer. 2006] differ with the one taken in this dissertation, in the sense that in here a more inclusive approach to the analysis of a subject system is favoured in order to understand the holistic context of a system's design, one that considers for example, its global; societal, ethical, economic and environmental aspects and not only those of a technical nature -and for which a large body of knowledge already exists- .This means that in the educational reverse engineering analysis of a product as suggested in the self contained document in Annex A of this dissertation, a number of educated guesses and speculations will have to support whatever raw data can be recovered from the inspection of a subject system.

The idea of an inclusive approach to educational reverse engineering analysis is not new, but it had been only barely explored, to the extent that as recent as 2011 authors such as [Lewis et al. 2011] were still stating that the majority of the product dissection activities (another name for EREA) that had resulted from previous efforts tended to focus solely on the technological aspects of a product (e.g. How it functioned (Function-form determinations) and how it was made (Product architecture)); to what they even added that “many existing product dissection activities have missed opportunities to highlight the wide range of issues (e.g. Global, economic, environmental, and societal) that influence product design and development”, [Lewis et al. 2011]. The approach followed in this dissertation for the study of EREA then, aimed to fit in the modern view of educational reverse engineering research and thus not only considered a broader range of analyses and criteria for the evaluations of a system but also placed the students’ acquisition and development of practice-related abilities during reverse engineering exercises at the forefront of its research approach.

1.2.3 The Research Questions

Figure 1.1 below lists the research questions that led the development of this doctoral project, they came up at the initial stages of the investigation not only as a natural consequence of the identified problem with the study and adoption of educational reverse engineering activities in engineering design education, but also from what it was believed at the moment that would provide the necessary insight into the phenomena under study.

Research Questions

RQ 1. What are the major challenges engineering design professors perceive in order to implement Educational Reverse Engineering Activities (EREA)?

RQ 2. How can educational materials based on reverse engineering activities be developed in a systematic way?

RQ 3. How can the effectiveness of Educational Reverse Engineering Activities as an educational tool be measured?

RQ 4. What are the characteristics of educational materials based on reverse engineering activities that are favored by engineering design students?

RQ 5. What are the tradeoffs and added value in engineering design education between reverse engineering exercises and forward engineering exercises?

RQ 6. Are there any legal boundaries to the dissemination in academical environments of results obtained through the use of Educational Reverse Engineering Activities?

Figure 1.1 The Doctoral Research’s Questions

The research questions intended to address those concerns expressed by potential adopters of EREA in exploratory discussions held at the beginning of the research project and were worded in a fully detailed way so they could be answered through empirical studies at the initial stages of this research, and also so they could be considered according to author's [Trochim. 2006] description of research questions as:

- Descriptive in the sense that the aim was "to describe what was going on or what existed"
- Relational because they aimed "to look at the relationships between two or more variables"
- Causal because they tried to determine "whether one or more variables caused or affected one or more outcome variables"

Unlike the research hypotheses that will be shown next, the research questions remained the same throughout the duration of the research project, and only certain subquestions arose from time to time until they were answered and incorporated into the different chapters of the collection of resources presented in Annex A of this document. A discussion of the rationale of the research questions though, and of the results obtained from them is presented in Chapter 4 of this dissertation.

1.2.4 The Research Hypotheses

Figure 1.2 below lists the definitive hypotheses that were tested in this dissertation and which helped to evaluate if the proposed solution to improve the research situation was indeed suitable for the problem detected.

The three hypotheses listed below though, were being tested initially in this dissertation:

- **H1:** The development, conduction and evaluation of reverse engineering exercises to support the teaching of engineering design can be systematized through a guiding manual that takes into account documented experiences, conclusions and best practices in reverse engineering praxis as well as relevant learning topics on the teaching of engineering design.
- **H2:** Increased awareness of a reverse engineering methodology as a tool to teach engineering design through the presentation of a guiding manual will increase professors' eagerness to use it and include it in an engineering design curriculum.
- **H3:** The analysis and explanation of a reverse engineering exercise to teach engineering design presented in a guiding manual will provide professors with ideas

on how to teach engineering design topics and increase their competence to develop examples of their own.

However as the understanding of the research topic grew and it became clear what the solution to the detected research situation would be like; that the researcher would only be able to impact the contents and structure of the suggested solution to the research situation, and that the eagerness, awareness and new ideas of a potential test population would be hard to measure, the hypotheses shown in Figure 1.2 were proposed in 2010 still at an early stage of the research since they better reflected the characteristic of this doctoral research and which in fact ended up leading the direction of most of the work in this dissertation from 2010 to 2015.

The hypotheses, just as the research questions then, came as a natural consequence of the identified needs and problems with the study of reverse engineering activities in the area of engineering design education and they were considered suitable to provide meaningful insight into the phenomena under study. Still it should be mentioned that the only way to prove the proposed hypothesis would be through a thorough literature review and comparative analysis among findings from similar projects, so the use of a formal methodology to arrive at the materialisation of the proposed solution to the research situation was made in order to have a higher chance of producing scientifically valid results, as it will be later explained in Chapter 2 of this dissertation

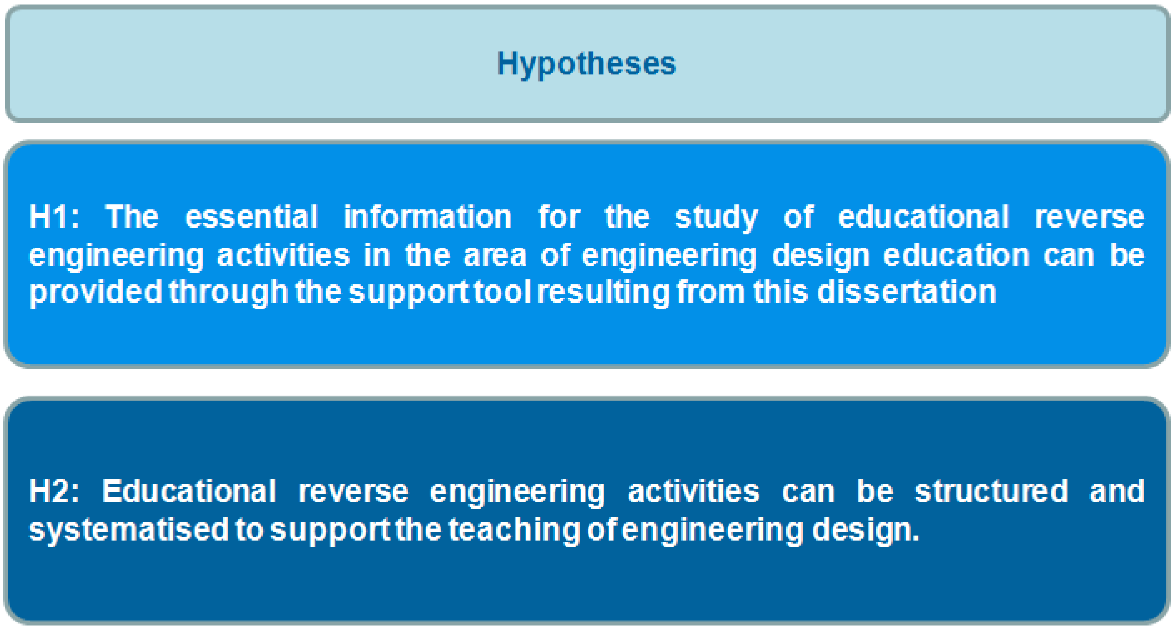

Figure 1.2 The Research's Hypotheses

Since no researcher is free of assumptions though, close attention was paid to comply with authors' [Frankfort-Nachmias & Nachmias. 1996] criteria so the characteristics of the definite hypotheses could be considered:

- Clear: So all of the variables were conceptually and operationally defined (e.g. Observed and assessed)
- Unspecific: To avoid bias and the expected direction of the answers
- Answerable: So it was possible to find an answer with available methods
- Value-free: To deal only with facts without needing to take a stand on values

The major constraint then, as in every doctoral project, was to assess each of the research questions and hypotheses within the timeframe of the project and the resources available for it.

1.2.5 General Research Objective

To facilitate the inclusion of educational reverse engineering activities in the teaching of engineering design.

1.2.5.1 Specific Research Objectives

Additional to the general objective, a number of specific ones based on the analysis of the research situation at the time, and on the needs detected in the initial exploratory studies were also pursued, namely:

- To investigate and document the benefits and drawbacks of educational reverse engineering activities
- To validate (either through bibliographical search or through direct experimentation) the use of EREA as a tool for the teaching of engineering design
- To clarify the line between the educational and non educational contexts of reverse engineering
- To lay the foundations to help educators develop their own scalable instructional materials, teaching strategies, and educational innovations applied to educational reverse engineering activities.
- To find out the areas specific to engineering design where educational reverse engineering activities could better enhance student's abilities
- To document how EREA could support creativity, innovation and invention

- To document how the properties of EREA could contribute towards the attainment of the desired learning outcomes of typical engineering design programs and of the expected competences from graduates of them.
- To provide engineering design professors with the information that justified the inclusion of EREA into existing teaching curricula.
- To highlight the suitability of EREA as a tool to reach some of the desired educational goals of an engineering design program.

The results from this doctoral research then, tried to provide an unbiased view of educational reverse engineering activities pointing out both their strengths and weaknesses.

1.2.6 Research Scope

This research was focused on the educational (rather than commercial) aspects of reverse engineering, and dealt with the exploration of the causes that contributed to the lack of diffusion and regard for reverse engineering activities in education, and also with the creation of a support tool to try to change the existing research situation (a "Collection of resources" as it'll be later explained in Chapter 3), and unlike previous related theses such as that by [Jounghyun. 1994] that focused mostly on the use of DFA (Design for Assembly) techniques to reconstruct the design history of a product; that of [Leek & Larsson. 2007] that focused on the development of an educational exercise, or the one by [Dalrymple. 2009] that focused on the pedagogical value of reverse engineering activities, this research instead, focused on the collection of existing evidence and approaches to educational reverse engineering, to come up with a comprehensive outline of the existing resources that could help educators to implement the educational benefits of reverse engineering activities as smoothly as possible into existing and future educational curricula in the area of engineering design, and also to measure their impact in supporting individual and group learning.

Because an actual contribution to the state of the art on the topic was sought in this doctoral research; its efforts and resources were not concentrated on the individual analysis tools, techniques or technologies for reverse engineering analysis itself -and for which an overwhelming amount of knowledge dispersed across several engineering domains is already available- but instead on the methodology to deliver them to students so they could acquire, develop or exercise practice-related abilities while doing them, because of this, familiar topics in engineering design and technical systems analysis such as:

- Artificial systems; product organs, inputs, physical effects, physical phenomena ,changes of state, behavioural models and the different constructs and relationships for modelling them
- Design analysis and optimization techniques

are barely mentioned in this document, and only whenever they truly add to the explanation of the topic in question.

The replication then; of previous research efforts or of previous researchers' results just to independently confirm them once again, was not the focus of this research either; that doesn't mean that previous results and conclusions from other authors were naively accepted and blindly followed, it only meant that given the available resources, all efforts were directed to the areas where an original contribution to the existing body of knowledge in the topic was actually possible.

1.2.6.1 Research Focus

The investigation of the causes that impede the adoption and expansion of educational reverse engineering activities in the teaching of engineering design, as well as the creation of a potential solution to such issue.

1.2.7 Research Justification

Additional to the reported benefits of EREA in the learning of engineering design which provided and still provide any researcher enough reason to keep investigating on the topic; a number of authors at the time of the beginning of this doctoral project had in fact already raised their concerns in regard to need to clarify the connection between reverse engineering analysis; design proficiency, education, and the fundamentals of such activities overall, examples of the statements that justified the development of this research include but are not limited to:

- Authors' [Lamancusa et al. 1997] statement regarding "the lack of professional quality, self standing course materials to support the teaching of product dissection"
- Authors' [Abe & Starr. 2003] statement that "in the literature, there is rarely an explicit connection between take-apart activities and the design process. It appears that the attitude is that 'it cannot hurt, but we are not sure how it helps.'"
- Authors' [Jensen et al. 2004] statement that there is already considerable literature that addresses the advantages of using hands-on experiences in an engineering curriculum but "despite the importance of active learning activities is well recognized, little formal guidance in a systematic approach for development exists"

- Authors' [Simpson et al. 2007] statement regarding the lack of materials "to support the planning that ensures a successful dissection activity"

The acknowledgment of such statements then, helped to commit to the definite topic for investigation in this research and marked the starting point of the creation of a suggested solution for the research situation.

1.2.8 Research Assumptions

This research operated under two basic assumptions, namely:

- That engineering design professors truly wanted to provide their students with hands-on experiences in the classroom (either through EREA; Make-and-Test activities cf.[Andrew. 2006], capstone projects, or any other delivery method of their choice).
- That the clear, contextualized presentation of evidence about the learning benefits of educational reverse engineering activities, and of the information on how to benefit from them would actually increase an engineering design professor's eagerness to integrate EREA into his/her teaching.

The discussion about these assumptions and how findings and results from this research directly or indirectly supported them is presented in Chapter 4

1.2.9 Expected Research Results

The expectation at the beginning of this research project was to document the experiences in developing a support tool that helped professors to integrate educational reverse engineering activities into their engineering design curriculum. It was believed at that time that by easing the potential adopter's learning curve for the preparation, execution, evaluation and follow up of such tasks; the knowledge gaps, unwanted complexity, and unnecessary steps that they could entail would be avoided and so suitable guidelines, methods, and tools to develop educational resources for instructor-led or self-directed learning would be produced by the results from this doctoral project. Chapter 4 discusses the findings and results from striving to achieve those goals.

1.3 Chapter Conclusions

Although early studies stated that hands-on activities such as educational reverse engineering ones could become a popular pedagogy to provide students with practical experience in the classroom, cf. [Lamancusa et al. 1996], at the time of the beginning of this doctoral research though, there were still many areas left to explore in the topic and thus there was a scarcity of relevant resources for its study; this situation became particularly evident early in the planning of this doctoral project when it was found that guidelines to develop educational initiatives based on reverse engineering activities were also lacking.

The set of initial exploratory studies; suggested research questions, and hypotheses then, intended to lead the investigation efforts towards the search of relevant answers and resources dispersed across varied areas of knowledge, and from which this research could eventually benefit.

The main challenge in planning the development of this research topic then, came from trying to find an appropriate balance that included the social; technical, didactic, and experiential issues relevant to the topic under study, while at the same time taking into consideration the research interests of potential adopters of EREA, as well as the existing administrative structures in academic institutions that could support or hinder the inclusion of new educational initiatives into existing educational programmes.

CHAPTER 2 THE RESEARCH METHODOLOGY

2.1 Chapter Introduction

At the beginning of this doctoral research some educators in the area of reverse engineering stated that engineering design students in modern times were less prepared to do well in engineering, since they lacked the experience and intuition that developed from "hands-on" activities from adolescent years; at the same time they declared that “To teach and study engineering design could be difficult sometimes, especially when transforming theoretical knowledge into practice”, [Ogot et al. 2008]. These two arguments could be logically related by author’s [Kolb. 1984] findings in the sense that reverse engineering activities can provide students with concrete and practical experience, and so ,as explained already, the need to provide high quality hands-on experiences to students was acknowledged.

To address such issue, this doctoral research developed as end result a collection of resources bundled together as a self contained document shown here in Annex A to help engineering design professors study and eventually implement, educational reverse engineering activities that could be adapted to the requirements of a typical curriculum in engineering design (e.g. Specific learning objectives; fundamentals, methods, test materials, and feedback mechanisms). The project required the documentation of the theoretical background behind hands-on activities in education, and of the technical and methodological knowledge needed to conduct reverse engineering exercises so the project’s hypotheses could be tested and the research questions thoroughly answered.

In order to give this doctoral project and the results from it the scientific rigor and scholar approach required, a research methodology to support the development of this investigation was sought and three major methodologies suitable for the area of engineering design education were found, namely:

- The research framework and methodology by [Duffy & Andreasen. 1995] and [Duffy & O’Donell. 1999]
- The soft systems methodology “SSM” by [Checkland. 1981] and [Checkland. 1999]
- The design research methodology “DRM” by [Blessing & Chakrabarti. 2009]

In the end, it was decided to go with the DRM methodology not only because it explicitly worked with the existing and the desired research situations and supported the development of solutions to get from one to the other but also because in 2009 the author had the opportunity to learn first-hand about the research methodology with her co-author

Lucienne Blessing during the 2009 summer school on engineering design research held first in Croatia to learn the theory behind it and then in Finland to present results related to one's doctoral research. Throughout this chapter then, the experiences and findings from using authors' [Blessing & Chakrabarti. 2009] "DRM" methodology for design research are presented.

2.2 "DRM" A Design Research Methodology

A design research methodology is an approach and a set of supporting methods and guidelines to be used as a framework for doing design research, The design research methodology by authors [Blessing & Chakrabarti. 2009] called "DRM" was chosen as the supporting framework for this doctoral project since its methods were intended to support a more rigorous research approach by helping to plan and implement design research, and because, if used flexibly as the authors suggested, this methodology should help make design research more effective and efficient.

The methodology framework proposed by Blessing and Chakrabarti consists of four stages, namely: Research Clarification (RC), Descriptive Study I (DS-I), Prescriptive Study (PS) and Descriptive Study II (DS-II), and as stated by the authors:

- The RC stage helps clarify the current understanding and the overall research aim, develop a research plan and provide a focus for the subsequent stages.
- The DS-I stage aims at understanding the situation under study and the factors that influence its behaviour, so the information obtained helps researchers develop their core contribution to science through the possible means, aids and measures to improve the research situation and that enable the evaluation of the core contribution of the researcher (a collection of resources for the study of EREA in engineering design education in this case)
- The PS stage aims at developing support tool in a systematic way, taking into account the results of DS-I.
- The DS-II stage focuses on evaluating the usability and applicability of the actual support and its usefulness.

2.2.1 Objectives and Benefits of Using "DRM"

Design education is a complex multidisciplinary research topic and as stated already "DRM" was used as the supporting framework for this project not only because it aimed to provide a set of supporting methods and guidelines to be used as a framework for doing design research, but also because it suited the variety of fields involved in the research of design education topics. The specific objectives of the DRM methodology that were of relevance to this dissertation then, are listed below:

- To provide a framework for design research for individual researchers and teams to help them identify research areas and projects academically worthwhile
- To allow a variety of research approaches and methods while providing guidelines for the systematic planning of rigorous research
- To help develop a solid line of argumentation positioning the research projects in reference to other design research and encourage reflection on the applied approach.
- To help select suitable methods and combinations of methods to carry out the stages of the research process.

The "DRM" methodology began to be used early in the development of this doctoral research and the findings and deliverables from them will be shown throughout this chapter.

2.2.2 General Overview of the "DRM" Framework

As previously mentioned "DRM" consists of four stages: Research Clarification, Descriptive Study I, Prescriptive Study (PS) and Descriptive Study II, Figure 2.1 shows the links between these stages; the basic means used in each stage, and the main outcomes, whereas the bold arrows between the stages illustrate the main process flow and the light arrows the many iterations among them.

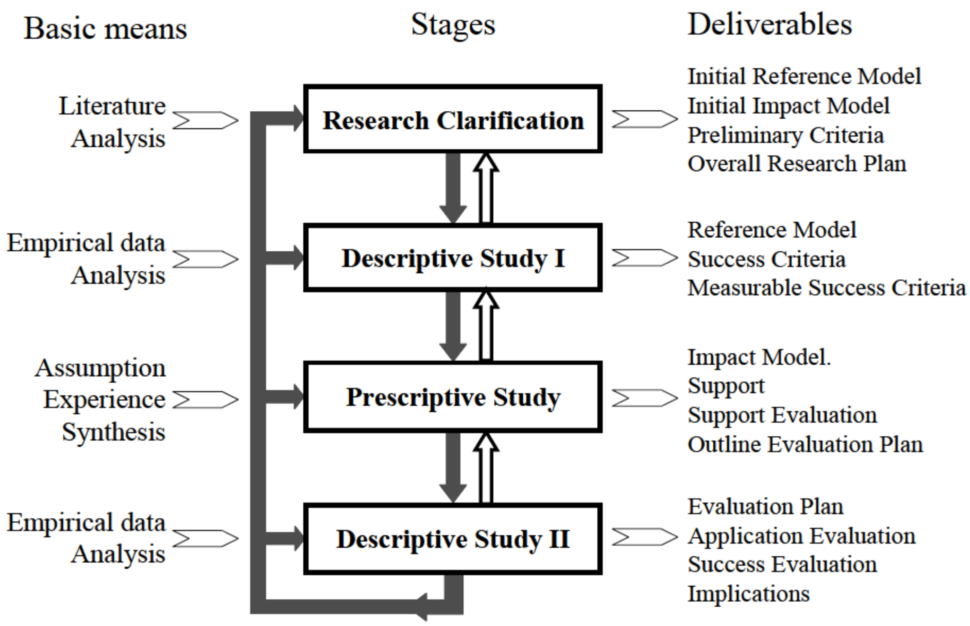

Figure 2.1 DRM Framework: Stages, Basic Means, and Deliverables, [Blessing & Chakrabarti. 2009]

As seen in Figure 2.1 above, the DRM Framework sets deliverables for every stage of it, although depending on the nature of project, and on the resources available for it, some of the deliverables could be only partially developed or fully skipped. The information leading to the respective deliverables from this research will be shown throughout the rest of this chapter in graphical and tabular form.

2.2.3 Possible Research Types According to the DRM Framework

Table 2.1 below shows the seven possible types of design research recognized by the DRM framework, they are based on the depth to which the individual stages are researched according to the studies conducted to understand the state-of-the-art with respect to a particular stage. A review-based study means it is based only on the review of the literature. A comprehensive study comprises a literature review, as well as studies in which results are produced by the researcher. An initial study closes a project and involves the first few steps of a particular stage to show the effects of the results and prepare them to be used by others. Authors [Blessing & Chakrabarti. 2009] have stated that it will be the research questions; hypotheses, available time and resources what will influence the type of research needed for every project.

Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1. Review-based →	Comprehensive		
2. Review-based →	Comprehensive →	Initial	
3. Review-based →	Review-based →	Comprehensive →	Initial
4. Review-based →	Review-based →	Review-based → Initial/ Comprehensive ←	Comprehensive
5. Review-based →	Comprehensive →	Comprehensive →	Initial
6. Review-based →	Review-based →	Comprehensive →	Comprehensive
7. Review-based →	Comprehensive →	Comprehensive →	Comprehensive

Table 2.1 Types of Design Research Projects and Their Main Focus (Iterations Omitted), Source: [Blessing & Chakrabarti. 2009]

According to the DRM methodology then, this was a “Type 5: “Development of Support Based on a Comprehensive Study of the Existing Situation” research project in the sense that the understanding of the research situation obtained from the comprehensive study of existing literature; initial, exploratory analyses and original results produced by the researcher from it, were enough to start the development of a support tool (The collection of resources for the study of EREA in engineering design education shown in Annex A of this document), therefore, this research involved both the development of the understanding of the situation (Comprehensive DS-I Stage) and based on this, the development of a support tool to change it (Comprehensive PS Stage) which in turn led to an Initial DS-II stage which closed the research project; showed some potential consequences of the results, and prepared them to be used and tested by others, meaning that the support tool itself is only initially or indirectly tested by the researcher in terms of its coherence and scientific validity, but it rests on others (e.g. the users) the confirmation of the usability the support tool. This type of research project then, is considered common for research situations such as this one where resources to achieve a given goal weren't suitable or didn't exist at all. The types of research six and seven in Table 2.1 for example are those developed by research groups with enough resources and people, whereas student project usually fall on the first five types, being type three and five the most common ones among them.

2.3 Deliverables from the DRM Framework

In the sections further below this research's deliverables for each stage of the DRM framework will be shown.

2.3.1 Deliverables from the Research Clarification Stage

Two main deliverables are expected from this research stage which can take one or several forms of the options listed below, namely:

A. Current understanding and expectations

1. Initial reference model
2. Initial impact model
3. Preliminary criteria

B. Overall research plan

1. Research focus and goals
2. Research problems, main research questions and hypotheses
3. Relevant areas to be consulted
4. Approach (Type of research, main stages and methods)

5. Expected area of contributions and deliverables
6. Time Schedule

Most of the stage deliverables concerning research questions, hypotheses, and research approaches have been presented already throughout Chapter 1 so it only rests to present here the following ones:

2.3.1.1 The Initial Reference Model

The design research methodology (DRM) required the visualization of the initial research conditions through a network of influencing factors and the relationships between them to better analyse the research situation and come up with a suggested support tool that could improve it.

At this initial stage and according to experience; assumptions, literature search, and own studies it was identified that the ultimate "Success Criteria" for this research project would be represented by a high level of "Integration of educational reverse engineering activities (EREA) into engineering design curricula", but the "Measurable Success Criteria" that could be identified and analysed in this research project would focus on the "Degree of applicability (of EREA) by engineering design professors" and "The students' understanding of engineering design principles (through EREA)" where the "Key Factor" considered to be addressed through the support tool would be the "Development of reverse engineering activities (a.k.a. D/A/A Activities)" which were considered to trigger a logical path of actual relationships and educated assumptions that would characterize the "Success criteria".

Figure 2.2 below graphically shows the initial reference model obtained for this research that was published to show the initial understanding of the research problem

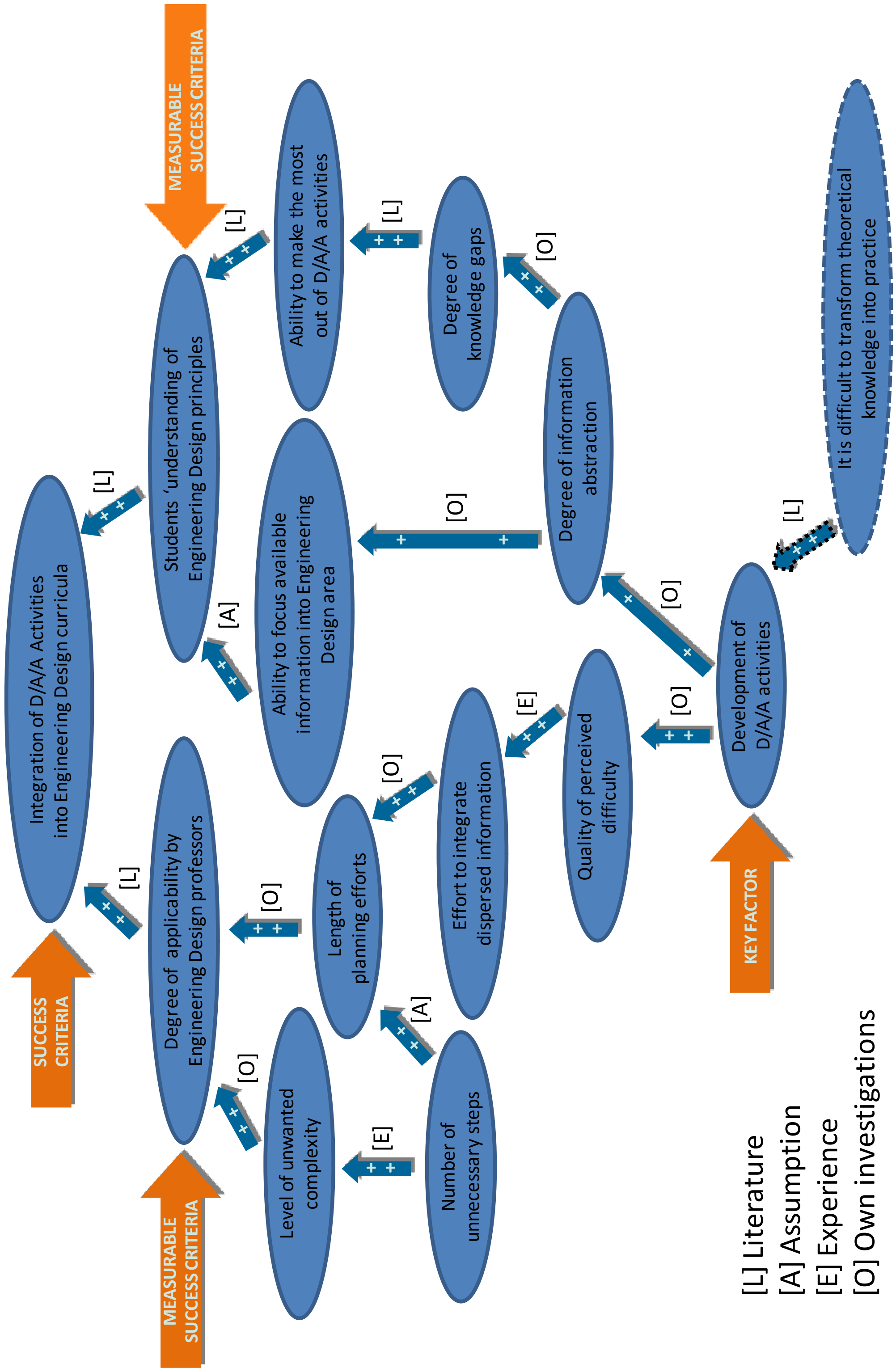

Figure 2.2 The Initial Reference Model, as Published in [Calderon. 2010a]

2.3.1.2 The Initial Impact Model

Figure 2.3 shown next represents what the DRM framework calls the "Initial impact model" and which was envisioned at the beginning of this research project; it can be considered a visual description of the desired, final research situation showing the expected changes to the initial reference model after the introduction of the support tool symbolized by the hexagon at the lower end of the picture, in this figure, and reflecting the expectations at that time, it is portrayed how the level of integration of a reverse engineering pedagogy in engineering design education would be considered the "Success Criteria" from this research but "Measurable Success Criteria" (using the DRM terminology) would be the eagerness by engineering design professors to increase:

- The number of courses including EREA in an engineering design curriculum
- The amount of time spent on EREA in an engineering design curriculum
- The number of reverse engineering activities in an engineering design curriculum
- The amount favourable perception about EREA

And updated version of this model though better reflecting the expectations of the research project and acknowledging that all that could be controlled as a researcher would be contents and structure of the proposed support tool was later created and is shown here further below in Figure 2.6

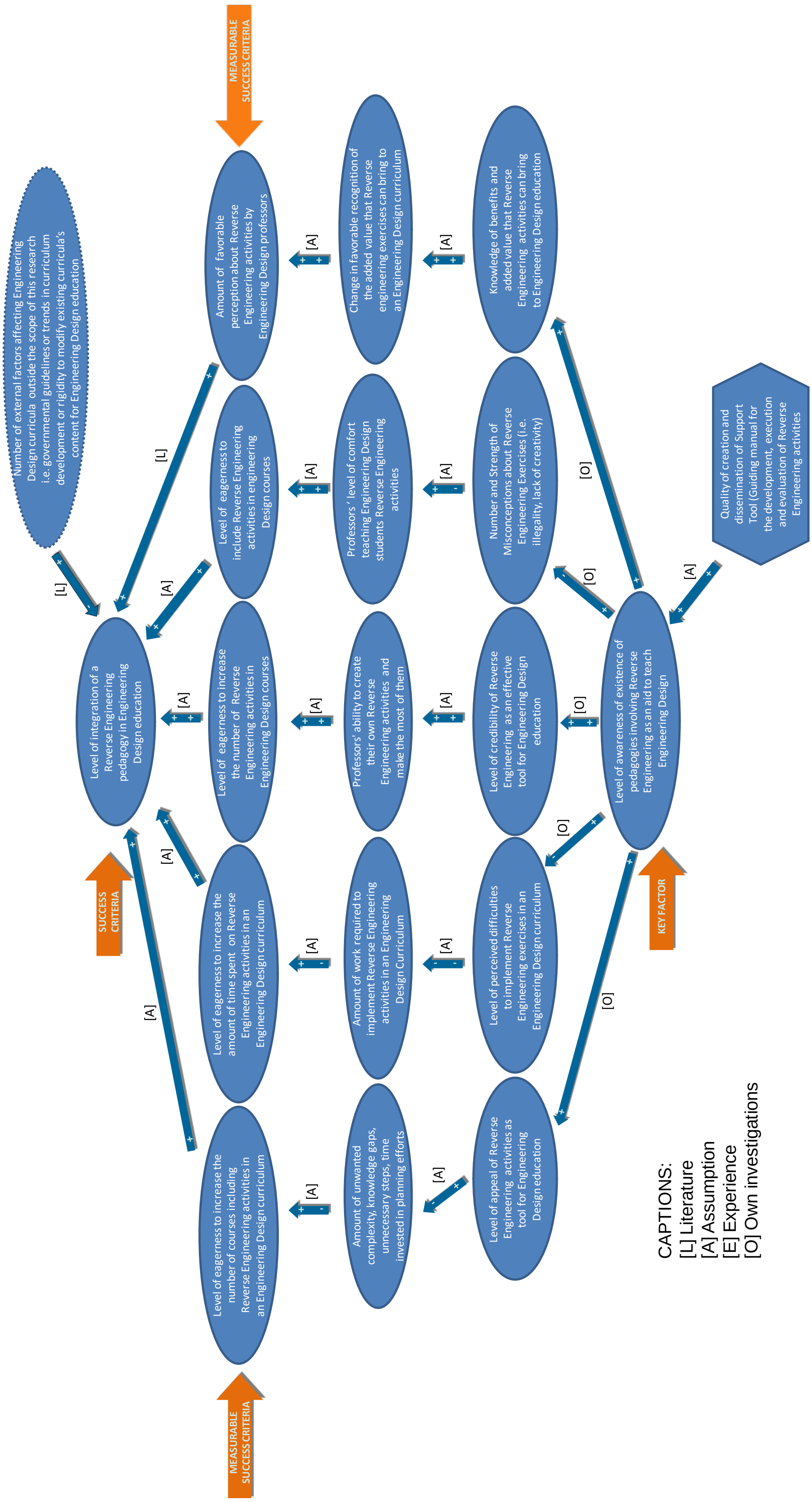

Figure 2.3 Initial Impact Model

However, this initial impact model helped direct the research efforts during early stages of this research and helped better understand the topic under analysis

2.3.1.3 Areas of Relevance and Contribution "ARC" Diagram

The ARC diagram serves the DRM methodology by providing a graphical representation of the main areas that will influence the development of the research project by classifying them as "useful" or "essential" according to the needs of the project and also by showing the reader where the main contribution of the research topic will be used. Figure 2.4 below shows the global areas relevant to this research project, they are colour coded to indicate the research topic itself, the areas essential to the research project in this case being the analysis of existing products and the synthesis of the knowledge extracted from the analysis; the educational areas of expected contribution of the research results and finally the areas that were considered useful for the execution and completion of this project. This figure was published by the author in [Calderon. 2010a]

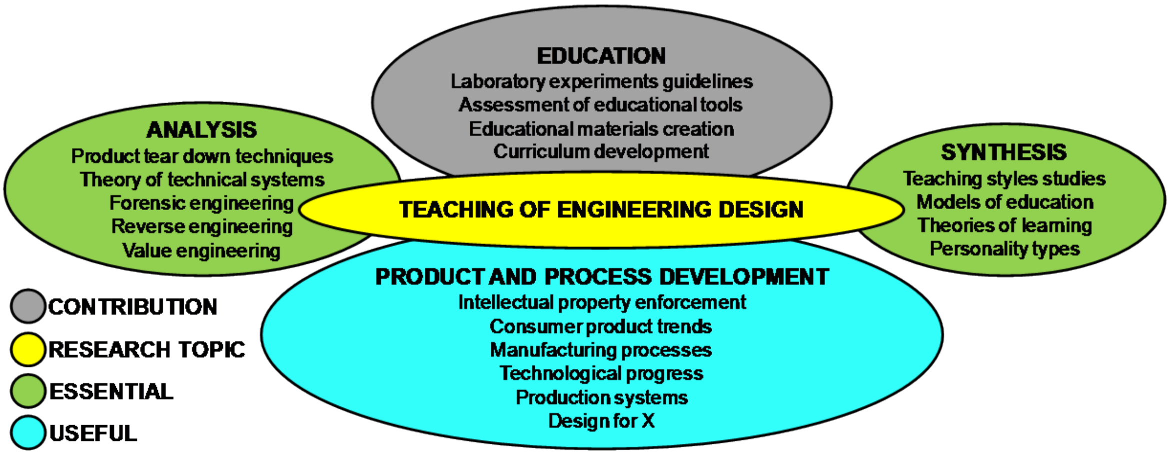

Figure 2.4 Diagram of Areas of Relevance and Contribution, as published in: [Calderon. 2010a]

2.3.1.4 Summarised Work Schedule

Table 2.2 below shows a summarized version of what became the actual correspondence of workload against the stages of the development of the research and according to the identified research type previously mentioned in Table 2.1

RESEARCH CLARIFICATION	DESCRIPTIVE STUDY I	PRESCRIPTIVE STUDY	DESCRIPTIVE STUDY II
Review based →	Comprehensive →	Comprehensive →	Initial
a) Literature analysis b) Development of understanding c) Definition of preliminary criteria and goals d) Confirmation that a support tool to improve the existing situation was needed	a) Identification of the state of the art b) Comprehensive study of the existing situation c) Preparation to improve existing situation based on findings	a) Development of support tool and related aids, data banks and procedures	a) Evaluation of support tool through indirect confirmation and validation (e.g. literature review or the use of a structured , recognised method to arrive at the materialisation itself of the support tool)
2008 / 2010	2010/ 2011	2012 / 2015	2015

Table 2.2 Summarised Work Schedule

In Table 2.2 above then, it can be seen how the actual creation of the support tool (The collection of resources shown in Annex A) took most of the resources from this research.

2.3.2 Deliverables from the Descriptive Study I Stage

Three main deliverables are expected from this research stage which can take one or several forms from the options listed below, namely:

A. Completed reference model, success criteria, measurable success criteria and key factors

1. Description of the existing situation and problems
2. Relevance of the research topic
3. Main line of argumentation
4. Most suitable factors to address to improve current situation

B. Updated initial impact model

C. Implications for the development / evaluation of support

The most relevant ones that turned out to be of key importance to the development of this research are shown and explained next.

2.3.2.1 The Completed Reference Model

As mentioned already the design research methodology (DRM) requires the visualization of the research conditions to better analyse the research situation and come up with a suggested support tool that can improve it; Figure 2.5 below shows the graphical representation of the completed reference model for the research situation, this figure was updated in late 2011 from the original one from 2010 (shown above in Figure 2.2) to better reflect the research conditions where according to experience; assumptions, literature search, and own studies, it was identified that:

- The ultimate success criteria for this research project would be a high level of integration of EREA into existing engineering design curricula
- Measurable success criteria that could be actually identified and analysed in this research project would focus only on the quality of the support tool to assist the use; adaption, appropriation, and discovery of EREA (which are common terms to measure adoption rates in education, cf. [Ceoforum. 1999])
- The key factor to be addressed through the support tool (the collection of resources presented in Annex A) would be the level of awareness of engineering design professors about the benefits and fundamentals of EREA in support of the teaching of engineering design

The major difference from the initial and the updated reference models then, was the discard of the aspects related to the measurements of the eagerness of the target users of the support tool, and instead it was decided to focus only on the quality of the contents and the methodological creation of the support tool

Figure 2.5 below graphically shows the network of influencing factors and the relationships between major actors in the research situation in a format that helped clarify its understanding and thus start developing a potential solution to it.

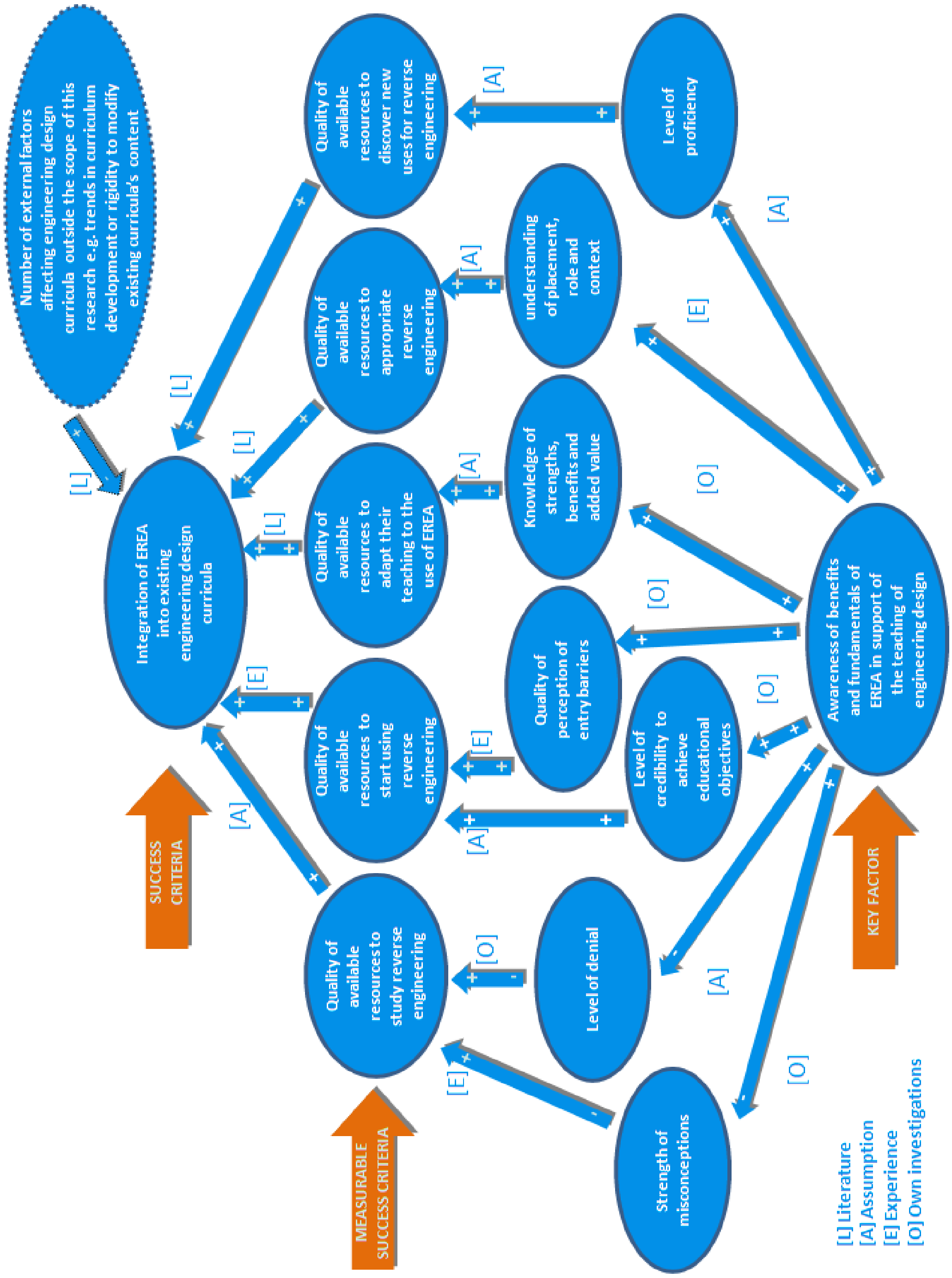

Figure 2.5 The Completed Reference Model, After [Calderon. 2010c]

2.3.2.2 The Updated Initial Impact Model

Figure 2.6 below shows a visual description of what the expected final research situation would be like after the introduction of the support tool symbolized by the hexagon at the lower end of the picture. In this project it was expected that after introducing the support tool (The collection of resources) the integration of EREA into existing engineering design curricula would increase, but measurable success criteria for the attainment of such goals would be the existence of resources to study, plan, execute, evaluate and follow-up EREA. The key factor to address then, would be providing the reader of the support tool with the necessary information to increase the awareness of benefits and fundamentals of EREA in support of the teaching of engineering design

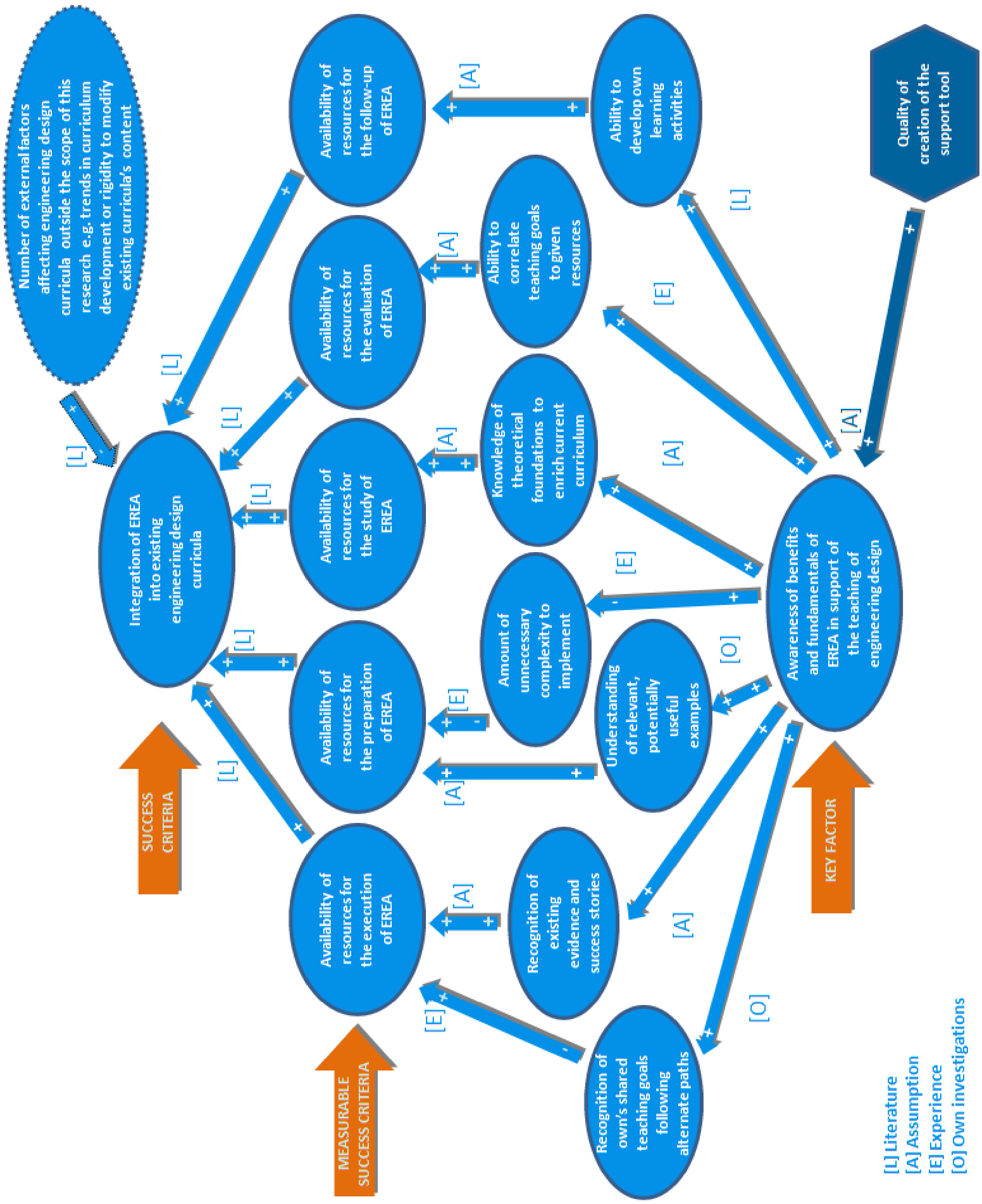

Figure 2.6 The Updated Impact Model

Additionally, the updated impact model also considered how other external factors could also hinder the introduction of EREA into existing engineering design curricula but they might be outside the scope of this research project (e.g. Rigidity to change existing curricula contents, or future governmental trends on the contents of engineering education programs). The attainment of the final research situation and the findings from striving towards it are discussed at the conclusions chapter of this document.

2.3.2.3 Clarification of the Area under Study and of the Relevance of the Research Results

In order to place the results from this research in the right context and thus help disseminate them and reach the right audience, it was determined that the area under study would be "Engineering Design Education" and thus it also had to be proved that it was indeed a scientifically valid area of research continuously studied by several authors. The paragraphs shown below thus, were actually published by the author in [Calderon. 2010c] to explain the scientific and academic validity of the topic under study.

2.3.2.3.1 Engineering Design Education under Design Research

Engineering design education can be interpreted as the academic process that enables students to learn the required knowledge and skills necessary to fulfil the expected requirements of a professional design practice, this interpretation is derived from the three following definitions:

- "Engineering design is a systematic; intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints", [Engineering Education Community. 2010]
- "Design education is primarily focused on students, and on helping them understand and experience the process and methods of realizing an artifact. The quality of the student-created artifact is often of secondary importance in the learning process", [Sheppard & Rollie. 1996]
- "Engineering education is the activity of teaching engineering and technology, at school, college and university levels. The goal of engineering education is to prepare people to practice engineering as a profession and also to spread technological literacy, increase student interest in technical careers through science and math education, and hands-on learning", [Douglas & Chitra. 2004]

A clear definition of engineering design education then as the one presented further above, helped position the educational nature of this research project and to clarify its areas of expected contribution.

2.3.2.3.2 Education as a Research Topic in Design

The educational aspect of design and the different names with which it is referred to, is a scientifically valid area of research and has been previously mentioned by authors such as [Archer. 1981] who identified "Design pedagogy" as one of the ten fields of design science as seen in Table 2.3 below.

Design History	Design Taxonomy	Design Technology	Design Praxiology	Design Modelling
Design Metrology	Design Axiology	Design Philosophy	Design Epistemology	Design Pedagogy

Table 2.3 Archer's ten Fields of Design, After: [Archer. 1981]

Education and a pedagogy for the teaching of engineering design then, has been also defined by authors Beheshti and Van Der Veer as an "area that define the influences of design in terms of studying both internal and external experiences of designing", [Beheshti & Van der Veer. 1999]; additionally, authors Fulcher and Hills considered research and education as part of the "third primary cluster" in their descriptive taxonomy of design research topics, [Fulcher & Hills. 1998]. But it is perhaps in Horváth's order of engineering design research, [Horváth.2004] shown below in Figure 2.7 where the design education domain is more clearly seen. Author Horváth proposed a teleology-inspired framework of reasoning to enable the grounded argumentation about the order of engineering design research and the articulation of the engineering design knowledge. This determined that the results from this dissertation fell mostly into the design education area, thus leaving the decidedly technical aspects of the reverse engineering activities under study in a low profile, since the primary focus of this chapter was to present the rational that led to this project and how the results could be implemented by interested engineering design professors.

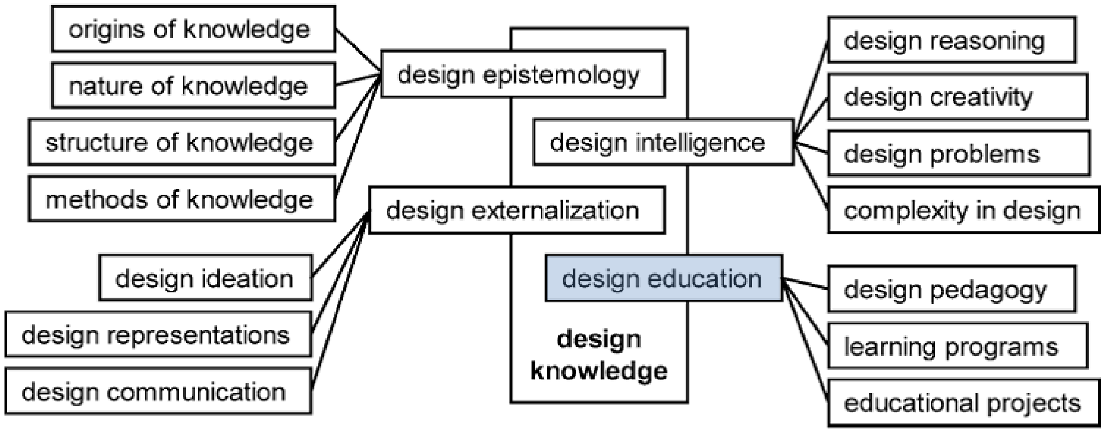

Figure 2.7 Research in Design Knowledge, Source: [Horváth.2004]

2.3.2.4 Data Collection and Research Methods

Once the research questions were established and the hypotheses defined, an analysis of the potential research and data collection methods was done in order to match the information needed, with the most appropriate methods to get them and thus plan accordingly along the duration of the research project; consequently the question-method matrix shown below in Table 2.4 was drawn with a structure and elements that detailed every research question and hypotheses considered for this research.

The leftmost column in Table 2.4 then, lists downwards the six research questions and two hypotheses generated during this research project whereas the rest of the column headers lists the data collection and research methods categories considered for every question or hypothesis under tests (documents and interviewing), which were then further subdivided for additional detailing. They are grouped and read from left to right in Table 2.4 as:

- Documents
    - o Study of existing cases on reverse engineering
    - o Study of relevant engineering topics
    - o Study of best practices in education (e.g. development of curriculum, educational materials)
    - o Study of educational psychology topics (e.g. learning models, cognitive processes, etc.)
    - o Study of existing curricula on engineering design

- Study of guidelines and standards on engineering design
  - Study of intellectual property law
  - Study of competitive intelligence topics
- Interviewing
  - Professors
  - Students
  - Product Designers
  - Educational Researchers
  - Intellectual Property Experts (Although a thorough bibliographical analysis also yielded enough information to answer the research questions posed).

To populate such matrix, cells were individually divided into an upper part that indicated the suitability of the method for addressing the research questions or hypotheses and a lower part that indicated the effort required from the researcher and the participants. In the cell's upper part, the number of ticks indicated whether the method was expected to fully answer the research questions and hypotheses or just to obtain a partial answer from it. Two ticks (√√) for example, indicated that the method was expected to fully answer the question or verify the hypothesis completely while one tick (√) meant that answers could only be obtained partially or indirectly.

The information in the cell's lower part referred to the effort (e.g. Preparation; application, processing, analysis, etc) from the researcher and the participants to address the research question or hypotheses and they were indicated either by a single letter "R" indicating a small effort for the researchers or two "RR" indicating a large effort. In the same way, a single letter "P" meant a small effort for the participant and two letters "PP" indicated a large effort, whenever the effort could be negligible though, this part of the cell could remain empty.

The two most common data collection methods used in design research are real-time, and retrospective, none is better than the other, they are used for different purposes. This research for example, did not require real time data collection methods; instead, it relied on retrospective data collection methods such as documents and interviewing, the reason for this was that both the research questions and hypotheses were focused on evaluating impressions and requests from the participants and not on the execution of the reverse engineering exercises themselves. This matrix format then, allowed the triangulation of data so multiple sources and methods to gather evidence about a particular phenomenon were used to strengthen the evidence.

	DOCUMENTS								INTERVIEWING				
	Study of existing cases on reverse engineering	Study of relevant engineering topics	Study of best practices in education (e.g. development of curriculum, educational materials)	Study of educational psychology topics (e.g. learning models, cognitive processes, etc.)	Study of existing curricula on engineering design	Study of guidelines and standards on engineering design	Study of intellectual property law	Study of competitive intelligence topics	Professors	Students	Product Designers	Educational Researchers	Intelectual Property Experts
RESEARCH QUESTION 1: What are the major challenges engineering design professors perceive in order to implement Educational Reverse Engineering Activities (EREA)?	√ RR		√ RR	√ RR	√ RR				√√ RR P	√ RR P		√ RR P	
RESEARCH QUESTION 2: How can educational materials based on reverse engineering activities be developed in a systematic way?	√ RR	√ RR	√√ RR	√ RR	√√ RR	√√ RR			√ R P	√ R P		√√ R PP	
RESEARCH QUESTION 3: How can the effectiveness of Educational Reverse Engineering Activities as an educational tool be measured?	√ RR		√ RR	√√ RR	√ RR				√√ RR PP	√√ RR PP	√ R P	√√ RR PP	
RESEARCH QUESTION 4: What are the characteristics of educational materials based on reverse engineering activities that are favored by engineering design students?	√ RR	√ RR	√ RR	√√ RR	√ RR				√√ RR PP	√√ RR P		√√ RR PP	
RESEARCH QUESTION 5: What are the tradeoffs and added value in engineering design education between reverse engineering exercises and forward engineering exercises?	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR PP	√ RR PP	√ RR PP	√√ RR PP	√ RR P
RESEARCH QUESTION 6: Are there any legal boundaries to the dissemination in academical environments of results obtained through the use of Educational Reverse Engineering Activities?	√ RR				√ RR		√√ RR PP	√ RR PP	√ RR P				√√ RR PP
HYPOTHESIS 1: The essential information for the study of educational reverse engineering activities in the area of engineering design education can be provided through the support tool resulting from this dissertation.	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR PP	√ RR PP	√ RR	√ RR PP	√ RR
HYPOTHESIS 2: Educational reverse engineering activities can be structured and systematised to support the teaching of engineering design.	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR	√ RR P	√ RR	√ RR	√ RR P	√ RR

Table 2.4 Question-Method Matrix for Data Collection and Research Methods

2.3.2.5 Implications for the Development / Evaluation of the Support Tool

Based on the understanding of what the key factors and success criteria for the results from this research would be, the search for the best solution to the research situation began, which ultimately ended in the selection of the creation of a collection of resources for the study of EREA in engineering design education but whose reasons for choosing it as the preferred support tool will be detailed further below.

2.2.5.5.1 Determined Requirements Lists for the Support Tool

The following is the list of requirements that were initially set for the support tool and that were considered suitable to improve the research situation, namely:

A. Impending Need:

- To develop a support tool to help engineering design educators to study educational reverse engineering activities in the area of engineering design education.

B. Performance:

- The support should suggest modifications to existing teaching curricula
- The support should be able to support the preparation, conduction, evaluation, and follow-up of educational reverse engineering activities
- The support should provide guidelines on how to integrate existing resources to the suggested activities
- The support should be able to use the information available in engineering design education as input
- The suggested activities should be achievable enough to be used as a regular activity within the engineering design education process

C. Ergonomics:

- The support should be usable by individual, experienced, and non experienced engineering design educators
- The support should be easy to introduce to the target population
- The contents of the support should be easy to learn
- The support should be easy to use
- The support should be easy to maintain

D. Cost:

- The support should be free and of unrestricted distribution

- The support should not be costly to maintain (i.e. No more than 10hr/month to be invested by the author or the reader to maintain it up-to-date or relevant)

E. Introduction:

- Only a computer, internet connection or a printer should be necessary to acquire the support tool
- It should be possible to use the support tool in conjunction with existing support available in engineering design laboratories

F. Life:

- The support, with maintenance, should have indefinite life, unless research in education changed paradigms completely at some point in time

D. Disposal:

- The electronic version of the support should have no problems beings disposed, the hard copy of it should be disposed in accordance with existing policies for environmental care

These requirements were derived from the analysis of existing resources for the study of educational reverse engineering: through exploratory discussions with experienced educators and potential users, as well as from the detected needs in the teaching of engineering design.

It should be mentioned though that the materialised resources did not comply properly with the ergonomic requirements set here since their length doesn't allow the easy transportation of a hard copy comprising all of them, however a wealth of resources are contained therein and thus the presentation of relevant information to the readers was favoured over complying with the ergonomic requirements.

2.2.5.5.2 Analysis of Concepts and Variants for the Support Tool

As mentioned before, design support in the DRM methodology can take several forms, it includes all possible means, aids and measures that can be used to improve design and as authors [Blessing & Chakrabarti. 2009] state, these are "prescriptions" – suggesting ways by which design tasks should be carried out – and can include strategies; methodologies, procedures, methods, techniques, software tools, guidelines, knowledge bases, workbooks, checklists, knowledge, tools and so on".

For the goals stated in this research all of the abovementioned possibilities were considered, even to determine if the solution to the research problem didn't actually lie within the realm of the author of this dissertation, so an estimate was made whether, or the extent to which, the identified user needs might be actually satisfied by using the current research resources.

The methods for synthesizing support proposals listed below in Table 2.5 below were used to help generate a variety of alternative proposals for fulfilling the individual requirements of the support tool, and helped to combine these into overall proposals

Method	Aim	Suggested by
Brainstorming	To stimulate a group of people to produce many ideas quickly	[Roozenburg & Eekels.1995]
Checklists	To discuss systematically a number of items	[Roozenburg & Eekels.1995]
Why? Why? Why?	To enlarge search space	[Cross. 1994]

Table 2.5 Methods used in this Research for Synthesizing Support Proposals

Four finalist candidates for the support tool of this dissertation were evaluated; the majority rule (which is an ordinal method just like Copeland rule; rank-sum rule, lexicographical rule, or Pugh charts) was used to rank alternatives per criterion on an ordinal scale and compare the alternatives against a list of criteria and their importance. Such candidates are shown in Table 2.6 below with a short summary of the advantages and disadvantages considered.

Type of Support	Collection of Resources	Workshops	Internet Video	Software
Advantages	Distributable, Citable	Interactivity	Availability	Suitable for self-study
Disadvantages	Fixed content	Follow up can be non existent	Language barriers	Learning curve

Table 2.6 Analysis of Concepts and Variants of Support Tool Candidates

In the end, from the findings of this stage, the creation in electronic PDF format, and the dissemination of a collection of resources for the study of educational reverse engineering activities in the area of engineering design education that could be read either individually or collectively, was considered the best trade off to make EREA activities accessible in a way that they could be read by interested educators; and thus suggest a theoretical contribution towards the attainment of the objectives stated in this research (e.g. to increase the awareness of pedagogies involving reverse engineering activities to teach engineering design.)

The advantage of creating an electronic, printable collection of resources then, lied in its ability to collect and distribute the results and findings from this doctoral research. The other approaches mentioned in Table 2.6 above were discarded for a variety of reasons including the lack of training from the author on software and video related topics; the lack of resources to conduct intensive workshops on the topic, and also not being a native English language speaker. In the end the creation of the electronic resources provided the most reasonable balance in content vs. delivery method, and in personalized vs. self-directed training.

It should be still clarified though, that although at first sight the terms "support tool" and "collection of resources" might seem interchangeable, they are not, since the term "support tool" is used in the DRM methodology to refer to a general concept and "collection of resources" was the final form it took from a myriad that it could have taken

2.3.2.6 Expected Research Deliverables

Finally, for this stage of the DRM methodology the expected deliverables as a result from the whole research were determined, namely:

- A doctoral thesis: Scholarly documenting the research studies needed to test the hypotheses and to answer the research questions that led to the creation of the collection of resources shown in Annex A
- A collection of resources: To document the theoretical background behind hands-on activities in education and to help engineering design professors implement reverse engineering activities adapted to the requirements of a curriculum in engineering design (e.g. Specific learning objectives, fundamentals, techniques, methodologies, test materials, venues, and feedback mechanisms)
- Academic Papers: To be presented at congresses or journals on relevant topics.

This document is the doctoral thesis itself; whereas the collection of resources is shown in annex A (and independently from the main body of this dissertation), the conference papers resulting from intermediate results from this research then, are listed below for reference:

- Product Visualization Praxis and its Integration to Academic Curricula, [Calderon. 2008]
- Analysis of Existing Products as a Tool for Engineering Design Education, [Calderon. 2009]

- Application of Reverse Engineering Activities in the Teaching of Engineering Design, [Calderon. 2010a]
- A Comparison of Competences Required in Reverse Engineering Exercises Versus Conventional Engineering Exercises and its Relationship to IPMA's Competence Baseline, [Calderon. 2010b]
- The Design Research Methodology as a Framework for the Development of a Tool for Engineering Design Education, [Calderon. 2010c]

2.3.3 Deliverables from the Prescriptive Study Stage

Five main deliverables are expected from this research stage which can take one or several forms of the options listed below, namely:

A. Documentation of the Intended Support

1. Intended: Support description, introduction plan, impact model

B. Actual Support:

1. The guiding manual itself

C. Documentation of the Actual Support:

1. Actual: Support description, introduction plan, impact model

D. Results of the Support Evaluation:

1. Consistency check: Each part at one level of detail is addressed by some part at the other
2. Completeness Check: each function intended to be addressed by the support is indeed addressed

E. Outline Evaluation Plan:

1. Evaluation of: Support itself, its application, success.

Those that were developed according to the nature of this research and to the resources available for it are shown and explained further below.

2.3.3.1 Analysis of Objectives and Requirements

The list of methods seen in Table 2.7 below were used by the author during this stage to help analyse the support tool's objectives; clarify the requirements that the support tool should fulfil, the relationships between the associated requirements, and their relative importance.

Method	Aim	As Suggested by
Stating objectives	To identify the external conditions with which the support tool had to be compatible	[Pahl et al. 2007], [Cross. 1994]
Literature search	To find published information that could be useful	[Jones. 1970]
Interviewing users	To elicit information known only to the users of the intended or existing support e.g. through conversations and semi structured interviews performed by the author	[Jones. 1970], [Dillman et al. 2008]

Table 2.7 Methods Used for Analysing Objectives and Establishing Requirements

The results from such methods can be more clearly seen in the selection of the specific contents shown in the collection of resources in Annex A and in the subsections listed further below in this chapter.

2.3.3.2 Development of the Support Tool in Relation to the Development of the whole Doctoral Research

Because of the way this research was planned there is a double set of reasoning rules and guidelines for the execution of the doctoral research.

- The first set belongs to the typical, methodological approach for the development of a doctoral research overall (e.g. Research questions, hypotheses, objectives, scope, expectations, etc.)
- The second set, which still originates from the first set but that it was fitted to guide the development of the support tool itself which means that it had its own objectives and delimitations that were devised to comply with the academic rigor expected from its role as the main result from this doctoral research

The second set will be explained in the subsections further below, namely:

2.3.3.2.1 Use of the Term “A Collection of Resources”

In practical terms, “standards” and “guidelines” may not be clearly differentiated from each other and so the term “A collection of resources for the study of EREA in engineering design education” or shortened as “Collection of Resources” was chosen to better reflect the intention of the document in Annex A to guide newcomers to the topic of educational reverse engineering into its fundamentals and the challenges for their implementation as an tool in the teaching of engineering design.

2.3.3.2.2 Description of the Collection of Resources

An electronic; freely distributable, and printable document comprised of nine major sections "Resources" suitable for individual or sequential reading, that intend to provide the reader with the fundamentals behind educational reverse engineering activities and their eventual integration into an existing engineering design curriculum by providing resources for the planning, execution, evaluation and follow-up of them

2.3.3.2.3 Justification for the Development of a Collection of Resources

Given that no clear correlation exists between effective research and effective teaching a freely distributable guiding manual was prepared under commonly accepted pedagogic principles (e.g. Presentation of sequential, accumulative information; use of an introduction; method, results, conclusions structure, etc.) to help engineering design professors to ease the learning curve about EREA and about their implementation into an existing educational curriculum

2.3.3.2.4 General Goal of the Collection of Resources

The support tool pursues its own goal which is related but different to that of the overall research project, the goal of the collection of resources then, is to increase the readers' eagerness to try reverse engineering activities in their teaching practice and it aims to do so by providing them with the information necessary to understand the benefits of reverse engineering activities and the ways to incorporate them into their teaching practice.

2.3.3.2.5 Specific Goals of the Collection of Resources

The specific goals of the collection of resources intended to address important concerns found in trying to implement EREA into existing engineering design curricula, namely:

- To help first time instructors of educational reverse engineering with the associated entry barriers and learning curves by providing them with accessible information, know-how and sample activities to start with.
- To provide engineering design professors with resources for the eventual development of further instructional courseware for the benefit of their students
- To support future lines of research and new approaches to educational reverse engineering

- To help potential adopters to make the most out of EREA and provide them with credible justifications and advises for each stage of their introduction into their teaching practices

The contents comprising the collection of resources then, directly and indirectly try to tackle these concerns.

2.3.3.2.6 Added Value of the Collection of Resources

The resources take into account and cite the most relevant; documented experiences, conclusions, and best practices in the research about educational reverse engineering and incorporate the latest findings (at the time of publishing of this dissertation) in the area

2.3.3.2.7 Expectations from the Collection of Resources

Given that a formal research methodology (DRM) was followed to satisfy the detected need to improve the teaching of engineering design; the collection of resources' contribution was also believed to be academically worthwhile since it exceeded the depth and span of information previously presented to the general public in past, related research, not to mention that the freely-distributable nature of the guiding manual was thought to contribute to its dissemination

2.3.3.2.8 Description of the Collection of Resources and its Contents

The collection of resources includes numerous references, reflections and Insight that can be used not only for the contextualization and understanding of the field of educational reverse engineering but also for the self production of laboratory activities and hands-on demonstrations that can be brought into the teaching practice. The information and guidelines provided there are aimed at the study of the fundamentals of the topic and towards an implementation of reverse engineering activities at the undergraduate level, still, enough detail is provided so they can be ported to different educational settings such as introductory high school activities or even graduate level projects. The contents of the collection of resources itself is aimed at engineering design professors but every effort has been made to present the information in a nontechnical terminology so its benefits and limitations can be better understood should a broader audience ever read the resources.

In order to present systematically developed statements to assist practitioners of EREA in their appropriate implementation in academic settings, the collection of resources itself includes a set of recommendations and steps that can be followed and that are supported by links to external resources on available research and evidence on the topic.

A short description of the contents of each of the resources in the collection is listed next:

- **Resource 1** Fundamentals of Educational Reverse Engineering Activities: Foundations and contextualization of reverse engineering research in the field of engineering design; differences and similarities with other approaches that bring practical experience to the classroom, challenges in the implementation of EREA, etc.
- **Resource 2** Reverse Engineering and Learning: Cognitive processes students undergo when performing educational reverse engineering activities.
- **Resource 3** Misconceptions about Reverse Engineering: Clarification of misunderstandings about reverse engineering in education.
- **Resource 4** Benefits of Reverse Engineering: An account of previously published advantages; potentialities, and added value reverse engineering activities can bring to the teaching and learning of engineering design.
- **Resource 5** A Proposed Methodology for Reverse Engineering Analysis in Engineering Design Education: A methodology addressed to the field of engineering design for the educational analysis of consumer products
- **Resource 6** A Suggested Pedagogy for the Teaching of Educational Reverse Engineering Activities: A collection of tips and advices dealing with the practical aspects behind the execution of the steps; analyses, tasks, and questions proposed in the methodology of Resource 5
- **Resource 7** Integrated Example of an Educational Reverse Engineering Activity on a Disposable Camera: A guided example, suitable for self-directed learning of an educational reverse engineering activity using a disposable photographic camera as subject system
- **Resource 8** Conclusions and Final Remarks: Thoughts on the present and future use of reverse engineering in education based on collected experience and an analysis of existing, published research
- **Resource 9** Miscellaneous Resources for the Study of Reverse Engineering: An assortment of references linking to published research with the potential to support the eventual development of additional, instructional courseware

The abovementioned resources can be considered self-contained and can be read individually, depending on the interests and needs of the reader in turn, however they can be considered of a sequential nature too since they purposefully converge at Resource 7 of the collection, given that the guided example shown therein expects to contribute in laying out the foundations for the eventual development of the readers' own scalable instructional materials; teaching strategies and educational innovations applied to educational reverse engineering activities. The full reading of the collection of resources then is suggested to better benefit from it.

2.3.3.2.9 Specific Area of Support of the Guiding Manual in Regard to the Resources Available for its Development

Different scenarios and needs exist in engineering design education, however limited resources allow only for the targeting of those with the highest chances of success, this situation is common to most projects as portrayed in Figure 2.8 below by authors [Verschuren. 1997] and [Blessing & Chakrabarti. 2009]

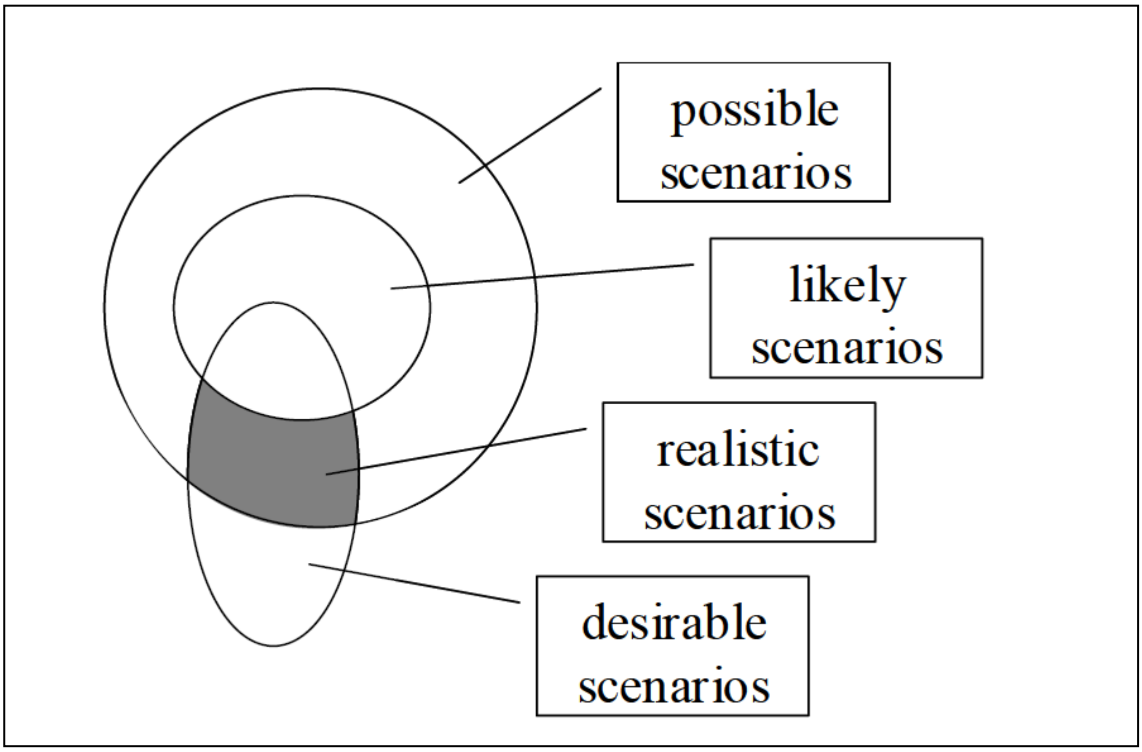

Figure 2.8 Schematic View of the area in which the Collection of Resources should Function, After: [Verschuren. 1997] and [Blessing & Chakrabarti. 2009]

Although a final version of the collection of resources was created from the results of this doctoral research and it's shown here in Annex A, it is still expected that new content can be added to it in the future, this is common in the creation of dissemination materials (e.g. Manuals, guidelines, etc.) where a better understanding of the research topic based on feedback received from the field makes the contents changes over time. It is important to emphasise though, that the resources available in a research project are often insufficient to realise the entire range of intended functionality, or the detail necessary for the introduction, use, and evaluation of the support in the target context. What is actually realised in the end (the actual support tool) can therefore be, and often is, more restricted than the intended support as explained in Figure 2.9 below

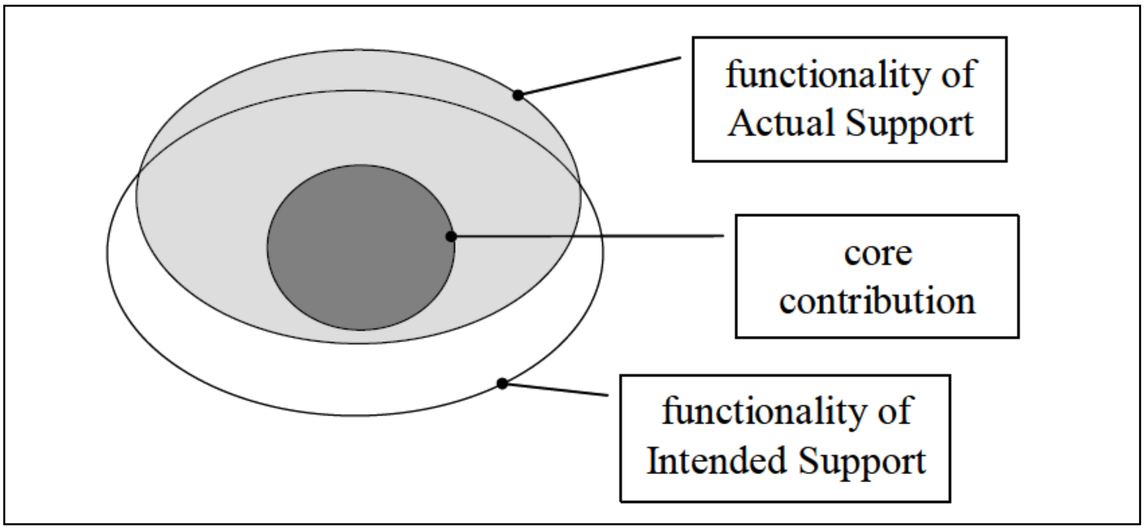

Figure 2.9 Core Contribution in Relation to Intended and Actual Support, Source: [Blessing & Chakrabarti. 2009]

The support tool presented in Annex A then, could be considered as a proof of concept and might differ from the ideal intended support in the sense that a different implementation form might be required; not all functionalities could be available, domain coverage could not be complete, or performance might not be optimized, however every attention to detail was put by the author and the reviewers of it to avoid all of the aforementioned issues.

In practice then, the core contribution of the collection of resources is the presentation of comprehensive, contextualised, summarised and quotable information for engineering design professors and from which, in every individual case, they'll benefit and apply it to a different degree.

The testing of the goals of the collection of resources then, can be only indirectly proved given that the actual introduction of an EREA in an academic institution could take a long time to materialise, however and as it'll be explained later, 12 academic departments from leading engineering design departments in universities across the United Kingdom, Ireland, France, Denmark and Germany accepted a copy of the collection of resources to read it and review it to themselves)

2.3.3.2.10 Scope and Assumptions of the Collection of Resources

Authors [Blessing & Chakrabarti. 2009] provide a checklist to help summarise and illustrate the support tool by identifying its scope and the underlying assumptions;

according to them, the resulting description clarifies the problem that is addressed; the approach, and the possible implications, and can thus allow the intended support and its concept to be more easily understood and assessed. The checklist helps to reveal how realistic the support is, and whether its scope has to be narrowed, it can also be used for drawing up profiles of the suggested support and hence compare it between similar, previous supports. Table 2.8 below summarises in five major categories and twenty elements the vision of the collection of resources as intended in this doctoral research and as presented in Annex A

Header	**Elements**	**Description**
Area of Use	Aims	The support is intended to help engineering design professors study and understand educational reverse engineering activities so they eventually incorporate them into their teaching curricula, the goal is both of a scientific and social nature since students can also benefit from having practical experiences in the classroom.
	Product type or domain	The supports serves the educational domain of engineering design in specific and engineering education in general
	Process type	Since educators regularly incorporate changes to their teaching curricula the change implied after reading the collection of resources can be considered only a “variant” of what they already do
Users and Tasks	Tasks or process to be supported	The collection of resources intends to support the

		learning and continuous training of educators (direct users) by providing them in a comprehensive manner the information on how to prepare, execute, evaluate, and follow up educational reverse engineering activities. The indirect user of the support tool is the author of the collection of resources who will be in charge of maintaining and updating the contents of the document
	Functions to be fulfilled	The collection of resources is intended to support the task of providing information for learning and guidance. As such the inputs are the attention of the readers, whereas the outputs are the impressions the information provided creates
	Number of users working in parallel	The support was written having a number of individually working users in mind, an eventual group interaction among the users is possible but only to provide feedback about the manual
	User description	Aimed mostly at undergraduate professors (though graduate level ones can also benefit) with little experience in hands-on activities in the classroom,

		and little experience in educational reverse engineering activities for which the support tool is introduced as a tutorial for self-learning
Interface	User's main role, human computer interaction	Interaction with the collection of resources is expected to happen at least once and then at recurring times if the information was deemed useful for the reader, the collection of resources is of a passive nature, and can be used either from a computer screen or a hard copy of it
	Input characteristics	Of a cognitive nature (attention , interest, etc.) by the reader
	Output characteristics	Either data; information or knowledge (as defined by [Ahmed et al. 1999]) depending on the level of assimilation by the reader
Implementation	Customisation	The support tool is tailored to the needs in the teaching of engineering design, it has been initially customised by its author, and the expected effort falls on the readers' side to at least go through all the contents presented, and eventually provide their opinion (ideally)
	Maintenance	The data can be stored either in a PDF electronic file or as

		a hard copy, the maintaining effort falls initially on the author of the collection of resources but he could share the responsibility should the project developed favourably in the long term
	Links with other systems or methods	The contents of the collection of resources are linked and referenced to current, published information and expect to add to the existing body of knowledge in the topic.
Effects	Needs	Users are expected to want to use the support because its contents were designed to be up-to-date, freely distributable, interesting, and compliant with existing research
	Problems	Just like for any other dissemination material some readers are expected to show over time an initial lack of interest in it, or be unconvinced of the contents despite the published evidence
	Problem-solving method, approach	The use of a systematic methodology (DRM) to arrive to the contents to be presented in the collection of resources, as well as the publication in peer-reviewed conference papers of the

		intermediate results from it were the actions taken to ensure valid results and build confidence in them
	Expected effect on the work situation (assumptions)	A favourable change in perception about reverse engineering activities in engineering design that increases the willingness of engineering design professors to include them in their current teaching curricula
	New work situation	Only an indirect change in the willingness of potential adopters can be measured in this research project (e.g. through interviews) since measuring an actual change in an existing teaching curriculum could take a period of time outside the available resources for this doctoral research
	Potential side-effects	The differences and similarities with existing approaches to bring practical experience to the classroom have been clarified as much as possible in the collection of resources, however it has been noted in previous discussions that for some educators small differences don’t count for a whole new approach, however, since the

		approach to EREA presented in the collection of resources makes use of newly available evidence and of multimedia tools that were not available before, the bases for the development of a new approach were indeed expected to be enough.
	Validation	Only through the compliance with the structured, methodological, and comprehensive effort to write the contents in the collection of resources

Table 2.8 Scope and Assumptions of the Collection of Resources

2.3.3.2.11 Underlying Assumptions Considered for the Success of the Support Tool

While the contents of the collection of resources were based on facts and documented research, the actual success of the ideas presented there is strongly dependant on the following assumptions that were thought to be true, namely:

- That students' learning can be enhanced by new learning experiences based on what students have already learned in the past
- That curriculum programs specify what is taught and learned and what all students should know, understand, and be able to do at the time of graduation
- That a target user of this manual (e.g. An engineering design professor) possesses a minimum level of acquaintance with electro-mechanical, manufacturing, production, logistic, and social concepts, that help him relate a system under reverse engineering analysis to its historical, technological and socioeconomic place.
- That most engineering design professors will respond positively to the question "Would you like to give your students real-life experiences in the classroom?"
- That a professor's increase in his/her willingness to try educational reverse engineering activities can eventually cause a change in his/her teaching practices

In the next and final stage of the DRM framework the evaluation of the usability and applicability of the actual support tool and its usefulness is assessed.

2.3.4 Deliverables from the Descriptive Study II Stage

Three main deliverables are expected from this research stage which can take one or several forms of the options listed below, namely:

A. Results of application evaluation

- Verify if the actual support was used for the task intended
- Verify expected effect on the Key Factors

B. Results of success evaluation

- Identify whether the support indeed contributes to success

C. Implications and suggestions for improvement of:

- The actual support
- The intended support
- The actual and intended introduction plan
- The actual and intended impact model
- The reference model
- The criteria used

2.3.4.1 Account of the Development of the Collection of Resources

The collection of resources addressed what were found to be the main concerns regarding the perception of educational reverse engineering activities as a valid teaching aid in the area of engineering design, as such it contained what the exploratory results indicated to be the contents with the highest possibility to impact the research situation and cause the planned changes, it contained for example, a historical account of the development and contextualization of reverse engineering activities as well as a guided example that intended to help the readers, to prepare; execute, evaluate, follow-up and eventually create their own instructional learning activities suited to their teaching practice.

The pedagogical approach chosen in the collection of resources for the teaching of EREA to students of engineering design was geared towards an instructor-assisted team learning rather than a self-directed learning by students, in this way, students can benefit not only from their professor's experience but also from a teamwork setting where information gaps can be filled by other team members and by the efforts of a pool of students contributing towards a unified goal.

Concerning the resources for the execution of the activities themselves, traditional consumer products were the artifacts chosen for the educational activities, since they integrate a number of technologies that can be discussed and studied in the classroom, and that serve as examples of design and its impact on the state of the art; the environment, and the quality of life. The examples of reverse engineering activities presented in the collection of resources then, intend to illustrate the interdisciplinary research, common to engineering design that help students understand the connections among materials science, manufacturing processes, general engineering, ecodesign, and the socioeconomic sciences.

2.3.4.2 Provisions to Avoid Unexpected Outcomes and Ensure the Success of the Support Tool

In order to avoid or at least minimize potentially negative or unexpected outcomes from the support tool, the following points were considered in designing it:

a) **Needs of the users:** The support tool intended to address the real needs of the users at the current time of use, the needs were not considered to be obsolete or come from unsubstantiated perceived needs

b) **Theoretical framework:** The theories and assumptions that link the concepts in the collection of resources to the expected benefits from it are thought to be correct based on an analysis of the state of the art

c) **Concept:** The concept was assumed to be well thought out based on existing research and similar approaches to the needs detected

d) **Support realization:** The support tool was assumed to have been realized correctly using the means that could reveal the expected impact

e) **Introduction of the support:** Although some related resources (cf. Theses) were introduced by others during the duration of this doctoral research, the resulting support tool was still thought to have been introduced correctly; using suitable means, with clear instructions for its use, and at the right time

f) **Unexpected changes to the working environment:** No counterproductive changes to the working environment caused by the introduction of the collection of resources itself were considered plausible

g) **Target work atmosphere:** The support tool was targeted to individuals who were supposed to work under academic freedom, however the author of this dissertation was aware that the context where the support tool would be used is dynamic and policies of all sorts could have a large influence in its acceptance / rejection

h) **User's competencies:** The target population are engineering design professors at the undergraduate level who were expected to have the appropriate competencies to benefit from the support tool

i) **User's Preferences:** This is indeed the major threat to the goals of the support tool since the users' preferences; beliefs, interests and motivations towards EREA might not be in line with the goals of the support tool despite the submitted evidence

j) **Resources available:** Though the resources for the completion of the support tool were limited, an appropriate research and scientific result was expected from it

k) **Unsuitable work environments:** The collection of resources was written so it could benefit any university even those with minimum resources at disposal, however there could be cases in the field where the available resources (e.g. People, time, equipment) are insufficient, or the available environment (e.g. Organisational and technical infrastructure, help service, etc.) could be unsuitable for carrying out educational reverse engineering activities as proposed in the collection of resources

2.3.4.3 Major Items to Test in the Support Tool

The comprehensiveness, structure, and academic validity of the collection of resources were the major items to test, its user interfaces, that is, the aesthetic elements of it were not a major concern because they don't make part of the core contribution of the collection, however, a readable and pleasing format was sought after to the best of the author's understanding not to affect the functionality of the collection of resources. The evaluation of the resources then, and in an effort to provide a real contribution to the body of knowledge that was academically and practically worthwhile, was focused on the core, essential and unique features of the support tool

2.3.4.4 Research Plan and Methodology for the Testing of the Research's Hypotheses

The hypotheses of this research were pre-tested via a literature review and then indirectly tested through the acceptance and publication in peer-reviewed conferences of the intermediate results from the research, the comments by those professors who received the support tool (e.g. "looks interesting", "send it", "I'll see what I can do", "looks promising" could add a certain, subjective feedback, but it was not taken into consideration since the reception of feedback came after the creation of the guiding manual and submission of the doctoral thesis for review. However the author intends to keep updating the support tool with feedback from the field for as long as it is relevant.

2.3.4.4.1 Recipients of the Guiding Manual

Instead of a formal test population to evaluate the hypotheses presented in this research two groups of researchers in academic institutions throughout Europe were contacted to know about their interest in the support tool.

The first group of researchers had previously expressed their interest in the final results from this research in 2008, 2009 and 2010 when intermediate results from it were presented at the following congresses:

- 10^{th} Engineering and Product Design Education International Conference, E&PDE’08. Barcelona, Spain
- 11^{th} Engineering and Product Design Education International Conference, E&PDE'09. Brighton, UK
- International Design Conference - Design 2010. Dubrovnik, Croatia
- XIV International Congress on Project Engineering, 2010. Madrid, Spain
- 12th Engineering and Product Design Education International Conference, E&PDE’10. Trondheim, Norway

The second group consisted of researchers who agreed to receive the support tool for their own perusal (and even provide some feedback without obligation, and at some point in time) and who belonged to one of the 38 different academic institutions with accredited courses on engineering design by the Institution of Engineering Designers of the UK (IED), (Database available at http://www.institution-engineering-designers.co.uk/courses) that were contacted to find out about their interest in this research

2.3.4.4.2 Demographics of the Recipients of the Guiding Manual

The demographics of the respondents included 13 engineering design professors (11 Male / 2 Female) from 12 different institutions with a background in engineering practice and research from several major disciplines and types of businesses (e.g. Consulting, manufacturing, maintenance, etc) and more than ten years of experience in academic practice, in the author’s opinion they could be considered a relevant representation of the community of engineering design researchers at an European scale. Table 2.9 further below details the recipient institutions of the guiding manual (the names of the recipients and e-mail communications are kept anonymous in this document, but were available upon request to the reviewers of this research)

Academic Department	Institution	Country	Accredited program on Engineering Design by the IED (Yes / No)
Faculty of Engineering	University of Bristol	UK	Yes
School of Computing, Engineering and Mathematics	University of Brighton	UK	Yes
Wolfson School of Mechanical and Manufacturing Engineering	Loughborough University	UK	Yes
Design and Craft Department	Buckinghamshire University Technical College (UTC).	UK	Yes
Faculty of Design, Media & Management	Buckinghamshire University Technical College (UTC).	UK	Yes
School of Engineering	London South Bank University	UK	Yes
Dyson School of Design Engineering	Imperial College London	UK	Yes
Department of Design and Engineering ,	Bournemouth University	UK	Yes
School of Mechanical & Design Engineering	Dublin Institute of Technology	Ireland	Yes
School of Science and Engineering	University of Limerick	Ireland	Yes
Section of	Technical University of Denmark	Denmark	No

Engineering Design and Product Development			
Institut de Mécanique et Ingenieríe de Bordeaux	Ecole Nationale Supérieure d'Arts et Métiers	France	No
Department of Mechanical and Automotive Engineering	University of Applied Sciences Ulm	Germany	No

Table 2.9 Recipients of the Support Tool

The recipients of the support tool, and according to the communication had with them, are part of that group of professors interested in educational reverse engineering activities and on their implementation in their teaching curricula. They can be considered to be a homogeneous group in the sense that they all do research on product and process development and are supposed to be well versed in its methodologies, it can be assumed then, that people with similar backgrounds to those of the recipients are the ones more likely to use reverse engineering exercises in their teaching.

2.3.4.5 Challenges in the Development of the Support Tool

The main challenges in creating the collection of resources came from selecting the topics to cover and the depth to which the information would be presented so it could be contextualized and adapted to the engineering design domain. Given that not all of the required information to analyse the research topic in detail was initially available, several exploratory studies; assumptions, and educated conjectures had to be made to fill the information gaps. Definitive proof is hard to get in social studies and learning theories, and this research was no different in that respect. It is expected though, that the challenges had been overcome and that thanks to future feedback from readers of the support tool, further revisions to it can be made to increase its usability and value to the engineering design community, until the right balance is found that ensures that the learning setting, the curriculum content, the teaching method, and the evaluation mechanisms are appropriate for the readers' development of the conceptual understanding of reverse engineering and its place in the design process.

As it could be seen from this last stage of the DRM framework one of the most important deliverables was to identify the mechanisms of the situation under analysis. Because of this several conclusions from the research situation could be drawn now and were shown later in the general conclusions chapter.

2.4 Chapter Conclusions

Research in the area of engineering design education carried a number of challenges; since the integration of the technical knowledge inherent to the topic of study itself needed to be placed in the context of education and of the varied fields it comprised, such as cognitive psychology in students, and educational strategies in academic institutions. However, the stepwise approach, and the need to provide specific deliverables for every step of the DRM methodology helped to build a research ground since the beginning of the project, where the ongoing work and progresses in the development of the investigation could always be referred back to the previous stages of the methodology as one kept moving forward.

It is also worth mentioning that in coming up with a thorough methodological approach to the development of this research the author sought to be accepted to the 2009 European Summer School on Engineering Design where he was admitted indeed and where he met Professor Lucienne Blessing who is one of the two creators of the DRM methodology and learned there first-hand how to use it, the author also met Univ.-Prof. Dr.-Ing. Christian Weber who provided valuable counselling for the progress of this research and who gave the author of this dissertation the opportunity to spend a period of three months at the Engineering Design Department of the Faculty of Mechanical Engineering at the Technical University of Ilmenau in Germany as a visiting doctoral student and where the following study opportunities were given that turned out to be highly relevant to the development of this doctoral research, namely:

- To analyse and understand the approach, procedures and examples used for the teaching of Konstruktionskritik (Systematic analysis of technical products / systems) at their department of engineering design
- To learn from the articles published by the faculty of TU Ilmenau at the International Symposium on History of Machines and Mechanisms.
- To learn from the Digital Mechanism and Gear Library DMG-LIB Project and the university’s long tradition in engineering design
- To learn from VDI norms such as VDI 2221 and 2206

Although DRM was a framework that provided supporting methods and guidelines to formulate and validate models and theories for the multidisciplinary nature of engineering design research; research in engineering design education was bound not only by technical topics but also by the cognitive processes of students and the educational strategies of the institutions under study as mentioned already, for this reason, it could be said that the stepwise approach of the DRM methodology helps novice and experienced researchers to develop a solid line of argumentation to plan and implement research stages in a more effective and efficient way to provide structured deliverables that enhance information traceability throughout the project stages

It should still be mentioned that while the DRM framework's emphasis on the documentation and scholar treatment of its stages helps to come up with a higher chance of scientifically valid and reliable results, the researcher's selection, application and design of methods to investigate and interpret research data can still influence the final results. While no research approach can guarantee perfect results from any given project then, it is still believed that the use of a methodology helped to come up with scientifically valid results that could be presented to the right audiences and that in the end were materialised into the collection of resources for the study of educational reverse engineering activities in engineering design education presented in Annex A of this doctoral research.

3 CHAPTER 3 RESEARCH RESULTS

3.1 Chapter Introduction

In this chapter an explanation of the results from this doctoral project is presented. It is explained here how the results themselves are of a decidedly empirical (cf. Observation and testing) nature and reflect a practical approximation to what was believed to cause a positive change in the detected research situation.

3.2 Major Results

The most important result from this research is the collection of resources for the study of educational reverse engineering activities in engineering design education presented in Annex A. Why it is considered a valid result and how it expects to elicit a change in the research situation is explained next.

3.2.1 The Collection of Resources for the Study of Educational Reverse Engineering Activities in Engineering Design Education

In Annex A nine major individual resources bundled as a collection are presented, each of them as a self contained document dealing with one relevant aspect necessary for the comprehensive study of EREA. The resources themselves are properly structured according to common conventions on the presentation of data and they include introductory, explanatory, original results, and final sections, they can be read individually according to the reader's needs, or they can be read sequentially to gradually increase the reader's awareness of the topic, the resources then, eventually converge at Resource 7 which presents a practical example of how an educational reverse engineering activity is done in a typical engineering design program. A summary of each resource in the collection is presented next.

3.2.1.1 Summary of Resource 1: Fundamentals of Educational Reverse Engineering Activities.

Contextualization of the varied scientific aspects that make educational reverse engineering activities a valid topic of research , it intends provide the reader with actual, published facts about the background, use, and future of such activities and intends to mitigate the perception of potential adopters of EREA about the lack of a formal theory behind them

3.2.1.2 Summary of Resource 2: Reverse Engineering and Learning.

An account of the mechanisms and conditions that explain the connection between the hands-on activities inherent to EREA and the associated cognitive processes that allow the students' acquisition of abilities related to the practice of engineering design. It intends to address potential adopters' perception of a lack of pedagogical value of EREA

3.2.1.3 Summary of Resource 3: Misconceptions about Reverse Engineering.

An explanation of how the use of reverse engineering in commercial contexts has damaged the view of the educational aspects of them because of their shared name. This annex intends to address the perception by early reviewers of this work that EREA could be unlawful or induce negative habits to students

3.2.1.4 Summary of Resource 4: Benefits of Reverse Engineering.

A report about published benefits, as well as the investigation towards original results regarding the strongest elements EREA can add to the teaching of engineering design. This annex intends to provide definite evidence about the benefits of EREA and thus help increase the reader's eagerness to include them into their teaching practice

3.2.1.5 Summary of Resource 5: A Proposed Methodology for Reverse Engineering Analysis in Engineering Design Education.

The original, core contribution from the collection of resources for the study of EREA that suggests a method for the reverse engineering analysis of consumer products in education and that covers the relevant aspects of the analysis of a product in the field of engineering design. This annex intends to solve the previously published concerns about the lack of resources to execute reverse engineering activities (cf. Section 1.2.7)

3.2.1.6 Summary of Resource 6: A Suggested Pedagogy for the Teaching of Educational Reverse Engineering Activities.

A suggested pedagogy for the teaching of EREA that consists of a collection of tips and advices regarding the analyses, tasks and questions that have proved successful in the past in guiding and supporting each of the individual stages of an educational reverse engineering methodology. This annex aims mitigate the potential adopters perception about a lack of resources for self-directed study of EREA (cf. 1.2.7)

3.2.1.7 Summary of Resource 7: Integrated Example of an Educational Reverse Engineering Activity on a Disposable Camera.

a self-contained example of an educational reverse engineering activity using a disposable photographic camera as a subject system. This annex is intended to show professors of engineering design in an integrated, practical way what an EREA would look like in a real educational setting, thus each step of the example, how it is handled and what the results from it are, should be understood both as an indication of what an EREA would comprise and how experience recommends to deal with, its main intention is to mitigate the potential adopters perception about the lack of guided examples of EREA (cf. 1.2.7)

3.2.1.8 Summary of Resource 8: Conclusions and Final Remarks.

An account of the present and future of the research and practice of EREA that intends to mitigate the potential adopters' perception that EREA is a distant area of research where no new results are being produced

3.2.1.9 Summary of Resource 9: Miscellaneous Resources for the Study of Reverse Engineering.

A group of links and references to existing resources from several fields of knowledge brought together to provide a comprehensive view of educational reverse engineering activities. This chapter intends to provide potential adopters of EREA with the elements for the study of the topic and the eventual creation of their own instructional materials.

The contents included in each of the resources and that if linked together could be thought of as a guiding manual –albeit a rather long one- for the integration of educational reverse engineering activities into an engineering design curriculum, intended to tackle the perceived needs of potential adopters of EREA, and thus positively impact their perception about them.

The contents in the collection of resources cite and reference to as much as possible of the existing, published research on the topic and still they can be considered an original contribution to existing body of knowledge in the topic because of their comprehensiveness; contextualisation to the field of engineering design, integrative nature, and the novel approach to the delivery of information presented therein

3.3 Published Results from this Dissertation

Although the collection of resources presented in Annex A was the actual result from this doctoral research, five conference papers -mentioned already in Section 2.3.2.6- stemming from this doctoral research were peer reviewed and presented at different conferences during the initial stages of the doctoral research, each of the conference papers then, can be considered an intermediate result from this research from a time where the fundamentals of it were still being explored, the results presented in the papers then, helped to clarify the topic of investigation and to come up with a methodology for its analysis, and for the direction to follow in pursuing a solution to the research situation. Most of the tables and figures presented in the four main chapters of this dissertation and in the collection of resources presented in Annex A at the end of this document derive in one way or another from those papers and the presentations that were delivered to the engineering design community.

A detailed account of the tables, figures and results from such papers is not given here and instead the information to find the full papers is given in the bibliography section of this document should the reader wanted to access them, still the following results are worth mentioning because of their importance in leading the research efforts in this project and in making their way in one way or another into the Resources 1 to 9 presented in this document, namely:

- An exploratory study on how to integrate design praxis into an academic curriculum taking product visualization techniques as a test case in [Calderon. 2008]
- Exploration into future research lines on the topic of EREA in [Calderon. 2009] and [Calderon 2010a]
- Fundamentals and descriptions of the research topic in [Calderon. 2010a]
- Determination of the different contexts of the term “Reverse Engineering” in [Calderon. 2010a]
- Publication of an account of the main milestones of reverse engineering in education in [Calderon. 2010a]
- Categorization of the desirable competences of a typical engineering design student and their links to the specific steps of a reverse engineering methodology in [Calderon. 2010a]
- Comparison of a reverse engineering exercise vs. a conventional engineering design exercise by showing events, competences and results to provide a solid argument for the added benefit that reverse engineering exercises can bring to engineering design education in [Calderon. 2010a] and [Calderon. 2010b]
- Determination of the suitability of EREA to exercise and develop the expected and desired competences of engineering design students, shown in Resource 4 and after [Calderon. 2010b]

- A list and calculation of the suitability rankings of the best elements to exercise through EREA, in [Calderon. 2010b]
- Determination of the suitability rankings of existing studies about engineering design competences and their constituent items to meet their goals through EREA as seen in Table 3.1 below

Study	Ranking	Focus	Reference
Expected qualities in a design engineer	Suitable	Engineering Design	[Sheppard & Jenison. 1996]
TIDEE's design process competencies	Suitable	Engineering Design	[Calkins et al. 1996]
Saeema's categorization of knowledge-process	Suitable	Engineering Design	[Saeema. 2007]
ABET's engineering program outcomes	Suitable	General Engineering	[ABET. 2010]
CDIO syllabus	Suitable	General Engineering	[CDIO Council. 2010]
Trevelyan's knowledge descriptors	Somewhat Suitable	General Engineering	[Trevelyan. 2008]
Taxonomy of engineering competencies	Somewhat Suitable	General Engineering	[Woollacott. 2009]
Desired attributes of an engineer	Somewhat Suitable	General Engineering	[Boeing Univ. Relations. 2010]
ICB – IPMA competence baseline version 3.0	Neutrally Suitable	Project Management	[Caupin et al. 2006]

Table 3.1 Suitability Rankings of Existing Studies about Competences and their Relation to EREA, After: [Calderon. 2010b]

- A report about the experiences of using the DRM framework by authors [Blessing & Chakrabarti. 2009] in this research in the field of engineering design education in [Calderon. 2010c]

The intermediate results from this research then, strengthened the need for new studies in the topic of investigation and thus helped to determine the direction of the doctoral research for the rest of the duration of the project.

3.4 Measurements against Bias in the Research Results

In cases like this where the researcher is also the developer of the support tool, bias is a serious problem, however:

- The triangulation of results from multiple published studies (i.e. Abundance of references throughout Resources 1 to 9 and even redundancy of them whenever possible)
- The avoidance of bias through subjectivity (consultation with experts has provided the form, focus and feedback for this research, e.g. Feedback from thesis supervisor; from the supervisor in the author's internship abroad, feedback from presentations at congresses, feedback received at the European Summer School on Engineering Design Research, and feedback from the reviewers of the doctoral thesis)
- The search of alternative explanations to the results found (i.e. Through an analysis of existing literature)

- The independent arrival to similarly reported results by other researchers (i.e. Through an analysis of existing literature)
- The explicit attempt to consciously use alternative views to find alternative explanations across the different topics covered in this research (i.e. Through an analysis of existing literature and feedback from thesis supervisor)
- Making all research assumptions explicit (cf. Sections 1.2.8, 2.3.3.2.10, and 2.3.3.2.11 of this document)

All of them counted as the strategies to detect and reduce bias in the results from this dissertation.

3.4.1 Validity and Verification of the Findings and Results from this Research

The following "Logical verification and verification by acceptance" methods proposed by author [Buur. 1990] were used to verify the validity of results in this research, namely:

A. Logical verification:

- Consistency: There are no internal conflicts between individual elements of the results (e.g. No contradictions arose from the results or ideas presented in Resources 1 to 9)
- Completeness: All relevant phenomena previously observed can be explained or rejected by the theories presented (e.g. The results and ideas presented in the collection of resources reference as much as possible existing, published research and Resources 1 to 4 in specific provide theoretical frameworks and explanations to the situations described therein)
- Well-established and successful methods were used and are in agreement with existing theories (e.g. The research method employed (DRM), and the results of a decidedly practical nature are presented in the collection of resources according to common conventions (i.e. format) for the dissemination of results)
- Cases and specific design actions can be explained by means of the results presented here (e.g. The proposed methodology, the suggested pedagogy, and the guided example of Resources 5 to 7, can be linked together and their deliverables are sustained by past published research)

B. Verification by acceptance

- The theories supporting this research are accepted by a relevant scientific community (e.g. Multitude of references and quotes across the length of the collection of resources , as well as original findings and results from the doctoral research always being presented in relation to past published research)

- The models and methods derived from this research were acceptable to experienced designers and educators (e.g. The proposed methodology for educational reverse engineering analysis in Resource 5, albeit new and integrative in its approach, can still be considered a derivative one from previous published ones by authors such as [Lamancusa et al. 1996] and [Otto & Wood. 2001]. Several elements from the results from Resources 6 and 7 are also based on past published research and are quoted accordingly)

Verification by acceptance then, provides the strongest support to the findings from this dissertation.

3.4.2 Reflective Questions before Communicating Research Results

Authors [Blessing & Chakrabarti. 2009] provide a series of reflective questions that are important to ask oneself in order to communicate credible, scientific results, the answer to such questions adapted to the results from this dissertation are listed below, namely:

- **Q1:** What is my contribution?
  A1: The dissemination of the benefits of educational reverse engineering activities in engineering design education through a freely distributable collection of resources that show how to study; prepare, execute, evaluate, and follow them up

- **Q2:** Why do I believe it to be academically worthwhile?
  A2: the DRM methodology which is specially suited for research in the area of engineering design education was used, along with standard peer-reviewed research practices

- **Q3:** Why do I believe it to be practically worthwhile, or to contribute to a practical goal?
  A3: The need to provide practical experience in the classroom to engineering students has been published several times (cf. Section 2.1) and reverse engineering activities can fulfil this need, thus the collection of resources for the study of EREA in engineering design education stemming from this doctoral research is presented in Annex A

- **Q4:** Why do I believe that I have the competences or can obtain the competences to execute this evaluation?
- **A4:** An interest in the research topic made the author of this research gather the information needed to go on with this investigation (e.g. Acceptance to the European summer school on engineering design research, and the acceptance as a visiting doctoral researcher abroad), also, the consultation with experts at multiple venues allowed for an exchange of views; valuable information, and guidance to complete this research project.

3.5 Plans for the Dissemination of Research Results

Besides aiming for the publication of a paper journal explaining the results and findings from this dissertation, at the end of the doctoral project an updated, freely distributable collection of resources for the study of EREA in engineering design education was expected to be re-sent to the academic departments mentioned in Table 2.9 above. Additionally the collection of resources was intended to be listed with NEEDS – the National Engineering Education Delivery System (http://www.needs.org/) and with the Engineering Pathway (http://www.engineeringpathway.com) which were two North American websites on resources for the teaching of engineering, unfortunately at the time of conclusion of this project both sites had closed already. After the completion of the research project though, the author expected to start writing the collection of resources again but in Spanish language time.

3.6 Chapter Conclusions

Unless otherwise stated all the findings from this research were of a purely practical nature but in order to properly contextualise the results from this research though, it should be mentioned that the resources available for the project (cf. Time) didn't allow the field testing of the collection of resources since it took extremely long to receive any feedback from it, results from the field though were expected to be added to future papers resulting from this dissertation

It should be mentioned too that the contents of the nine individual resources in the collection, represent the main deliverables from this dissertation but it was impractical to evaluate them through peer consensus because of their length and comprehensiveness. Because of this, the collection of resources in Annex A (despite being the result of a formal methodological approach) is presented only as a theoretical, exploratory approximation to what could cause the desired change in the detected research situation.

The full research project then, consisted of:

- A doctoral thesis for the dissemination of results among the academic community, and as an evaluation of the author's performance as a researcher
- A collection of freely distributable resources (the only one available as of October 2015) for the study of EREA in the field of engineering design education that documented the theoretical background behind hands-on activities in education and the technical and methodological knowledge needed to perform reverse engineering exercises in an engineering design curriculum,
- A paper-like summary of the whole research for those interested in the project but with little time available to get involved in it
- Five peer reviewed conference papers presented at congresses across Europe discussing relevant topics to the research project
- A detailed power point presentation (available to everyone by contacting the author) that was aimed at a general audience in order to disseminate the results from this research

All other plausible views and alternatives to the results from this research were acknowledged by the author and will still serve as a starting point for further research in the topic; in the next and last chapter then, the conclusions from this doctoral project are presented.

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CHAPTER 4 RESEARCH CONCLUSIONS AND FINAL REMARKS

4.1 Chapter Introduction

Although published studies stated that hands-on activities such as EREA could become a popular pedagogy to provide students with practical experiences in the classroom, [Lamancusa et al. 1996]; at the beginning of this doctoral research around 2008 there were still several pedagogical, organizational, and even methodological areas left to explore in the topic. After initial exploratory studies and discussions with domain experts in academia and industry the need to provide resources for the study of EREA in engineering design education to the potential adopters of them was acknowledged, and a research effort was planned to materialise a possible solution to such situation.

This chapter discusses the conclusions from trying to achieve the research goals of this dissertation and provides the reader with an overview of the present and future of the practice of educational reverse engineering activities as an aid in the teaching of engineering design.

4.2 Attainment of the Expected Outcomes of the Research

At the beginning of this project the expected result from it was the contribution of new practical knowledge to the area of engineering design education by documenting and understanding the impact educational reverse engineering activities could have in it. It was believed at the time that by easing the potential adopters' learning curve for the preparation; execution, evaluation and follow up of such tasks, the knowledge gaps and unwanted complexity they could entail could be avoided, and so a planned effort started to come up with a support tool (a collection of resources) for the study of EREA in engineering design education that included suitable guidelines; methods, and examples for self-directed learning. This section discusses the conclusions from striving to achieve those goals and lists the steps and considerations taken to answer the research questions, assess the research objectives and assumptions, and validate the research hypotheses.

4.1.1 Answer to the Research Questions

In projects of an eminently practical nature such as this one, research questions are of paramount importance since the answer to them provides a solid ground on the understanding of the research situation and the baseline from which to start working on the solution to the research problem. Figure 4.1 below shows the research questions for this dissertation, the degree to which they were analysed, and what type of answer was given to them

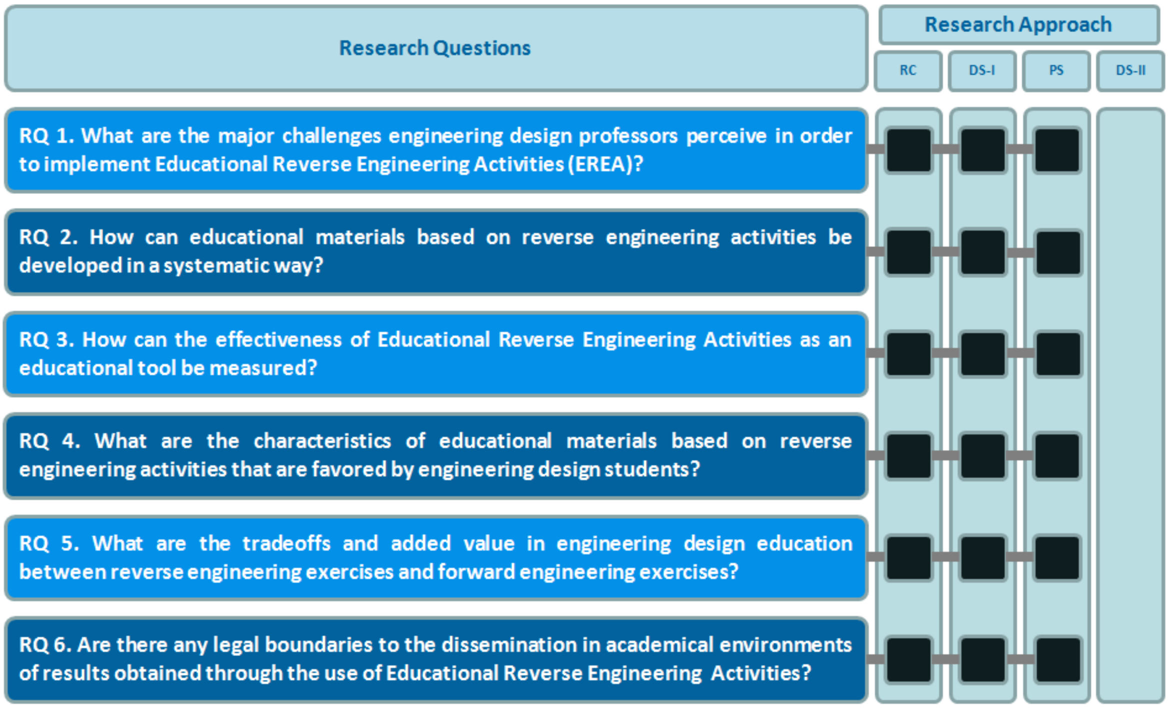

Figure 4.1 Research Questions against Impacted Stages of the DRM Framework

The answer to each of the questions and how they impacted the creation of the support tool (the collection of resources in Annex A) is shown next.

A. Research Question 1: Since a scarce implementation of educational reverse engineering activities was detected at the beginning of this research, this question aimed to answer what the perception was of engineering design professors regarding the problems in implementing such activities.

This question was answered by the author in [Calderon. 2010a] by reporting that the information available on how to prepare, conduct and evaluate these activities was abstract; not detailed, dispersed, and there were no standardized guidelines on how to make the most out of these activities leaving this task to the experience of the professor at work, which was a particularly important challenge for first time or novice instructors of this type of activities.

In the same publication it was also reported how EREA had been perceived as “interesting and favourable by some professors but also as complex; unappealing, unlawful, and unnecessary by others" and so an effort was committed to "improve their credibility as a teaching tool and easing the entry barriers and learning curve for those interested in integrating them into their teaching", [Calderon. 2010a]

The work done to fulfil that promise then, was reflected in the writing of the collection of resources shown in Annex A and specifically in:

- Resource 3, "Misconceptions about Reverse Engineering", to clarify major misconceptions about EREA in education.
- Resource 4, "Benefits of Reverse Engineering", to present the reader with previously published advantages; potentialities, and added value reverse engineering activities could bring to the teaching and learning of engineering design.
- Resource 5, "A Proposed Methodology for Reverse Engineering Analysis in Engineering Design Education", to suggest a methodology for educational reverse engineering analysis that included the planning; executing, evaluating and following-up of them
- Resource 6, "A Suggested Pedagogy for the Teaching of Educational Reverse Engineering Activities" to provide a collection of tips and advices dealing with the practical aspects behind the execution of the steps; analyses, tasks, and questions inherent to an educational reverse engineering analysis
- Resource 7, "Integrated Example of an Educational Reverse Engineering Activity on a Disposable Camera" To provide a guided example, suitable for self-directed learning of an educational reverse engineering activity using a disposable photographic camera as subject system
- Resource 9, "Miscellaneous Resources for the Study of Reverse Engineering" to provide the reader with an assortment of references linking to published research to support the study of EREA

Because an actual result was created by the researcher in order to answer Research Question 1, it means that it covered the three first stages of the DRM framework and thus an actual understanding of the situation was first achieved, followed by a deeper research into the factors that influenced it, to finally end in the creation of a result (the collection of resources) to answer the research question.

B. Research Question 2: This question aimed to find the patterns that educational reverse engineering activities could have, in terms of content and methodology that had been considered successful in the past, or that could be considered successful in the current conditions. It was answered by the author in [Calderon.2010b] where it was published the intention to “develop and document the practical knowledge across dispersed disciplines needed to develop an assimilable and readily applicable manual for the systematic and effective development, execution and evaluation of D/A/A (Disassemble, Analysis, Assembly) activities to support the teaching of engineering design adapted to the requirements of a typical curriculum” and the specific actions that were considered necessary to lead to it were listed as “considering specific learning objectives, fundamentals, methodologies, tools, test materials and feedback mechanisms” all of this done “through the use of a methodological framework that allows the creation of systematic, structured, methodological , scientifically valid results” in order to “ease the learning curve for the preparation, execution and evaluation tasks by reducing knowledge gaps, unwanted complexity and unnecessary steps”, [Calderon.2010b]

In the end, an analysis of previously published educational materials based on educational reverse engineering activities revealed that they were based on the work led by four major individuals or research groups, namely: [Sheppard. 1992a]; [Lamancusa et al. 1996], [Otto & Wood. 2001], or [Lewis et al. 2011], however, it was noted that certain methods, analyses, or desired goals published by a given researcher were absent in the examples from the others and vice versa, and so an analysis of all available examples at the time was done to come up with a comprehensive, summarised, and contextualised methodology that included all relevant steps and tools suggested by previous researchers but that for a number of reasons had been ignored by others

Additionally, an analysis of the strongest elements EREA could add to the teaching of engineering design was done and presented in Resource 4 “Benefits of Reverse Engineering” after the work already done leading to the publication of “A Comparison of Competences Required in Reverse Engineering Exercises Versus Conventional Engineering Exercises and its Relationship to IPMA’s Competence Baseline” in [Calderon. 2010b] and from those elements listed therein that were suitable to be taught through EREA the guided example of an EREA presented in Resource 7 was planned (cf. Focus on activities dealing with information collection; disassembly, the analysis-synthesis cycle, the redesign of a subject system, and the dissemination of results). This novel approach to a comprehensive methodology for educational reverse engineering analysis suited to the field of engineering design that united the best practices in the practice of educational reverse engineering was indeed the core contribution of the collection of resources

Because Resources 4 and 7 were written to answer this research question and it could be determined that EREA share the characteristics of hands-on activities and that this same level of interactivity is what should be replicated in EREA, this research questions also covered the three first stages of the DRM framework and thus an actual understanding of the situation was first achieved, followed by a deeper research into the factors that influenced it, to finally end in the creation of a result (Resources 4 and 7) to answer the research question.

C. Research Question 3: After defining effectiveness as the capacity of producing a desired effect, this question aimed to measure how educational reverse engineering activities as an educational tool compared against traditional (forward) engineering design exercises. After analysing previously reported benefits of EREA by past researchers and after determining in Resource 4 what the strongest elements EREA could add to the teaching of engineering design, it was found out that after performing EREA students were expected:

- To improve the understanding of simple information (Vocabulary; facts, equations, quotes)
- To improve the understanding of complex information (Differentiation; comparison, contrasting, synthesizing of information)
- To improve their theorizing, analyzing, and problem solving performance
- To improve the use of tools and procedures
- To investigate the natural and industrial world
- To improve their communication and team work skills

And so Resource 6 was written where one of its four major sections deals specifically with the evaluation of EREA from professors to students, from students to students and even from students to professors considering the abovementioned points (e.g. Tools; techniques, grading policies, standards of evaluation, etc.). Additionally an example of evaluation of an EREA that focused on measuring the progress in abilities and knowledge of students after an EREA and that had been previously published by researcher [Dalrymple. 2009] was presented and contextualised to fit the goals of this research and to show the reader one of the possible ways to measure the effectiveness of EREA as an educational tool in the field of engineering design

Finally, in Resource 2, an exploratory analysis regarding the cycle of students' acquisition and development of competences through EREA was made and presented and thus it can be said that the answer to this research question covered the three first stages of the

DRM framework and thus an actual understanding of the situation was first achieved, followed by a deeper research into the factors that influenced it, to finally end in the creation of a result (Resources 2,4,6) to answer the research question.

D. Research Question 4: This question was devised to detect the successful elements of educational reverse engineering activities so they could be replicated in varied exercises but sticking to a common core of best practices; proved strategies, and contents. The development of the suggested methodology for educational reverse engineering analysis in engineering design education shown in Resource 5 as well as the guided example of an EREA following such methodology in Resource 7 are the practical answer to this research question given that in order to come up with them, an analysis of all available examples of EREA at the time was done to write a comprehensive, summarised, and contextualised methodology for educational reverse engineering analysis that included all relevant steps and tools deemed successful by previous researchers such as [Sheppard. 1992a]; [Lamancusa et al. 1996], [Otto & Wood. 2001], [Durfee. 2008] and [Lewis et al. 2011]. The answer to this research question covered the three first stages of the DRM framework and thus an actual understanding of the situation was first achieved, followed by a deeper research into the factors that influenced it, to finally end in the creation of a result (Resources 5 and 7) to answer the research question.

E. Research Question 5: It is a common mistake to think that reverse engineering is the opposite of forward engineering, the answer to this question aimed to clarify such misunderstanding so a proper comparison among the two activities could be made and thus be able to correlate them as complementing teaching tools rather than competing ones. In Resource 1 an explanation was first given about the positioning and focus of reverse engineering against traditional "forward" engineering, later in Resource 2 a comparison between the two approaches in education was illustrated by showing their typical events, associated competences exercised, and results. This comparison ended up being published in [Calderon. 2010a] and thus it can be said that the answer to this research question covered the three first stages of the DRM framework and so an actual understanding of the situation was first achieved, followed by a deeper research into the factors that influenced it, to finally end in the creation of a result (Resource 1 and 2) and the publication of the answer in [Calderon. 2010a]

F. Research Question 6: Since the educational aspects of reverse engineering activities are wrongly equated by many people with the illegal uses of reverse engineering in commercial; software, and intellectual property contexts, this question aimed to clarify the legality of EREA so they could be implemented with confidence in educational settings and the results from them be disseminated without concerns.

The totality of Resource 3 deals with clarifying the most relevant misconceptions in the practice of educational reverse engineering activities and a specific section dealing with the lawfulness of reverse engineering as an educational practice is included therein where the internationally recognised principles of "First sale doctrine of patent law", "Fair use", and "Fair dealing" are explained, contextualized to the field of engineering design education, and linked to proper examples and references for their study.

As it can be seen here the research questions were answered through the different resources presented in the collection of them in Annex A and several of them ended up being published in peer-reviewed conference papers. In the next section an explanation of how the research hypotheses were tested in a similar way is presented.

4.1.2. Validation of Research Hypotheses

Additional to the explanations already given in all of Section 2.3.3 concerning the variety of actions taken to ensure the validity of the support tool, and in Section 2.3.4.2 in specific, concerning the provisions taken to avoid unexpected outcomes and ensure the success of the support tool. Sections 3.4 and 3.4.1 also discuss the measurements taken against bias in the research results from this research, as well as the validity and verification of the findings and results from it.

The hypotheses in this research then, can be considered to have been pre-tested via a literature review of all articles available to the researcher for the study of EREA, and then having been indirectly tested through the acceptance and publication in peer-reviewed conferences of the intermediate results from this research, Figure 4.2 below shows them and an explanation of the approach followed for their testing is given further below.

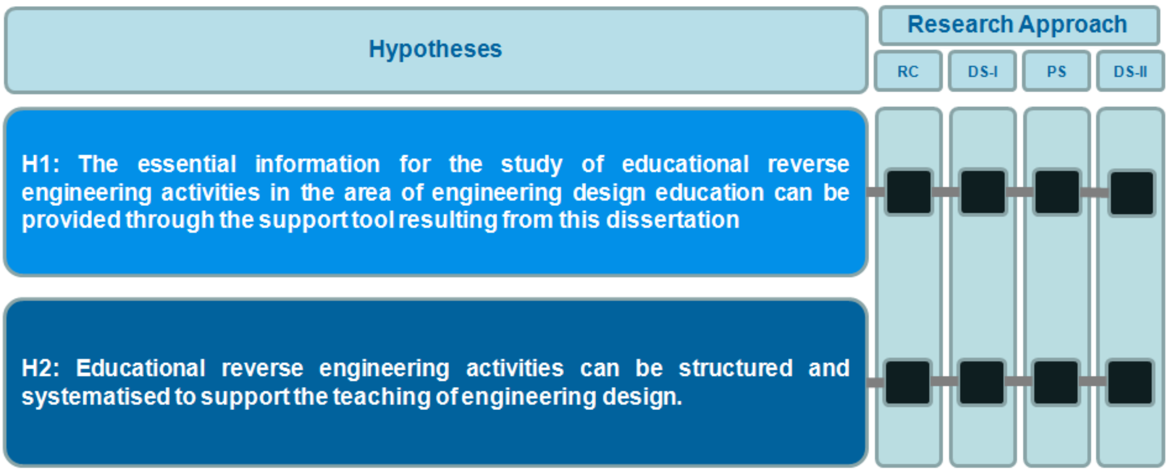

Figure 4.2 Doctoral Research's Hypotheses against Impacted Stages of the DRM Framework

A. Research Hypothesis 1: Hypothesis one was conceived to prove that the creation of a collection of resources for the study of educational reverse engineering activities was indeed possible since its need had been already stated by several authors and documented in several sources as shown already in Section 1.2.7, the collection of resources itself presented in Annex A, that is the major result from this doctoral research proves hypothesis one because of the following reasons:

- No other collection of resources, guiding manuals or instructional materials were made available online to interested professors of engineering design for the study of EREA for the duration of the project and until its end in October 2015
- No collection of resources, guidelines, or dissemination materials previously published (and listed in Resource 9 of the collection of resources) was comprehensive in the number and reach of topics the covered and explained
- The collection or resources in Annex A was made freely available under the Creative Commons license "Attribution-NonCommercial 3.0 Unported" (CC BY-NC 3.0) meaning that it could be shared and copied by anyone to help in its dissemination but it was never allowed to make any commercial gain from it as the license stated
- It is "essential" in the sense that it provides the resources that were lacking according to the published results from initial exploratory studies and that were deemed indispensable for the study and eventual implementation of EREA, the resources themselves follow commonly accepted conventions for the presentation of information in academic circles (e.g. Structure, references, original results, etc.) to ease their comprehension

Because all of the abovementioned points Research Hypothesis 1 was considered accepted.

B. Research Hypothesis 2: Hypothesis two was devised to prove that EREA could be properly organised in a comprehensive form so any potential adopter of them could replicate them in an academic environment and still make the most out of them according to previously published best practices in the area, the need for guidelines of such characteristics had been already stated and published by several authors as shown here in Section 1.2.7. and so the hypothesis was considered proved and accepted because of the following reasons:

- An analysis of all relevant resources about educational reverse engineering activities available to the author and published before the year 2013 (more than 400 documents dispersed across several fields of knowledge including books, papers, presentations and web pages) was done to come up with the commonly accepted elements that comprised an EREA and that had proven successful according to their authors' opinions. The results from such analyses were reflected in the suggested methodology for educational reverse engineering analysis in engineering design education presented in Resource 5 which reflects the agreed understanding about EREA, their potential, and their associated best practices. This proposed methodology is considered by the author the core contribution from this doctoral research.
- To support the teaching of engineering design, an analysis of the most suitable competence elements that could be taught through EREA to students of engineering design (cf. Focus on activities dealing with information collection; disassembly, the analysis-synthesis cycle, the redesign of a subject system, and the dissemination of results) was done, after information previously published by the author in [Calderon. 2010b], and these elements determined the kind of analyses, questions and tests that were favoured in the suggested methodology, pedagogy, and examples of EREA written by the author and presented as the result from this doctoral research in the collection of resources in Annex A and more specifically in Resources 4;5,6, and 7

Because of the above-mentioned points Research Hypotheses 2 was considered accepted.

From Figure 4.2 above then, it can be seen that in order to prove the research hypotheses, every stage of the DRM methodology and their encompassing studies were considered, meaning that an actual understanding of the situation was first achieved; followed by a deeper research into the factors that influenced it, that resulted in the creation of a support tool that could be expected to change the detected research problem, and then this support tool was prepared and distributed for testing and use by others, meaning that the support tool itself (the collection of resources in Annex A) was only initially or indirectly tested by the researcher in terms of its coherence and scientific validity, but it rested on others (e.g. the users) the confirmation of the usability the support tool.

The way the hypotheses were tested in this project though, obeyed the nature of the end results from it, meaning that on the one side the actual implementation of EREA in the teaching curriculum of a potential adopter could take a long time to happen and the time span and resources allocated for this dissertation would be unsuitable, and on the other, the comprehensive nature of the collection of resources made its length unsuitable for field testing since a potential reader would hardly have enough time to go through the nine different resources included therein. It should be mentioned though that the comprehensiveness vs. usability tradeoff was deemed acceptable by the author since resources of this kind didn't exist and weren't available to the general public before, so as a future project, and as it'll be explained later the creation of a short guideline for the study of EREA based on the results presented in this dissertation will remain a future task for the author.

Based on the information presented above then, it can be considered that the hypotheses were tested and accepted to a depth seemed reasonable enough, but just as in any other research project, there are always trade-offs, lines of research, and assumptions that could benefit from further investigation.

Last but not least, it should be considered that authors [Blessing & Chakrabarti. 2009] stated that in current times and "in particular because of the lack of understanding in design, much research will be non-experimental, but not less worthwhile or necessarily easier"; authors [King et al. 1994] also wrote that "both experimental and non-experimental research have their advantages and drawbacks; one is not better in all research situations than the other" and even author [Yin. 1994] stated that "paradoxically, the 'softer' a research strategy, the harder it is to do". With the resources allocated to this research and to the best of the author's understanding the goals of this doctoral project were met and a freely distributable collection of resources for the study of EREA was made available to anyone interested in it.

4.1.3 Assessment of Initial Research Assumptions

Although no formal way to prove if the research assumptions turned out to be true is usually required, still, and as a personal experience from the author, it should be mentioned that through the feedback collected at the different venues where the theoretical fundamentals and the intermediate results from this research were presented, the assumptions mentioned before in Section 1.2.8 concerning the engineering professors' desire to provide hands-on experiences to their students; and concerning the statement that the clear, contextualized presentation of evidence about the learning benefits of EREA could actually increase an engineering design professor's eagerness to integrate EREA into his/her teaching, both of them indeed, can be said to be true and correlate to a high degree based on the feedback received from reputed professors in the field of engineering design, however this will remain information of a purely anecdotic nature, since a formal, numerical result to support this statement would require measuring methods other than the informal conversations where this assumptions were discussed at the beginning of the doctoral research.

In regard to sections 2.3.3.2.10 and 2.3.3.2.11 of this document, concerning the scope and assumptions of the support tool and the underlying assumptions considered for the success of it. Not only can be stated that they turned to be true in the end but also that the author believed so strongly in them that the form the results from this research took (the collection of resources) were heavily influenced by these assumptions.

4.1.4 Attainment of the General and Specific Research Objectives

Concerning the general objective from this research presented already in Sections 1.2.5 further above, it can be said the facilitation of the inclusion of educational reverse engineering in the teaching of engineering design has been achieved through the writing of the collection of resources freely given to anyone interested and presented here in Annex A, although concerns remain regarding the actual usability of the support tool because of its length, it is expected though, that because the resources were written so they could be read individually too, some of this usability concerns are mitigated. It remains future work for the author then, to come up with a short simplified collection of resources for anyone interested in the topic, not only engineering design professors as done for this dissertation.

Concerning the attainment of the specific research objectives presented in Section 1.2.5.1 already, they can be considered to have been achieved since each of them has a direct 1-to-1 relationship with the topics covered in the collection of resources in Annex A.

4.3 Specifics of the Doctoral Research

In this section, relevant information to better classify and assess this research and its results is presented.

4.2.1 Type (Applied Research)

The work done in this dissertation can be described as “applied research” since the aim was to determine whether a research situation had improved (practically or potentially) after an intervention. Applied research then, deals with solving practical problems and generally employs empirical methodologies where strict research protocols are relaxed and thus the transparency in the methodology used is crucial (a formal research methodology to have a higher chance to come up with scientifically valid results was followed in this research and is thoroughly explained in Chapter 2).

4.2.2 Academic Relevance

The added value and differentiating factor this dissertation brings, is that it is adapted and contextualized to the engineering design domain rather than the more general engineering one, and that the depth with which this dissertation interconnects the cognitive aspects of these activities to the rest of the components of the reverse engineering process can serve as evidence and support to those needing to justify why they would want to integrate reverse engineering activities in their teaching curricula.

The relevance of this dissertation then, lies in addressing the understanding and implementation of reverse engineering activities and their potential exploitation within engineering design education. In trying to prove the main proposition, this thesis also assessed the role of legality; cognitive processes, and a number of procedural tasks, that are also part of reverse engineering and that added up to an integrative view of EREA in engineering design education.

The presentation of solid evidence about their value and their relationship to engineering design education, should help reverse engineering activities in their integration and dissemination in educational curricula, therefore to find out which were the areas where reverse engineering activities could better enhance engineering design student's abilities, several planned investigation efforts were done as it can be seen in Resource 4 of the collection of resources

Finally, a possible associated benefit of this dissertation would be that the same steps taken to prove the validity of reverse engineering activities as a teaching tool could be used to test the credibility and effectiveness of any other new educational approach to be introduced in engineering design education.

This research then, aimed to provide a small but valid contribution to the current body of knowledge in the topic.

4.2.3 Novelty

In regard to the originality of this research, the author concludes that this is the first effort to integrate all available information about educational reverse engineering activities in engineering design education into a collection of resources that is directed at engineering design professors, it is also expected that the freely-distributable nature of it helps to reach interested readers more easily and thus benefit from an eventual collection of feedback that helps keep updated the collection of resources.

4.2.4 Original Contributions to the Body of Knowledge of the Topic

The main contribution of this doctoral thesis is to present and review the proposition that educational reverse engineering activities are a valid tool in the teaching of engineering design, for such purpose a collection of resources directed at professors of engineering design that describes how to prepare, execute, evaluate, and follow up such activities to eventually integrate them into their teaching practice was presented in Annex A

No significant theoretical contribution to the state of the art was made in this research, however, practical knowledge and contributions from this research include:

- The detailed documenting to support the study and introduction of EREA into existing engineering design curricula (given that no detailed support was available before this, other than very generic guidelines and examples)
- The organization and contextualization in the field of engineering design education of the existing knowledge and experiences with educational reverse engineering activities
- The collection of resources for the study, preparation, execution, evaluation and follow-up of EREA
- Five published peer-reviewed conference papers presenting intermediate results from this research as listed in Section already 2.3.2.6
- A proposed methodology for the reverse engineering analysis of consumer products for the area of engineering design education that is comprised of proved and tested analytical tools common to the subject area (e.g. Technical systems analysis, DfX analyses, engineering tests, etc.), as well as comprised of methodological tasks arranged in a such a way that allow for the sequential, accumulative analysis of a subject system. This methodology indeed can be considered the core contribution from this doctoral research.

This research then, helped concentrate into a single document (cf. the collection of resources) the knowledge scattered over different areas of knowledge, in order to facilitate the study of EREA in engineering design education

4.2.3 Applicability of Research Results to Varied Academic Institutions

This research and the results stemming from it are aimed, and are relevant, only for the educational context of reverse engineering, other contexts dealing with commercial reverse engineering were outside the scope of this research since the very beginning and would have required the consideration of different theories, individuals, tools, organisational aspects, and testing methodologies, as such no inferences or associations can be made to contexts other that the educational one.

For the educational context of reverse engineering then, this research was developed with a general view in mind so the findings could apply to educators and institutions even with the minimum infrastructure available for the introduction EREA (the only condition was that the students' safety could be ensured at all times), in this sense EREA can work well in different educational settings, but the greater the differences in levels of technical support; training, resource materials, and facilities, the greater the caution instructors need to pay in ensuring that EREA will work well in their institutions. The advice given in the collection of resources in Annex A then, has been written considering all realistic scenarios for the implementation of EREA and thus the core learning effect in students and the results brought about by them should remain valid irrespective of the amount of resources available at the time of their implementation.

4.2.4 Challenges Faced

The results from this dissertation show that reverse engineering is a special subject not easily understood or taught; and because proficiency in it requires knowledge from many different areas, it requires its practitioners to be synergistic, which generally demands expertise in all underlying subjects. In practice for example, reverse engineering a product requires knowledge about all parts of it which requires a heavy amount of information to be gathered and contextualized by teachers and students alike. This is the main reason behind the length and comprehensiveness of the collection of resources resulting from this research and presented in Annex A

Concerning the research topic itself, regarding the proposition to prove the worthiness of EREA as teaching aid, it was challenged indeed several times during the development of this dissertation and the two questions that arose most of the time were:

- Why should the engineering design community give reverse engineering activities a try in the teaching of engineering design if they already have other proven methods for instruction?
- Is it academically worthwhile to consider what at first sight seems like an unproductive, questionable way to learn about a subject?

This research tried to answer favourably those questions based on past published research and original results from this investigation, and then, should the readers had been convinced of the answers presented, it provided them with a way to prepare, execute, evaluate and follow-up EREA with an emphasis on the cognitive process, the rational sequence of steps, and the potential sources of information that empower educational reverse engineering analysis.

4.3 General Conclusions

EREA and the effort done in this dissertation to promote their use as an educational tool has left the author with a range of experiences about what EREA currently are and what they could still become, these experiences seem worth sharing and will be described in the following sections for the consideration of the reader

4.3.1 Present of Reverse Engineering Activities in Engineering Design Education

From the research leading to the writing of this dissertation, which included the analysis of all available data to the researcher, and the drawing of conclusions from published results, and experiences collected throughout the duration of the project, it could be concluded about the use of EREA as an educational tool, that they:

- Are just another tool for the teaching of engineering design, they don't try to abolish other approaches and as such they are a complement rather than a substitute for traditional engineering design projects or any other existing teaching tool.
- Are fun: Because students have the opportunity to disassemble and see the insides of everyday products, thus engaging in a novel and appealing challenge that can help them stay motivated and interested.
- Are dynamic: Because in to order to complete a successful activity; a simultaneous collection, integration, and contextualisation of knowledge from different areas has to be done which demands from students an increased sense of awareness and a display of resourcefulness.
- Provide a realistic opportunity for practice: EREA provide opportunities for repetition and reinforcement of key information where students can make mistakes and learn from them and also from the feedback provided by their instructor, besides, the infrastructure and rules inherent to an educational environment provide students with

a safe environment to fail and try again, thus encouraging them to test new ideas and behaviours.

- Make learning concrete: EREA are realistic, complex experiences that allow students to link information to action, and to reinforce engineering concepts through hands-on experiences which could later help them use concrete learning in real life situations.

- Help learning to permeate: EREA have the potential to enhance students' learning by providing them with an opportunity to bring whatever has been learnt theoretically, into a practical environment where all information can be challenged; analyzed, discussed and interpreted to come up with a realistic explanation of what has happened during the design process of the product under analysis and during its actual operation

- Help students work as team: EREA are a group activity where specific roles and responsibilities are set; and as such, students can mix their abilities and ideas with those of their team members thereby helping reinforce learning and interaction in the team; should noticeable differences in experience; knowledge and status among team members arise during an EREA, the opportunity to safely repeat the activity until a desired state is attained contributes to level the knowledge about the product under analysis of all team members.

- Let the instructors observe the learning process: Professors and teaching assistants can observe the students while they perform the hands-on tasks and discuss about what they see and how they relate it to theory; educators then, can provide feedback and guidance whenever needed while team members take active responsibility for the learning that occurs during the activity.

- Foster cooperation with industry partners: Existing industrial requirements could be handed to students to help find a suitable solution, (e.g. By proposing and designing improved derivative products from the one under analysis)

- Are mostly technology oriented: As previously mentioned, EREA are just another tool available to support the teaching of engineering design and as such they will cover just a set of the total possible, expected competences of an engineering design student

- Have an added value that lies in giving students early in their studies, the opportunity to acquire and develop, through interesting and engaging activities, some of the abilities required to lead a successful career in engineering design.

These points represent the current understanding in the practice of EREA whereas in the next section a discussion about the future of them is presented

4.3.2 Future of Reverse Engineering Activities in Engineering Design Education

In complement to the abovementioned conclusions; and given that the actual introduction and development of EREA in the field of engineering design can still be considered a relatively recent one, several lines of new research were identified throughout the duration of this project, and the most promising ones are mentioned in Table 4.1 below to help the interested reader get an overview of potential, future developments in the area.

Category	**Research Line**	**Description**
Product Engineering	Cycle time compression	How reverse engineering in product development can further shorten lead times to market a new product
	Effectiveness of technical obfuscation measures	Development of obfuscation measures to avoid reverse engineering of sensible designs
	Reverse engineering of processes rather than products	Development of analyses to help uncover a whole manufacturing process and its practical limits, rather than just uncovering a manufacturing process that is already optimised for a specific product
Software	Virtual (product) dissection	Virtual reality-based dissection for real time interaction between students and the object of study (but reconciling the fact that the physical object is being taken away from the student again for the sake of convenience and mass reaching)
	Creation / Expansion of digitized product	The capturing and digital publishing of product teardown reports to be accessible to interested people all over

	teardowns	
	Integration of reverse engineering activities with new technologies	Streamlining of the reverse engineering method considering the integration of existing and future technologies. (e.g. The current integration of computational techniques in the analysis, tracking and support of a reverse engineering project is still limited)
	Curriculum development	To study the mechanisms that could help instructors of educational reverse engineering to add the value from their industrial experience and research accomplishments into their teaching curriculum. Also, to research on how to reuse the findings and conclusions at a class level from one semester to the next, etc.
Education	Capturing of embedded knowledge and transference to new designs (i.e. Transfer)	Exploration into research opportunities about the statement by author [Kutz. 2007] in the sense that "an important challenge both to those doing reverse engineering and to those attempting to apply its lessons is how to capture the embedded knowledge in such a way that it can be both readily identified and applied to new design contexts."
	Educational experiences beyond purely technical topics	Exploration into research opportunities about the statement by author [Kang. 2011] in the sense that "Integrating the global, economic, environmental, and societal issues in engineering design education is a promising new direction for courses that incorporate product dissection activities"
	Delivery of real life-like experiences in the classroom	Measures to avoid the reverse engineering experience to be taught by non-practitioners or by non experienced professors (this research itself focuses on that line)
	Product	To understand and evaluate a product's performance

	performance prediction	based only on available data about it without resorting to a dissection or testing of the actual, physical product.
	Design for X	Reverse engineering activities enhance the awareness of materials and manufacturing processes used in consumer products, thus the inclusion of Design for Disassembly (DFD) and other relevant DfX areas into a reverse engineering methodology should be explored
	Software assisted product teardowns	The reverse engineering method proposed in Resource 5 follows a rather algorithmic, brute force approach, and as such, it is prone to a software implementation of computer assisted reverse engineering tools that can serve students as an interactive guide in the realization; planning, structuring and contextualization of a reverse engineering exercise
	Product families and platforms	Author [Kang. 2011] for example, has suggested to update his own product dissection methodology "for dissecting a group of products, and for an after-dissection analysis of the product family and product platform", further research opportunities in this topic then, should be also available for the interested reader
Dissemination	Creation and dissemination of study materials	Development of physical hands-on kits; textbooks, resources and reference materials not only for students but also for, independent, self-paced learners; the same materials could be further translated to languages which are currently lacking. (e.g. Spanish)
Engineering Design	Codes and standards of engineering	The results obtained through a reverse engineering analysis help to learn from the mistakes and successes of others, this experience should not be

Practice	design practice	lost and could be used to assist in the continuous development of codes and standards of engineering design practice
	Experience and design decisions	After the studies by authors' [Kuffner & Ullman. 1991] uncovered that up to 90% of the design decisions made to come up with a finished product could be derived by unrelated designers by experience alone, it would be interesting to see how different this percentage is for people with different levels of experience in the area of product design (e.g. From students to senior designers), and how experience would play a role in reverse engineering analysis.
History of Science and Technology	Analysis of ancient mechanisms	It concerns the study and reproduction of the manufacturing processes of ancient objects in order to gain some insight on the knowledge, resources, and available technologies at the time. This line of research can also be about contributing to the understanding of the use of ancient objects. (e.g. The research conducted on the Antikythera mechanism [AMRP. 2012])
Commercial Ventures	Business start-ups	There is a market for professionally made hands-on kits to promote learning. Educators gaining experience with reverse engineering activities could later start a company to develop hands-on experiences for use at home, institutions, or distant educational settings.
Intellectual Property	Settlement of patent disputes	Analysis of existing hardware at the mechanism or even semiconductor level can help determine whether proprietary technologies have been used by competing companies; educational reverse engineering activities could at least provide students with an initial experience in the integration of hardware analysis and patent law and could serve as a possible line of collaboration in the area of

		intellectual property.
Manufacturing	Uncovering of manufacturing processes involving non reversible reactions	Although materials and manufacturing analyses are an integral part of educational reverse engineering activities, manufacturing and materials' processes that include irreversible reactions (e.g. Plastic deformations, chemical interactions, etc.) are beyond the reach of typical engineering design practitioners and call for the collaboration of multiple specialists; the reverse engineering of such processes rather than that of specific products then, opens up another potential line for future research as hinted in the article "Investigation of the Brewing Process: An Introduction to Reverse Process Engineering and Design in the Freshman Clinic at Rowan University" by [Farrell et al. 1999]

Table 4.1 Potential Research Lines in Educational Reverse Engineering

While some other potential lines of research also exist, the abovementioned ones represent the state of the art in the field at the time of submitting this dissertation (October 2015)

4.3.2.1 Other Authors' Views on the Future of Educational Reverse Engineering and Similar Activities

Of relevance to this research are the words by editor Myer Kutz who has provided an interesting view on what he expects reverse engineering to achieve as an educational practice , he states for example that the practice of reverse engineering principles will "facilitate the education of a new generation of students on knowledge areas critical to their survival and success as engineers such as functional modelling; competitive product design, information technology, globalization, and product platforming within an enterprise". What's more, he states that, "the proliferation of reverse engineering principles and practice has even further-reaching implications" (since) "the sustained development of engineering principles, technologies, and tools will continue to shape and influence product development processes in globally competitive markets" (and) "similarly, the teaching of these principles, technologies, and tools will help prepare a wide range of engineering students to enter the workforce with a more effective understanding of how to efficiently develop consumer-driven; cost-effective, and environmentally friendly products in a distributed, technology-mediated environment.", [Kutz. 2007], the information presented in this chapter, and in Resource 4 of the collection of resources about the documented benefits of reverse engineering activities aim indeed to support author Kutz's views on the topic

4.4 Specific Conclusions

The following conclusions are of a rather specific nature and describe experiences in the development and presentation of results from research

4.4.1 Use of EREA in Engineering Design Education

There is no better or worst approach to the teaching of engineering design and in that sense educational reverse engineering activities are not a panacea for the teaching of engineering design, as such, they are only suitable for a subset of the total expected competences (technical and behavioural) of an engineering design graduate, that's why they are considered only as one of the tools in the teaching of engineering design as a whole, and should not be seen as a substitute for traditional (forward) engineering exercises which in turn are also suitable only for a subset of the total expected competences of a student too

4.4.2 Teaching Approach of EREA

It can be said that the approach to the teaching of engineering design through EREA as envisioned in this dissertation doesn't focus on the explanation of a given technical topic from a typical engineering design curriculum, but rather on presenting students with an opportunity to acquire and develop certain competences that can be introduced via EREA as explained in Resource 4 of the collection of resources

4.4.3. Conclusions regarding the use of the DRM Framework

Concerning the use of the DRM framework by authors [Blessing & Chakrabarti. 2009] for the research done in this dissertation it can be concluded that:

- At the end of this doctoral research the use of the DRM methodology provided a foundation not only for the execution of the research project itself but also for the dissemination of results, and the presentation of results with a scholarly approach
- DRM is a framework that provides supporting methods and guidelines to formulate and validate models and theories for the multidisciplinary nature of engineering design research.

- The stepwise approach of the DRM methodology helps the novice researcher to develop a line of argumentation to plan and implement research stages in a more effective and efficient way with the aim to provide structured deliverables that enhance information traceability throughout the stages of the doctoral project
- Research in engineering design education is bound not only by technical topics but also by the cognitive processes of students, and the educational strategies of the institutions under study.
- Just like any other methodology, it only tells where one is in the research, but the development of the individual stages, and the use of the right methods and tools for a particular project, still depend on experience and interaction among the stakeholders.
- The framework allowed the creation of a collection of resources that emanated from a transparently presented and systematic methodology that aimed to produce results of a consistent nature

As the framework becomes more popular then, new research, approaches, and experiences will be published and will help enrich the understanding of the stages, transitions, steps and praxis of the methodology.

4.5. Expectations

At the end of this project, and after presenting the reader the information resulting from the triangulation of published evidence with the findings and conclusions from this research, it is expected that:

- A meaningful contribution is made so EREA can finally be properly contextualised and disseminated
- Interested educators will have a better understanding not only about EREA but also about the assessment of their learning outcomes
- A basis for a shared understanding of what to expect from EREA is established so researchers and educators understand the position and potentialities of EREA in engineering design education
- The interdisciplinary and articulated domains that take part in an EREA are better understood
- Educators can identify the location of EREA within the global area of engineering design and thus better integrate them at the appropriate course and time from those in their teaching curriculum
- Interested educators can eventually create subject materials and courses based on EREA and for the benefit of their students

- Granters and those who take decisions about potential investments in education can better connect the potential of EREA with their educational programs and with the needs of the local industry

It is one of the intentions from this research then, to provide curriculum planners with the evidence and support to justify the inclusion (or at least the test) of EREA into their existing teaching curricula

4.6 Future work and Self-critique

Despite having written the collection of resources in Annex A as self-contained, individual elements, the length of the resulting collection made the document itself of interest to a niche population (engineering design professors with a strong interest in EREA), this was not the initial intention of the author since the original idea was to come up with comprehensive yet short, guiding manual for the preparation; execution, evaluation and follow-up of EREA in engineering design education directed to any professor of engineering design irrespective of his/her interest in the topic

Because of the length and comprehensiveness of the resources too, a traditional field test of the resulting document to measure the impressions of the readers was not possible either, since few of them would have the willingness to go through all of them and provide meaningful feedback, and so once it was detected around 2012 that the length of the resources would be bigger than that of a traditional guiding manual a different approach to their testing had to be devised

It should be emphasised though that to the author, the tradeoff between Comprehensiveness vs. Usability was well worth it, since there were no similar resources available to the reader before the one resulting from this research, and the freely distributable nature and length of them only reflects the intention to cover every relevant detail about the current practice of EREA and make it reachable to anyone, after all, every project (specially a student one) is prone to be improved over time and the feedback from future evaluators will help find the right balance in the information presented that ensures that the learning setting; the curriculum content, the teaching method, and the evaluation mechanisms suggested support students in their attainment of the learning goals expected from an EREA.

It remains as future work for the author then:

- The creation of a short guide for the study of EREA with better usability, and addressed to a general rather than specialist audience

- The search of new areas of application for the topic such as those concerning the development of computer assisted tools for the automation of reverse engineering analysis, and the use of virtual reality in product dissection exercises,
- The writing in Spanish language of the collection of resources in Annex A

It is also expected that the author eventually joins a community of educational reverse engineering practitioners and new publications that benefit from the experience gained in this research are produced

4.7 Final Remarks

The planning of the introduction of a novel educational experience in the field of engineering design posed a number of challenges to the researcher where domain knowledge had to be derived from the study of relevant bits of information dispersed across several areas of science, it can be said then, that this research was not only bound by the technical topics inherent to the activities under study themselves but also by the impact in the research of:

- The administrative issues in trying to suggest changes to the way engineering design was taught in a typical target institution
- The didactic and experiential activities suggested for students in accordance with best practices in education
- The existing learning theories and the implications in trying to suggest educational activities that still fit into them
- The differences in target students in terms of gender; intellect, and socio-cultural backgrounds
- The shift in moving from faculty centred activities to student centred activities that EREA propose
- The presentation of objective information regarding the reasonable expectations from an EREA so educators could plan their introduction at a time that fitted their teaching needs
- The setting of a baseline so the reader of this work could actually benefit from previously published findings as well as from the original results presented here
- The technical, societal, and organizational challenges found in trying to create a viable interdisciplinary solution for the current teaching of engineering

It is concluded for this dissertation that there will always be a need to improve engineering education and thus, new approaches such as EREA will have to be explored;

tested and expanded, because of this, continuing studies about educational reverse engineering can be reasonably expected and should be considered healthy for the development of the topic.

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ANNEX A A COLLECTION OF RESOURCES FOR THE STUDY OF EREA IN ENGINERING DESIGN EDUCATION

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BarcelonaTech

Departament de Projectes d'Enginyeria

Escola Tècnica Superior d'Enginyeria Industrial de Barcelona

Projectes d'Innovació Tecnològica en l'Enginyeria de Producte i Procés

A Collection of Resources for the Study of EREA in Engineering Design Education

Presented by

Marco Lino Calderón Saldierna

October 2015 Barcelona, Spain

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Unless otherwise stated all Tables / Figures were created by the author of this collection of resources

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PREFACE

Educational reverse engineering activities are in general, highly regarded hands-on activities that help students bridge the gap between theory and practice in the safety of an educational environment; they can be included in any engineering design curriculum to help students increase their awareness and understanding of the design process and to show through real-life examples what worked for other designers and what didn't. However, as promising as they sound, the number of programmes that have introduced them into their teaching curricula can still be considered low in comparison to the number of academic institutions offering degrees in the global community of engineering design; while the causes for it are many and of a varied nature, it was found during initial exploratory studies with experts and stakeholders in academia and industry that major factors impeding their full adoption were:

1. The limited awareness of their educational benefits, especially in relation to the expected competences of an engineering design student at the time of graduation
2. The lack of a standardized guideline on how to actually prepare; deliver, and evaluate these activities to make the most out of them, to not leave this responsibility solely to the experience of the professor in turn (a challenge for first time instructors of this type of activities)
3. The perception that the already existing resources on the topic were either dispersed or unsuitable as a tutorial (c.f. Self-directed learning)
4. The idea that current literature on the topic required a re-contextualization in light of progressing technologies now available in education
5. A number of misconceptions about educational reverse engineering, mostly concerning its lawfulness and ethics

This collection of resources then, is a freely distributable document that intends to deal with the causes that contribute to the lack of diffusion; adoption and regard for reverse engineering activities in engineering design education and presents a potential solution to such issues by providing potential adopters with the information and guidance for a seamless integration of educational reverse engineering activities into their existing teaching curriculum.

Every effort has been made to ensure the quality of this collection of resources that intends to be rigorous at the bibliographical level and comprehensive in content so the work and ideas presented here can be verified empirically by independent practitioners, your questions and feedback to help improve this document are most welcome indeed.

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INTRODUCTION

Educational reverse engineering activity(es) -hereinafter referred to as the acronym "EREA"- help engineering design students to: Acquire and develop a set of abilities that raise their awareness of the design process; expand their sources of inspiration, position their actions within the lifecycle of a product, and transform theoretical knowledge into practice. However, as mentioned already, it was noted that although such activities spark interest among engineering design educators, they are either absent from typical engineering design curricula or are not fully exploited

After analysing the causes for it and determining that the creation of a collection of resources was the best way to reach a geographically dispersed community and thus start trying to change the existing situation, the development of this document began with the goal to address as many of the concerns as possible found whenever trying to implement EREA into existing engineering design curricula

The contents selected for this collection of resources then, were derived based on the feedback received from peer reviewed conference papers stemming from the doctoral research from which this document also originates, and from the presentation of intermediate results to early reviewers of this collection of resources; because of this, the information presented here targets first time (or novice) instructors of reverse engineering activities and takes into account not only the technical but also the pedagogical and administrative considerations implicated in the introduction of new academic activities into an existing engineering curriculum

Given that some relevant information about the topic already existed but it was dispersed across different areas of knowledge; rather than developing all topics from scratch again, a conscious effort was made to examine published literature and to consult with domain experts to integrate and contextualise all existing information into a coherent body that could be complemented with the original results originating from this project.

The major sections of this document then, are listed below along a brief explanation of their contents:

• Resource 1: Fundamentals of Educational Reverse Engineering Activities: Foundations and contextualization of reverse engineering research in the field of engineering design; differences and similarities with other approaches that bring practical experience to the classroom, challenges in the implementation of EREA, etc.

• Resource 2: Reverse Engineering and Learning: Cognitive processes students undergo when performing reverse engineering activities.

• Resource 3: Misconceptions about Reverse Engineering: Clarification of misunderstandings about reverse engineering in education.

• Resource 4: Benefits of Reverse Engineering: An account of previously published advantages; potentialities, and added value reverse engineering activities can bring to the teaching and learning of engineering design.

• Resource 5: A Proposed Methodology for Reverse Engineering Analysis in Engineering Design Education: A methodology addressed to the field of engineering design for the educational analysis of consumer products

• Resource 6: A Suggested Pedagogy for the Teaching of Educational Reverse Engineering Activities: A collection of tips and advices dealing with the practical aspects behind the execution of the steps; analyses, tasks, and questions proposed in the methodology of Resource 5

• Resource 7: Integrated Example of an Educational Reverse Engineering Activity on a Disposable Camera: A guided example, suitable for self-directed learning of an educational reverse engineering activity using a disposable photographic camera as subject system

• Resource 8: Conclusions and Final Remarks: Thoughts on the present and future use of reverse engineering in education based on collected experience and an analysis of existing, published research

• Resource 9: Miscellaneous Resources for the Study of Reverse Engineering: An assortment of references linking to published research with the potential to support the eventual development of additional, instructional courseware

The abovementioned sections are of a sequential nature and purposefully converge at Resource 7, given that the guided example shown therein expects to contribute in laying out the foundations for the eventual development of the readers' own scalable instructional materials; teaching strategies and educational innovations applied to educational reverse engineering activities.

The information presented here thus, intends to provide an unbiased view of educational reverse engineering activities that points out both their strengths and weaknesses to help those educators interested in these activities to:

• Implement them as smoothly as possible into existing and future educational curricula in the area of engineering design

• Make the most out of them by providing a general framework; credible evidence and advice for each of the comprising stages

• Measure the impact of EREA in supporting individual and group activities in ways that extend current engineering design student's experiences.

The document in your hands, aims to provide engineering design professors with an assimilable and readily applicable collection of resources for the systematic and effective planning; execution, evaluation and follow-up of Educational Reverse Engineering Activities (EREA) in support of the teaching of engineering design; and it is the author's belief that by providing students with non-traditional educational experiences and by encouraging educators to deliver content and knowledge in a non-traditional way, beneficial, opening experiences can be brought to the teaching of engineering design.

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RESOURCE 1: FUNDAMENTALS OF EDUCATIONAL REVERSE ENGINEERING ACTIVITIES

1.1 Resource Introduction

The beneficial use of reverse engineering analysis in design education is confirmed by a variety of findings dispersed across several areas of knowledge, in this resource a presentation of them and an analysis of how they contributed to the development and shaping of EREA in its current form is introduced to the reader.

1.2. Principles of Educational Reverse Engineering

1.2.1 What is Reverse Engineering?

Reverse engineering has different meanings depending on the context where it is mentioned; the different areas of applicability of the term then, generate a concept that can be found in such diverse areas as legacy software; geometrical shape extraction, component analysis, intellectual property and more, the term can be even used as a verb, “to reverse engineer (something)” for example, portrays the idea that any system or situation can be understood by investigating the traces left by their current, perceivable effects and matching them to the potential causes that originated them at a previous point in time.

Reverse engineering as an exploratory activity per se, is founded on the designers’ capability to analyse available pieces of information, and to reconstruct those unavailable ones based on their domain knowledge and expertise in gathering and contextualizing new data, because of this, reverse engineering can be used for commercial, competitive or educational purposes; in this document though, only the educational aspects of reverse engineering are considered and thus Educational Reverse Engineering (ERE) is seen as an investigative method to support the teaching of engineering design that is defined here, as the analysis in the areas of interest of an engineering design program of an existing consumer product, by taking it apart and studying its structure, function and operation, with the attempt to recapture the abstract and functional top level specifications envisioned by the original designers during the Product Design Specification (PDS) stage, and thus compare against the analysts’ own knowledge, the design rationale and tradeoffs the original designers faced to go from the multiple solutions originally available, to the delimited solution boundaries embedded in a final product, therefore providing the analysts with an educational hands-on experience, and an opportunity to asses a product's fulfilment of customer requirements and its market failure or success.

The set of actual academic tasks, questions, laboratory tests and exercises that are later explained in the method for reverse engineering analysis proposed in this collection of resources should be understood as "Educational Reverse Engineering Activities" (EREA) and thus, be considered a derivative, modern effort that is pedagogically oriented and benefits from media technologies not available before to provide engineering design students with complex, but realistic hands-on experiences that can be safely repeated and that help them understand and catch up with the ever changing methods and technologies relevant to the praxis of engineering design.

As opposed to previously published works on educational reverse engineering activities that focus intensively on the theory of the technical system under analysis, the preferred approach here is to focus instead on the student's acquisition of abilities through the use of individual, well-known, engineering analyses performed to an existing product and where the exactness of the numerical results from such analyses is not as important as the acquisition, exercise and development of student abilities relevant to the learning of engineering design.

1.2.1.1 The Different Contexts of the Term "Reverse Engineering"

As implied above, "Reverse engineering" is a generic term used in several and often unrelated contexts where the word "Reverse" intends to portray a backwards path, from a final condition to an initial one; however, the failure to distinguish the differences in the broad scope where the term is used creates confusion in the readers about what reverse engineering really is, how it connects with related disciplines, and strengthens the assumption that whatever the characteristics reverse engineering has in one of the contexts they will be also shared across others as well. Table 1.1 below lists the contexts where the term "Reverse Engineering" has been used so far, and lists some of the representative activities inherent to them.

Context	Representative Uses
Acquisition of foreign technologies	This context is similar to the military one shown further below, except that in this case it is usually a state sponsored effort and the target technologies to acquire are intended for immediate, practical use (rather than being state of the art ones); It has happened already at times of isolation, blockade, or denial of technologies, for example the Chinese cloning of Russian locomotives and motorcycles from WWII designs and the cloning in eastern

	countries of western computers and home appliances in the 70's and 80's.
Commercial competitiveness	Competitive intelligence (e.g. Automotive clinics), benchmarking of products and processes (e.g. Competitive tear downs).
Computer software industry	Legacy software; interoperability, security, artificial intelligence (machine learning).
Education	Disassembly; analyse and assembly activities mainly used to teach engineering and manufacturing principles (e.g. Mechanical, physical, hydraulic).
Extraction of geometrical features	CAx scanning systems; land surveying, shape recognition.
Fictional	The term "Reverse Engineering" is often mentioned in movies, TV series and documentaries.
Forgery	Cloning of electromechanical products of significant market value.
Hobby	Hardware hacks a.k.a "mods" or "tweaks" done by enthusiasts.
Industrial manufacturing	Recreation of blueprints, performance specifications and manufacturing information of pre CAx designs (e.g. Designs done before the 70's), quality control, etc.
Information management	Used to acknowledge the legal side and implications of public policies (e.g. vulnerabilities of handling private data)
Intellectual property enforcement	Investigation of patent or copyright infringement
Military	Acquisition or development of foreign technologies to pursuit or maintain a military advantage (can be done by state or private companies alike)
Natural sciences	Used in systems biology; brain and cognitive sciences, bioengineering, psychology, and cell engineering mainly to describe cognitive neuronal processes but also to portray a forensic approach to them.
Semiconductors industry	Extraction of topologies.

Technically protected digital content	Research on circumvention and anti-circumvention measures (e.g. Protection of cable and satellite television programming)

Table 1.1 The Different Contexts of Reverse Engineering, Expanded from: [Calderon. 2010a]

1.2.2 Reverse Engineering as an Integrative Activity that Links Theory and Practice

Authors [Leek & Larsson. 2007] state that a reverse engineering process requires skills and knowledge from several engineering areas such as mathematics, analytics, problem solving and design. Indeed, it could be even said, that reverse engineering is a kind of analysis that needs to draw knowledge from the different fields that were required for the creation of the subject under analysis in the first place. Figure 1.1 for example, shows the typical functional groups involved in the creation of mechatronic consumer products

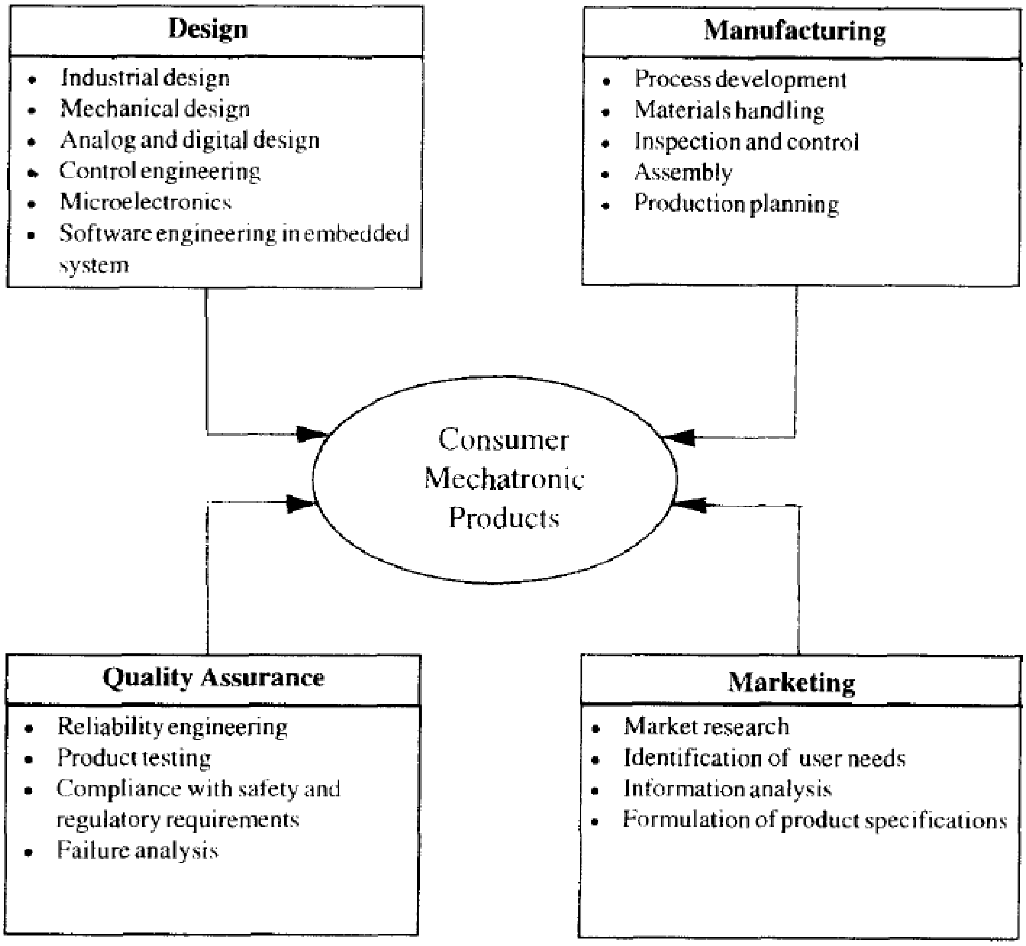

Figure 1.1 Involvement of Various Functional Groups in the Design of Consumer Mechatronic Products, Source: [Chan & Leung. 1996]

Whereas Figure 1.2 below shows the typical knowledge domains involved in design itself

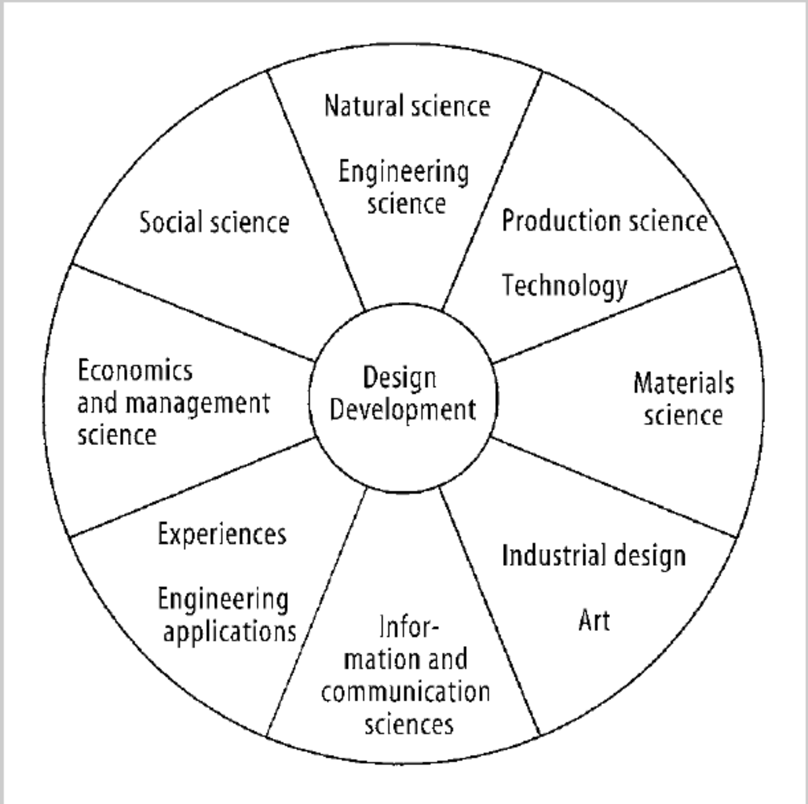

Figure 1.2 Related Knowledge Domains that Support Design and Development, Source: [Pahl et al. 2007]

Since a reverse engineering analysis has to uncover the individual contribution of each domain involved in the creation of an existing product, it is easy to see why such activities can bring multiple points of view to the educational experience of students and are integrative by definition.

1.2.2.1 Technical analyses as a Starting Point for Educational Reverse Engineering

As powerful and affordable testing and measuring equipment may become over time (cf. Moore's law [Moore. 1965]), an existing product cannot be fully known through technical analyses only. Author [Augustine. 1983] for example, published -concerning the need of real experience as an important complement to theoretical knowledge; appropriate cognitive skills, and good attitudes- that the actual behaviour of hardware systems once they are in use, exemplified in this case by the measurement of reliability, as shown in Fig 1.3, cannot be accurately derived "either analytically or through laboratory measurements, (and) only field experience can provide a more accurate picture of how systems behave"

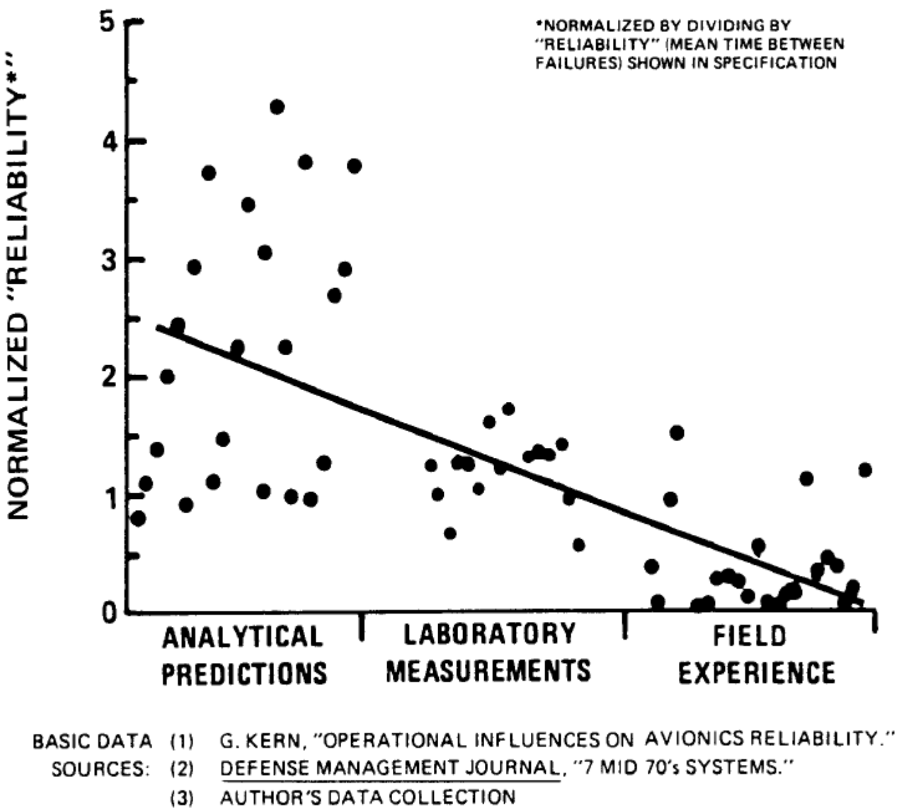

Figure 1.3 Inability of hardware to withstand real world pressures, Source: [Augustine. 1983]

Thus, in the uncovering of the design history and design rationale of a consumer product, additional dissection, and educated conjecturing about it (two elements inherent to reverse engineering analysis) has to be done to complement whatever data can be obtained from it in the first place.

In this regard, authors such as [Lamancusa et al. 1996] for example, have already recognized reverse engineering as a solution for bringing practical experiences into the classroom and potentially alleviate students' disconnection between theory and practice through educational exercises which inherently imply hands-on activities and whose effects are explained in several existing theories of learning in design such as Piaget's early learning model [Piaget.1952], Felder-Silverman learning styles [Felder & Silverman. 1988]), or Kolb's learning model [Kolb 1984] which is in fact the preferred one in this document, to link concrete and practical experience to reverse engineering activities.

After all, and in the words of author [Menchu. 2007]. To reverse engineer a system you must have a full understanding of that system (and) if you understand a system, you understand:

- The players: the key components that make up the system.
- The functions: the main building blocks of the system.
- The relationships: the threads that tie the functions together.
- The flow of information: the energy and the information used to carry out the system strategy.
- The strategies: which define what the system is supposed to do and how it will do it

And the stimulus; processes, and the outcomes from user inputs to all the steps that take place and lead to the system’s output.

1.2.2.2 The Subject System of Educational Reverse Engineering Activities

Consumer products are devices that are usually mass produced; they are based on customer and market demand and thus, cost effectiveness and efficiency of resources employed during all phases of their development is of utmost importance, because they are affordable; feature current technologies, serve as examples of design, and impact the state of the art, the environment and the quality of life, they have been considered already an ideal test bed for educational exercises. Author [Dalrymple. 2009] for example, has explained how consumer products support reverse engineering activities by describing said activities as a discovery based instructional method (i.e. One where regularities of previously unrecognized relations and similarities between ideas are uncovered by the learner, resulting in a sense of self confidence in one’s abilities) as opposed to being an expository method (i.e. One where the student is given the problem along with the correct answer), and thus, in order to provide sufficient parameters to direct students’ attention to topic-relevant concepts and avoid the inability to constrain students’ exploration without guidance (e.g. What students self- discover may not always be what was intended to be taught in the sense that actively constructing objects is not necessarily the same as constructing an understanding of how they work) she suggests that an alternative approach to traditional discovery-based activities is where an “expert version” (e.g. A consumer product that will serve as a vehicle for learning) is provided to students to let them deconstruct it and understand it, given that “The hope is that such an approach includes an inherent restraint that will provide better parameters for students’ discoveries so subsequent learning will be facilitated and motivation will remain high”, [Dalrymple. 2009]. Analyzing a consumer product in detail then, helps unveils the design choices and tradeoffs made not just for engineering reasons but also in targeting particular markets.

1.2.2.3 Educational Reverse Engineering Activities as a Source of Integrative Knowledge:

According to author [Blessing. 1994], knowledge; experience, skills, beliefs and preferences, all play a role in how a designer tackles the design process, on the generation of feasible solutions, and eventually on the selection of them. Technical knowledge about working principles; existing physical effects, and experience with similar projects is claimed to contribute to the generation of innovative and feasible design solutions, and since knowledge itself can be classified by levels of generality, namely: Personal; company-specific, branch-specific, profession-specific, culture-specific, and universal, this knowledge will be indeed related both to products and processes. Figure 1.4 by [Blessing. 1994] shows the different sources that contribute to the knowledge of designers. Hands-on activities such as reverse engineering ones, contribute to expand and deepen on the sources of information available to the design student, especially in the areas of literature, background and previous projects which are all areas mentioned in the figure shown below. It could be said then, that along the design process designers will make decisions based on information from multiple sources including information about competitors' products; the current state of the art; product requirement specifications and that, experience acquired through reverse engineering activities can improve the student's abilities in these areas.

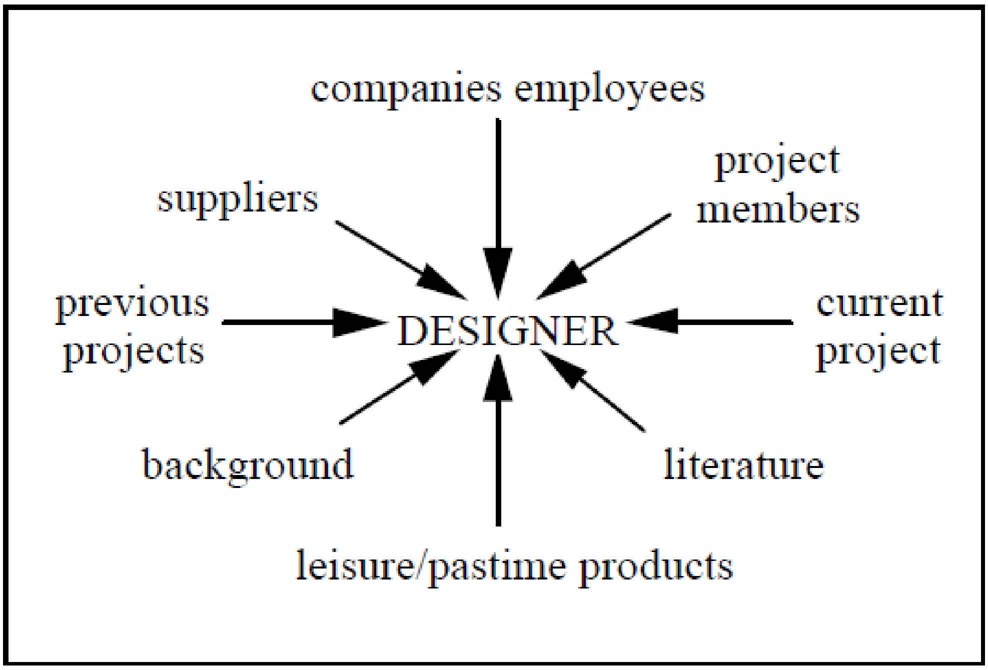

Figure 1.4: Sources contributing to the knowledge of the designer, Source: [Blessing. 1994]

In praxis, design engineers have a working knowledge of materials, structures, computer science and electromechanical engineering, knowing something about all of these areas of technology and science helps them better tackle a variety of design projects for which reverse engineering exercises provide the opportunity to get in touch with different areas of science, hence it can be argued that reverse engineering in education is an experience worth having, since it aims at providing future designers with as varied experiences and sources for inspiration as possible during the duration of their studies.

1.2.2.4 EREA as an aid to Expand Students' Base Knowledge of Solutions and Design Possibilities

In the words of author [Hyman. 2003], design engineers, like all people, approach problems from a perspective derived from their own experience and expertise; each tends to value their own knowledge and believes that their own specialty is important, the author even provides Figure 1.5 to show eight different versions of a proposed airplane design, each one representing what the plane would look like if it were designed by: An aerodynamics engineer; a structural engineer, a propulsion engineer, etc. with the intention to state that Design engineers have their own biases and special interests and that " The cartoon's depiction of the vastly different concepts of airplane design only slightly exaggerates the reality that design engineers are the ultimate special interests." Reverse engineering then, due to its integrative nature can at least help students expand their horizons and broaden their base knowledge of solutions and design possibilities, an assortment that will be further explored along this collection of resources.

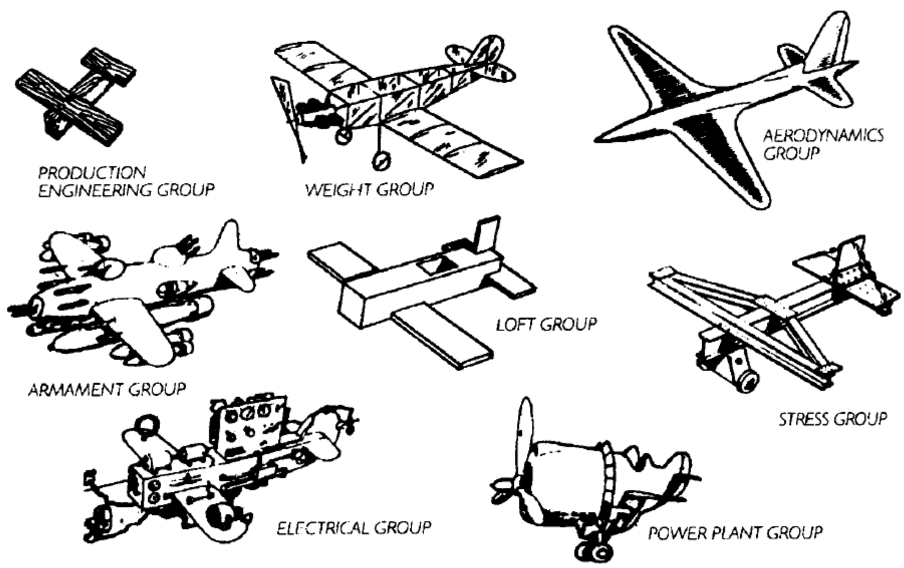

Figure 1.5 Aircraft Design by Special Interest Groups of Engineers, Source: [Hyman. 2003]

1.2.2.5 EREA as a Vehicle for the Acquisition of Experience and Expertise

Authors [Brereton et al. 1995] have long stated that in the daily work of designing; troubleshooting, modelling and discussing, engineers use various levels of abstraction to help them relate to real artifacts, experiences, and vice versa as can be seen in Figure 1.6

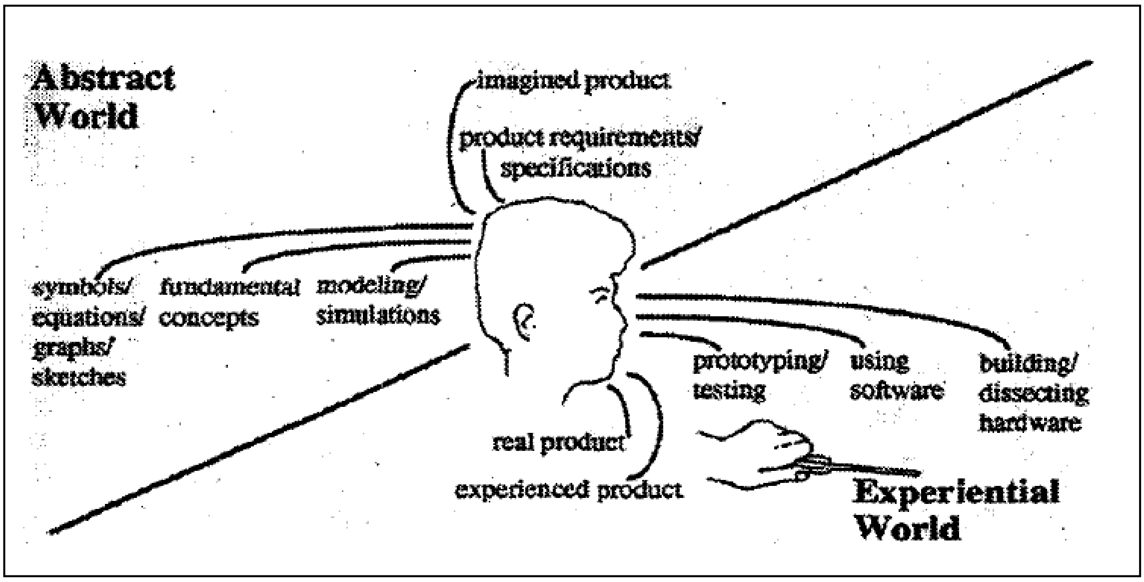

Figure 1.6 Learning Engineering Design by Developing Links between Experiential and Abstract Understandings, Source: [Brereton et al. 1995]

From the figure seen above and the information presented in this section, one can conclude that EREA provide students with a simulation of real life situations that help them exercise both the abstract and experiential world and thus serve as a didactical activity that helps students acquire much needed experience while still in the safety of an educational setting.

Additionally, it is worth mentioning that authors [Hatano & Inagaki. 1986] coined the term “Adaptive Expertise” to distinguish different types of expertise; people who can execute procedures rapidly and accurately for example, show routine expertise whereas those who can adapt their routines to solve new types of problems show adaptive expertise. This concept is critical to reverse engineering activities since routine expertise is inflexible and with the continuously evolving technologies and knowledge, the practices and problems of today are not likely to be those of tomorrow, cf. [Dalrymple et al. 2011]. Authors Hatano and Inagaki knew this, so they suggested that optimal instruction should aim for adaptive expertise (e.g.an understanding of a procedure or concept that is deep enough to allow adaptation to solve new problems) and in this regard authors [Dalrymple et al. 2011] stated that if D/A/A activities do promote greater design learning and engagement by engineering students than traditional methods of instruction, then it may be a key vehicle for promoting that defining quality of professional engineers, the “adaptive expertise”.

1.2.3 Similar Approaches to EREA in the Teaching of Engineering

In design education there are a number of product analysis tools that can be mistaken for EREA; they share the same concept of disassembling a device to further analyze it, and they have been known and practiced in engineering for a long time; Table 1.2 below that intends to be comprehensive lists these tools and provides the reader with representative bibliography for their study, however, any new virtual deviation tool to learn from design failures could still be included in this list.

NAME	REPRESENTATIVE PRACTITIONER / AUTHOR AND ASSOCIATED RESOURCES
A) Analysis of known solutions	Pahl & Beitz, [Pahl et al.2007]
B) Competitive benchmarking	Robert J. Boxwell, [Boxwell. 1994]
C) Design recovery	Chikofsky & Cross, [Chikofsky & Cross. 1990]
D) Forensic engineering	National Academy of Forensic Engineers, [NAFE. 2000]
E) Konstruktionskritik	F. Hansen, [Hansen. 1966]
F) Product reengineering	Harold Chestnut, [Chestnut. 1967]
G) Teardown analysis	Sato & Kaufman, [Sato & Kaufman. 2005]
I) Value engineering	Lawrence D. Miles, [Miles. 1972]
J) Weak points analysis	F. Hansen, [Hansen. 1966]
K) Zenbara	Japanese companies, [Higashi & Lauter. 1990]

Table 1.2 Product Analysis Tools Likely to be Mistaken for EREA

There are however, dedicated methodologies too, that aim to test a student’s knowledge of the engineering principles and design processes associated to a product under analysis. To discern the differences and verify the borders among such approaches isn’t that straightforward though given that they all pursue equivalent goals; use similar tools, and theoretically they rather differentiate themselves by the reach and depth that their authors originally planned for the activities and the steps included in them, still, Table 1.3 below lists such methodologies and intends to explain their main characteristics as well as some of the differences among them, and in respect to EREA.

Approach	Description of the Approach and Major Differences with Respect to EREA	As Championed

		by Person / Institution
Product Dissection	According to author [Dalrymple. 2009], reverse engineering and product dissection share common characteristics, and are used interchangeably when referring to equivalent industry practices, from a pedagogical perspective however, she points out that the two processes differ in their learning objectives and outcomes. The term “Product dissection,” she explains, has been used to refer to the process of disassembling an artifact to understand how it works or is assembled whereas the term “Reverse engineering,” “is reserved for processes that extend beyond disassembly for the purpose of understanding how a product works or is assembled”, she later quotes authors [Otto et al. 1998] and [Otto & Wood. 1996] too, to conclude that reverse engineering is viewed “as an advanced version of product dissection”.	Prof. John Lamancusa, [Lamancusa et al. 1996] / Pennsylvania State University, University of California at Berkeley
Disassemble / Analyze / Assemble. (D/A/A) Activities	According to [Dalrymple et al. 2011] authors Ogot and Kremer introduced the term “Disassemble/Analyze/Assemble (DAA) activities,” to refer to educational activities patterned after the industry practice referred to as reverse engineering, product teardown, or product dissection. These activities involve the systematic deconstruction of an artefact and the subsequent analysis, and possible reconstruction of its components for the purpose of understanding the physical, technological, and developmental principles of it. They are different to the ones presented in this collection of resources, not only because EREA have a more explicit interest in the social; economical and environmental aspects of the design of the product under analysis, but also because the sequential approach of (D/A/A) activities span the duration of a 4 year career in engineering, as opposed to the self contained approach of EREA that can be as long or short as the instructor decides.	Profs. Dalrymple; Ogot and Kremer, [Dalrymple. 2009], [Ogot & Kremer. 2006] / Pennsylvania State University
Product Archaeology	According to Profs. Lewis, Ulrich and Pearson, product archaeology is a paradigm for product dissection activities whose goal is to “Teach the global, economic, environmental, and societal foundations of engineering design through product archaeology”. A multi-university team, supported by many of the pioneers in this type of activities was made to	Profs. Lewis, Ulrich and Person, [Lewis et al. 2011], [Ulrich & Pearson.

	leverage the previous 20+ years of product dissection-based research and educational advancements and under the new concept they created a pedagogical analogy with archaeology and engineering , their goals and concepts are similar to the ones proposed in this collection of resources except for the fact that in here, a more general method for analysis is proposed that enables the analysis of any product; under any category of analysis, at any depth of detail, and for as long or short as needed whereas in product archaeology, their new approach is mapped to the existing structures for product dissection, which in a preferred case is extended over four years of college education.	1998] / Massachusetts Institute of Technology, University of Buffalo
Mechanical Dissection	Mechanical dissection as envisioned by the courses taught at Stanford University by Professor Sheppard is an approach that teaches students about engineering concepts and design principles by having them explore the engineered products around them. This exploration involves having students work in small teams to disassemble and reassemble machines which leads to insight on materials; functions, design alternatives, human factors and manufacturing, ,mechanical dissection then, relies on strong foundational knowledge about the product/topic under review, whereas the approach to EREA presented here has a different orientation in the sense that, it is considered to be more comprehensive in regard to the number of topics under analysis but requiring lower depths of detail, thus it can be considered less rigorous than mechanical dissection and more focused on the students' experience, and their assessment of it.	Prof. Sheri Sheppard, [Sheppard. 1992a] / Stanford University
Reverse Engineering	It's a methodology for new product development and product redesign supported by teardowns and technical analyses proposed by authors Otto and Wood which differs from the approach presented here in that EREA don't require the comprehensive results from technical analyses from the former, but the scope in EREA, is broader instead as to look for the relevant results that also help understand the socio-economical and ecological characteristics of the product under analysis.	Profs. Otto and Wood, [Otto & Wood. 2001] / MIT & University of Texas at Austin

Table 1.3 Comparable Approaches to EREA in Design Education

The abovementioned methodologies place the students' learning at the forefront and they can be associated to the formal study of the design itself; they mostly rely on product development methods and they are typically oriented to system analysis or immediate industrial applications; EREA on the other hand, and as presented in this collection of resources, are fully focused on the pedagogical value of their inherent hands-on approach, and on the students' learning of the non-technical aspects of the product under analysis (e.g. The varied knowledge domains of design development seen in Figure 1.2, or the socio-technological understanding of products as suggested by author [Ropohl.1999]). The most important results from EREA then, are not the pieces of data or numerical results acquired from the product under study, but rather the results that prove the students' acquisition and development of relevant abilities and skills that may not be obvious or easy to measure at first sight.

However, educational reverse engineering activities as presented in this document, cannot be considered an isolated approach independent from the abovementioned methodologies, EREA do share the same basic tools and principles too, but also try to combine and complement them with the new advances in multimedia and computer assisted design technologies in an effort to improve the students' understanding of the broader context of engineering design in areas not usually covered by traditional approaches, because of such shared roots and similarities between approaches then, the extrapolation of findings from previously conducted studies benefits the own research conducted for the creation of this collection of resources and makes possible the use of other authors' results in their efforts to prove the pedagogical viability of EREA

1.2.3.1 Introduction to the Terminology in use in the Area of Educational Reverse Engineering

As seen in Table 1.3 above, several terms exist in engineering education to refer to a set of comparable, hands-on activities that revolve around the dissection of a product for its analysis. It should be clarified then, that with only notable exceptions (cf. D/A/A activities by [Ogot & Kremer. 2006]) such terms are, by practical means, used interchangeably. If we take into consideration the relevant literature on educational reverse engineering though, we could see that: the term "Mechanical Dissection" is credited with the revival of such activities in education; the term "Product Dissection" is relevant because of the availability of updated materials available for its study, the term "D/A/A activities" is important because an actual study was done to come up with such name and was later adopted by other researchers too, the term "Product Archaeology" is a recently revived one adopted by early and new practitioners of dissection activities, and finally the term

“Reverse Engineering”, which is the most relevant to this document, not only because it is the earliest recorded term in the area (author [Tilton. 2004] traces it back “at least to 1960 in connection with hardware when it meant an attempt to fathom and reconstruct the circuitry inside a potted electronic module”), but also because it’s been used by reputed authors such as [Otto & Wood. 2001] in their published research about the topic; because of this, and like the early practitioners of this type of activities, this research prefers to stick to the original term “Reverse Engineering”; to acknowledge, because of historical reasons, its pre-eminence as an umbrella term (a supertype), to recognise that it contains the rest of the terms mentioned in Table 1.3 (the subtypes), and ultimately, to favour it because it better reflects the interdisciplinary, integrative nature of its activities in engineering design.

Worthy of mention too is the term “Dissection” which has developed a special significance in the area, to the point where it is even considered a valid term to refer to educational reverse engineering activities in general. Indeed, that was the name given to these activities in their resurgence in education in the 90`s, and the term is prominently featured in the published research from the time, however, in a modern, fully fledged EREA, dissection is preceded by information collection and followed by equally important analysis, reassembly, synthesis and briefing stages and thus to use the term “Dissection” as a synecdoche (a figure of speech in which a term for a part of something is used to refer to the whole of something, or vice-versa) detracts the activities from their methodological, integrative approach. Past researchers have also noticed this situation by stating for example, that “Reverse engineering is sometimes called mechanical dissection because it involves taking apart or “dissecting” a mechanical system” [Barr et al. 2009], however, there hasn’t really been an attempt to reconcile and reach a shared terminology in the area. Paradoxically, the last point to clarify is that the actual “Reverse Engineering” term can be a misnomer too, “reverse” is not a type of engineering; there is traditional “forward” engineering, but “reverse engineering” is only the name given to a methodology whose tools help to go back from a detailed often materialized solution into its initial conceptual foundations.

1.2.4 Historical Development of Reverse Engineering in Education

Educational reverse engineering activities have their origins in their industrial counterparts where the analysis of varied systems for understanding and acquisition of ideas and technologies has been a driver for development and transformation; still, the ancient origins of reverse engineering cannot be accurately traced, there have been however, events than can arguably count towards its historical development, for example the exchange of artifacs between ancient civilizations (e.g. Trade routes of Egyptians, Greeks and Romans); the studies by Leonardo Da Vinci and his attention to analogies between nature and machines, the copy and modification of exchanged goods between colonial trading companies and indigenous population, or the creativity of Thomas Alva Edison who used to combine and modify existing inventions. The only formal reference to reverse engineering-like activities in past times then, refers to the imitation and replication of foreign technologies by individuals, that can be formally traced back to the early industrial age as shown in a recent exhibit by the US Library of Congress [Library of Congress. 2010] or the importing and analyzing of technology from the United Kingdom into the United States in the 19th century [Nelson & Winter. 1982], concerning more recent times though, author [Kutz. 2007] states that initially, most reverse engineering was directed towards extending the useful life of existing products by providing the knowledge necessary to produce replacement parts.

A properly documented story of reverse engineering however, begins not long ago when a major state sponsored project that might well be considered the birth of modern reverse engineering happened in 1947, when the former Soviet Union started mass producing the TU-4 bomber just three years after three B-29 American bombers made an emergency landing in the Vladivostok garrison in eastern Russia after experiencing problems while raiding Japan in 1944; Author [Hardesty. 2001] for example, provides a detailed description of how three American B-29 bombers were confiscated, and one was fully disassembled , another one was grounded to serve as reference and a third was sent to the air force flight test centre at Zhukovskiy to learn about it. It is said that Stalin and Tupolev representing the highest levels of responsibility on the project personally supervised the copying of the American bomber to come up with a Soviet clone and so the first batch of Tu-4s rolled off the assembly line on schedule in 1947, less than two years after the project was launched, or three years since the aircrafts made the emergency landing. In practice, The Tu-4 became truly operational in 1948 and 1949 as production reached full capacity and by 1950 the Soviet Long Range Aviation had deployed nine Tu-4 regiments, each with 32 bombers, [Hardesty. 2001]. Whether the Soviets or other nations had already embarked on similar reverse engineering projects at that time, or if such initiatives ended up successfully anywhere else is unknown, however, it is safe to assume due to the success and speed of the Soviet development, that some previous experience in the reverse engineering of machinery was around already and that the idea of reverse engineering itself had existed long before too. Indeed the success of the Soviets caught the attention of other nations who later started reverse engineering foreign technologies as a previous step to conducting original scientific research as has been documented to occur in the transfer of German rocket technology to the USSR's guided-missile and space programs [Neufeld. 2002]; in the Japanese innovation system based on widespread use of reverse engineering in the 1950s and 1960s [Freeman. 1987]], in Korea where the development of technological learning strategies started from copying and imitation skills, [Methe. 1995], [NTRM. 2002], [Hobday et al. 2004], in “The change from being a country of reverse engineering experts to a country that develops its own products from ground up” as author [Mitra et al. 2006] states about India, in the acquisition of foreign technologies and semiconductor topographies during the cold war, and more recently in China whose mixed efforts on legitimate and illegitimate reverse engineering of foreign products are used to acquire foreign technologies to pursue a copy-and-develop technology development strategy [Minagawa et al. 2007]. Last but not least, a recent example of what reverse engineering has come to be is the beginning in 2005 of the Antikythera Mechanism Research Project [AMRP. 2012], which is a multidisciplinary investigation to figure out the meaning of what is considered the most sophisticated mechanism known from the ancient world.

1.2.4.1 Birth and Milestones of Reverse Engineering in Education

The first full scale implementation of product dissection activities can be traced back to Prof. Sheppard’s course “ME99 Mechanical Dissection” [Sheppard. 1992a] offered at Stanford University in the USA in 1991, whose course’ objective was to give mechanical engineering students an understanding of mechanical artifacts by answering the question, “How did others solve a particular problem?” ; Such course marked the birth of the systematic study of dissection and reverse engineering activities in engineering education and created the basis for the subsequent development of educational exercises. Author [Nicolai. 1995], [Nicolai. 1998] later explained that the motivation to develop reverse engineering courses was in response to a general agreement by U.S. industry, engineering societies, and the federal government that there had been a decline in the quality of undergraduate engineering education over the previous two decades and that American engineering schools were being accused of “turning out great scientists, but mediocre engineers” and that the general feeling was that “engineering graduates possessed very good knowledge of engineering science, math and analytical techniques; however, they were poorly equipped to use the knowledge in the design of components, processes or systems”.

Why reverse engineering-based activities in education seemed like a good option to achieve the goals sought by the Synthesis Coalition (the funders of the abovementioned ME99Course) and led to a resurgence of engineering dissection activities in U.S.

universities was considered in hindrance by author [Kutz. 2007] to be due to the emphasis on reverse engineering activities in industry and to the recognition of the significant learning opportunities that occurred when reverse engineering was properly conducted, to which author [Dalrymple. 2009] later added that engineering curriculum reform initiatives focused on improving engineering design education, which in turn led to a resurgence of industry design practices within the undergraduate curriculum for which product dissection practices were likely candidates for inclusion given their inherent educational qualities.

After the foundations for dissection courses were laid then, other prominent researchers added their own findings and ideas for the development of them; early authors known for including practical exercises to complement theory in the classroom are: [Agogino. 1992]; [Carlson. 1995], [Hibbard. 1995], [Niku. 1995], [West et al. 1990] and [Otto et al. 1998], whereas influential researchers on curriculum development to fulfil the need for hands-on experience in the teaching of engineering design were [Sheppard. 1992a], [Lamancusa et al. 1996] and [Otto & Wood. 2001]

From the above mentioned information then, it can be seen that the milestones of reverse engineering activities in the field of education go a long way back on events that cross both the industrial and academic domains and that have made educational reverse engineering what it is today; Table 1.4 shown next summarizes those major milestones and includes a brief description of their associated accomplishments

Milestone	**Type**		**Year**	**Description**
	Industrial	**Academic**		
1) Beginnings of Reverse Engineering	X		1944	Duplication in a two year period of American bomber B-29 by the Soviet Union, and mass production of it in three years, designed and named as Tu -4. Cf. [Hardesty. 2001]
2) Outset of Value Engineering	X		1947	Product value improvement through examination of functions by Lawrence D. Miles at General Electric Co. and then introduced to Japan in 1955. Cf. [Miles. 1972]
3) Start of	X		1956	A German technique to search for errors

Konstruktionskritik "Designs Critique"				in manufacturing; construction, design, use and repair of engineered systems. [Hansen. 1966]
4) Development of Automotive Clinics	X		1960	Automotive dissection techniques at General Motors Co. later introduced to Japan, Cf. [Sato & Kaufman. 2005]
5) Consolidation of Product Tear Down Analyses by Yoshihiko Sato	X		1972	Fundamentals and methods of Tear Down Analyses for use in automotive manufacturing. Cf. [Sato & Kaufman. 2005]
6) Introduction of Kolb's Model of Learning		X	1984	Educational psychology and foundations of hands-on activities by author [Kolb. 1984] who states that concrete and practical experience can be obtained through product dissection activities which in turn help reduce the gap between theory and practice in experimental learning environments.
7) Publication of author Rekoff's "On Reverse Engineering" paper		X	1985	A seminal paper describing the fundamentals of reverse engineering as well as most of the terminology used up to this day, Cf. [Rekoff. 1985]
8) Introduction of Mechanical Dissection Courses at Stanford University		X	1991	Well regarded courses by engineering students, plus development of educational materials, Cf. [Sheppard. 1992a]
9) Publishing of "Reverse Engineering" by Katheryn Ingle and the University of	X		1994	A book by [Ingle. 1994] discussing from the engineering perspective, the step-by-step process of reverse engineering on a product and how to amass the necessary critical data needed to successfully re-design an existing product.

Michigan				
10) Creation of "The Learning Factory" at Pennsylvania State University		X	1995	Continuous development of the theoretical foundations of hands-on activities, Cf. [Lamancusa et al. 1996]
11) Publishing of "Product Design: Techniques in Reverse Engineering and New Product Development" by Otto and Woods from MIT and the UoT at Austin		X	2001	Dedicated book for reverse engineering and associated analyses in engineering education. Cf. [Otto & Wood. 2001]
12) Beginning of the Antikythera Mechanism Research Project		X	2005	Multidisciplinary research to figure out the meaning of what is considered the most sophisticated mechanism known from the ancient world. Cf. [AMRP. 2012]
13) Publication of findings on why (PBL) Project-Based Learning is the most-favoured pedagogical model for teaching design		X	2005	A paper by [Dym et al. 2005] where reverse engineering pioneers such as Agogino and Leifer explain how reverse engineering works under a PBL approach and how new avenues for it are open in the area of case-based reasoning
14) Launch of CIBER-U Wikimedia		X	2006	A web-based platform to collect and browse product dissection examples. Cf. [Simpson et al. 2007]
15) Documented		X	2007	A paper by [Simpson & Thevenot. 2007]

use of product dissection activities for graduate courses too				describing how graduate students of a course on product family design use product dissection activities to improve their understanding of platform commonality
16) Submission of the doctoral thesis "The pedagogical value of Disassemble/Analyze/Assemble (DAA) activities: Assessing the potential for motivation and transfer" at Purdue University in the USA		X	2009	A dissertation by [Dalrymple. 2009] on the potential of reverse engineering activities to help the transfer of learning beyond the classroom
17) Launch of the Product Architecture website		X	2011	Online resources about the product dissection approach by the Product Archaeology project. Cf. [Lewis et al. 2011]

Table 1.4 Milestones of Reverse Engineering in Academy and Industry

1.2.5 Past and Present Research Initiatives for the Inclusion of Dissection Activities in Education

Unlike reverse engineering in industry which is considered already a regular practice, the systematic analysis of the benefits of these activities for learning and instruction is regarded as a relatively recent phenomenon cf. [Dalrymple. 2009], research on product dissection-based activities then, goes on, particularly in the United States where individual research as well as funded proposals continue to explore the area, Table 1.5 below lists the major initiatives identified so far that led to the publishing of most of the existing study materials on the topic.

Initiative	Description	Website
The Gateway Coalition	The Gateway Engineering Education Coalition was a multi-institutional collaborative program headquartered at Drexel University and supported by the Engineering Directorate of the National Science Foundation in the USA. The CIBER-U initiative is assumed to stem from it.	http://www.gatewaycoalition.org/
Cyber-Infrastructure-Based Engineering Repositories for Undergraduates (CIBER-U) initiative	The CIBER-U project is a collaborative online learning laboratory and digital repository of design tools and teaching materials to support education rooted in engineering dissection projects. For further information about the CIBER-U initiative the author suggest the reading of "Using Cyberinfrastructure to Enhance Product Dissection in the Classroom" by [Simpson et al. 2007]	http://gicl.cs.drexel.edu/wiki/CIBER-U
The Product Archaeology Project	The product archaeology project is a multi-university project funded by a grant from the National Science Foundation in the USA whose goal is to synthesize concepts from archaeology with advances in cyber-enhanced product dissection to implement new educational innovations that integrate global, economic, environmental, and societal concerns into engineering design-related courses using product archaeology.	http://productarchaeology.org/index.html
The Synthesis Engineering Education Coalition	The National Science Foundation's Synthesis Coalition in the US was a group of eight colleges and universities that begun in 1993 and that emphasized a hands-on approach to engineering education cf. [Sidler-Kellog & Jenison. 1997]	http://www.synthesis.org/
The University of Missouri–Rolla's Design Repository	Digital repositories for the archiving of product data are digital storehouses where product information is captured and catalogued so it can be further retrieved and represented in a consistent and standardized way. The University of Missouri–Rolla's Design Repository, focuses primarily on design artifacts, which may be composed of	http://function.basiceng.umr.edu/

	additional subartifacts, serving as an archive of expert knowledge to support novice designers and concept generation techniques, cf. [Kutz. 2007]	
The National Design Repository	The National Design Repository hosted at Drexel University, is a digital library of Computer-Aided Design (CAD) models and engineering data from a variety of domains cf. [Regli & Gaines. 1997]	http://edge.cs.drexel.edu/repository/repository/
Virtual Assembly Technology	Researchers at Iowa State develop virtual assembly technologies in an interactive and haptic feedback environment, author [Kutz. 2007] explains that this kind of technology would allow design engineers to engage in reverse engineering processes without the cost of acquiring both actual products to dissect and product assembly procedures in order to rapidly check assembly rules, geometric constraints, and collision detection.	http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1028&context=me_pubs
The Manufacturing Engineering Education Partnership (MEEP)	After the success of the Synthesis Coalition, another US National Science Foundation funded initiative, The Manufacturing Engineering Education Partnership (MEEP) was charged with the task of integrating design and manufacturing into the engineering curricula and thus developed their own product dissection course that provided experiences that would demonstrate how fundamentals discussed in engineering science and mathematics classes related to engineering practice, cf. [Dalrymple. 2009]	http://www.mne.psu.edu/lamancusa/welcome.htm

Table 1.5 Documented Research Initiatives on Product Dissection-based Activities

Similar goals exist between this collection of resources and those pursued by the abovementioned initiatives, if comparing EREA to the CIBER-U initiative for example it can be seen that both of them share a common goal of introducing changes to existing teaching curricula in an effort to improve engineering education. If compared to the 2011 "Product Archaeology Project" then, it can be seen that both of them depart from the original method of educational product dissection activities in the 90's and present a new complementary approach to them.

1.2.5.1 Dissemination Efforts for Reverse Engineering-like Activities

Table 1.6 below lists past and current efforts for the presentation of product dissection activities to interested audiences; their occurrence on academic and non academic sources though, can be considered very low which further strengths the goal of this collection of resources to help in their promotion and present details about their actual implementation into existing educational programmes.

Name of the Resource/Event	On line Resources / Associated Webpage	Description/Notes
FIE Conference	http://www.computer.org/portal/web/csdl/doi/10.1109/FIE.1998.738774	A discussion about reverse engineering led by author Alice Agogino took place at the F2E Session of the 1998 FIE Conference in the United States, [Agogino. 1998] unfortunately, the only material available online from such discussion is the session invitation.
A Hands-On Product Dissection Workshop for Engineering Educators	http://gicl.cs.drexel.edu/wiki-data/images/3/39/ASEE.Workshop.Slides.pdf	Slides presented at the "2008 ASEE Annual Conference & Exposition event " in Pittsburgh, USA about a 3 hour long hands-on product dissection workshop for engineering educators to introduce the practice of product dissection, unfortunately no further resources from that workshop or the actual dissection exercise done there can be found online.
Approaches to the Teaching of Design	http://www.engsc.ac.uk/downloads/scholarart/design.pdf	An online guide by Andrew McLaren from the Loughborough University based Engineering Subject Centre of the "Higher Education Academy" in the UK that covers "Mechanical Dissection" as an approach to the teaching of design [McLaren. 2008].
Redwood Science Project 2003. How It Works Institute	http://www.dyfference.org/dyf-institute-ii-thursday/ and http://www.humboldt.edu/rsp/programs.html	Announcement in 2009 of a presentation of information about how the Mechanical Dissection/Reverse Engineering approach can be used in class at the Humboldt State University in California, USA, unfortunately no resources for external people were posted on the website.
Product Archaeology project	http://productarchaeology.org/docs/workshop/prodarc	Sample exercises and information about their approach to product dissection activities were made available in late 2011 at the National Science

	h.workshop.8.10.slides.pdf	Foundation's "Product Archaeology" project webpage

Table 1.6 Examples of Dissemination Efforts of Reverse Engineering Activities

1.2.5.2 The Need to Collect and Contextualise all Relevant Knowledge about Educational Reverse Engineering

While useful and foundational in their approach, most of the dissemination resources presented in Table 1.6 above provide only partial details about the topic and assume a certain level of existing proficiency in it, because of this, updated, accessible materials are still needed for a broader expansion and impact of educational reverse engineering activities in the teaching of engineering design. Indeed an analysis of published resources about the implementation of reverse engineering in education has shown that current materials focus heavily on the individual, technical tools needed for the analysis of a product, and that a number of principles on engineering and design seem to be taken for granted in those publications, the newcomer to the topic then, quickly realizes that the actual praxis of reverse engineering in the classroom is mostly left to the professor in turn and little specific information can be found in existing dissemination materials, Table 1.7 below suggests one of the possible ways to characterise existing resources for the study of educational reverse engineering and thus, better know what to look for depending on one's existing level of proficiency in the topic, namely:

Resource level	Purpose and Examples
1	To show what reverse engineering is (i.e. Non academic webpages, magazine articles, indirect references to the topic)
2	To tell what to do to be competent in reverse engineering (i.e. Most of published academic papers)
3	To define the processes that constitute reverse engineering (i.e. Theses on reverse engineering)
4	To detail how to apply tools and techniques in a reverse engineering analysis (i.e. Published books on reverse engineering)
5	To detail the implementation, use and rationale behind reverse engineering, as well as determining its impact on students, practitioners and education overall (i.e. Workshop materials, minutes of congress discussions)

Table 1.7 Levels of Detail about Existing Resources for the Study of Reverse Engineering

Additional to the above-mentioned findings resulting from the research leading to the creation of this collection of resources, it was found in a paper about the learning factory - an approach to integrating design and manufacturing into the engineering curriculum and where product dissection activities play a major role- a statement about the need for "Professional quality self standing course materials" (to support the teaching of product dissection) but which were deemed hard to achieve because "high cost and long development times are required for proper instructional development and a publisher is needed", [Lamancusa et al. 1997]; later and along the same line, authors [Simpson et al. 2007] stated when referring to product dissection activities that "making sure that students learn what you want them to learn from the activity, versus just having fun taking things apart and not being able to put them back together again, requires considerable forethought and planning to ensure a successful dissection activity", to what they even added that "several product dissection activities can be found online through various course websites and digital libraries such as the National Engineering Education Delivery System (http://www.needs.org/); however, most of these are rather dated and offer limited instructional support beyond the formulation of the assignment itself" [Simpson et al. 2007], the statements from these two groups of researchers, along with the detected scarcity of dissemination materials on the web helped to realise the need to contextualise all past research on the topic and thus create instructional materials to make the most out of product dissection activities. This collection of resources then, aims to provide detailed information on the actual implementation of reverse engineering activities to help newcomers to the area get in one single document the most relevant information on the topic and thus ease the learning curve towards their adoption.

1.2.6 Relationship of Educational Reverse Engineering Activities to the Engineering Design Process

Although analysis in itself is not the same as design, the direct and indirect relationships between them have long been recognized in the field, Figure 1.7 shown below for example, represents a concept map by authors [Turns et al. 2000] that shows 18 important concepts in engineering. The nodes contain the concepts whereas the links between them show their relationships, in such figure we can see how engineering and design can be linked directly or indirectly through analysis, and if we refer back to the description of EREA in Section 1.2.1 we'll notice how these three concepts are indeed considered key components of educational reverse engineering activities.

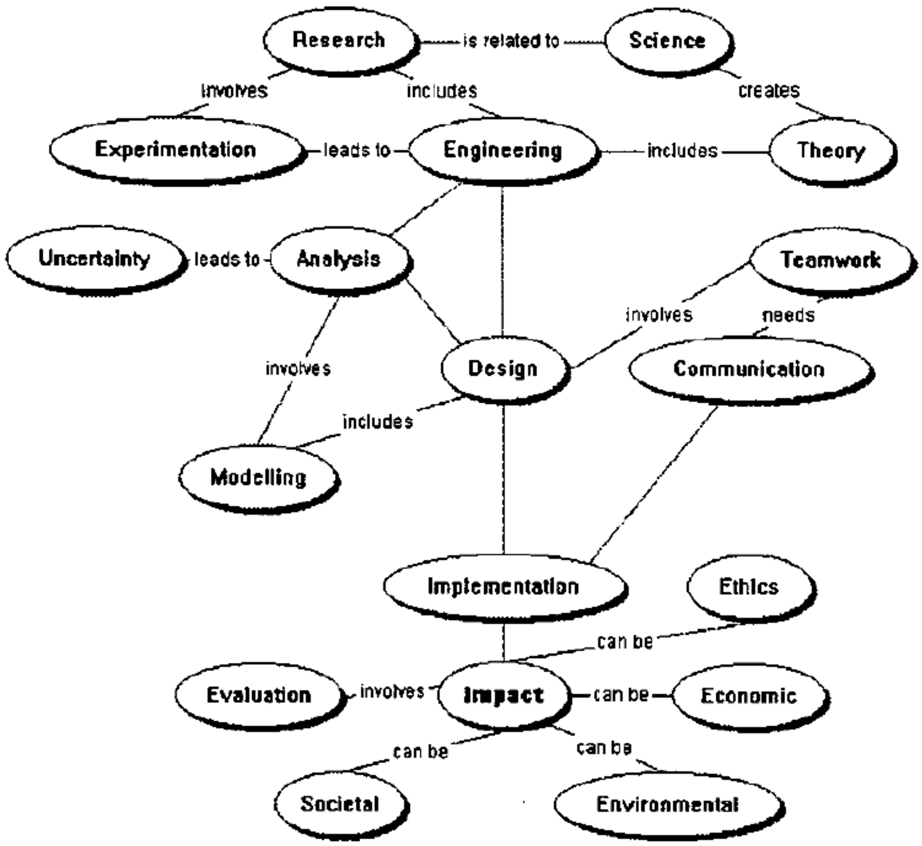

Figure 1.7 Concept map for Engineering, Source: [Turns et al. 2000]

To fit EREA into the actual engineering design process though, it should first be acknowledged that the stages of it have been defined already in a number of well known sources and they usually include: Problem definition; gathering of relevant information, generation of multiple solutions, analysis and selection of a solution, and testing and implementation of it. It is usually at the initial stages of the design process then, when researching about the problem in question; when recognizing, developing and gathering information about it, or when investigating about a number of different, potential solutions to the original task, that reverse engineering can be the most useful.

If we consider for example the stages shown in Figure 1.8 below from the VDI 2221 [VDI Verlag GmbH. 1987] design guideline, reverse engineering activities will naturally fit in stage three “Search for solution principles and their combination” and also into stages four, and five to a lesser extent.

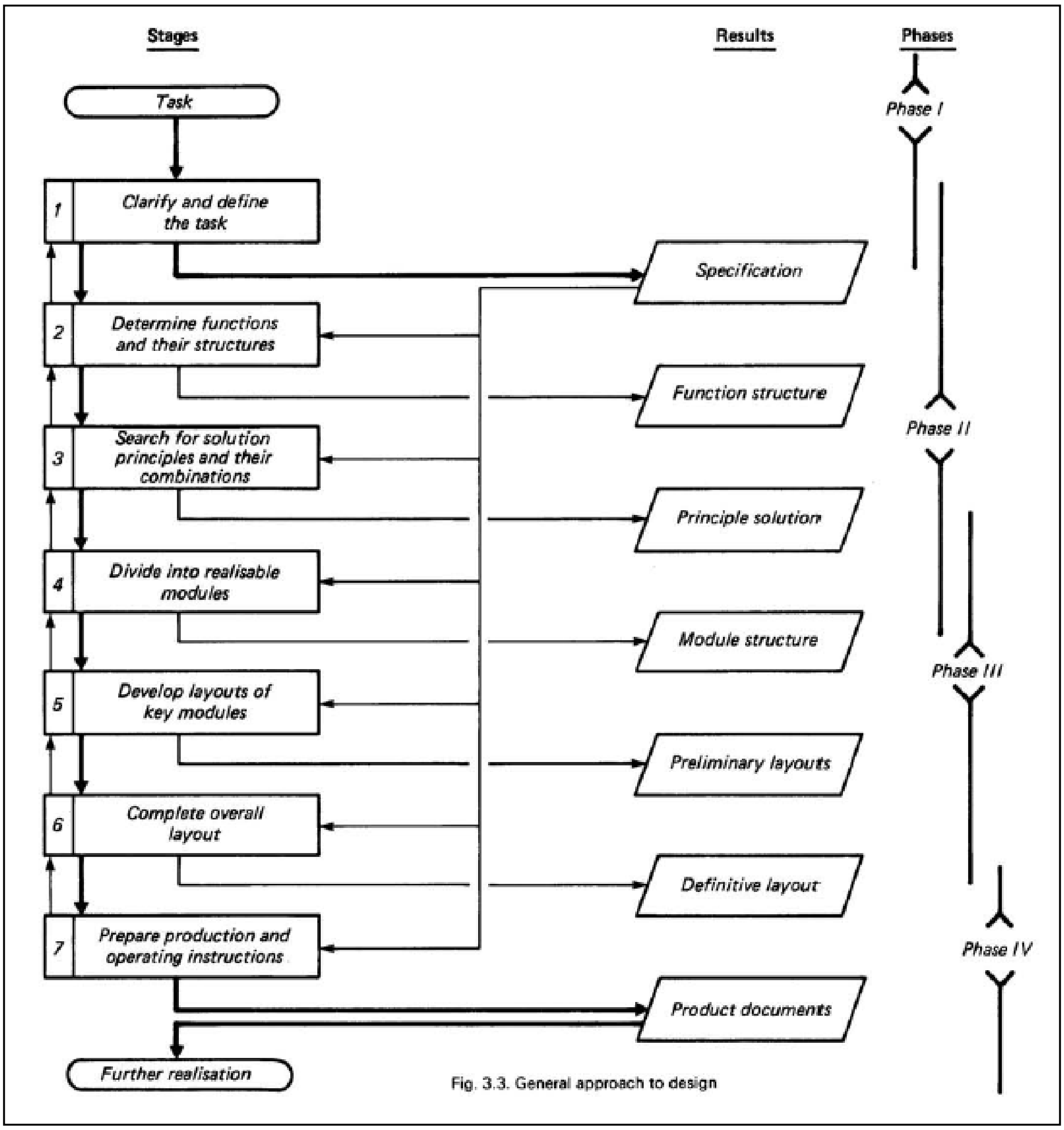

Figure 1.8 General Approach to design [VDI Verlag GmbH. 1987]

The use of reverse engineering analysis at these stages then, can help to solve a number of questions usually made at this point regarding the availability of published materials about the problem to solve; or about the advantages and disadvantages of existing solutions to the problem, or even about the forces (economical, social, ecological, etc.) that affect the solution of it, and in this regard, finding sources for information; collecting it, and determining whether it is relevant to the problem to solve or not is an important skill reverse engineering activities help students to tune, because as author Eide has stated regarding professional praxis “most of a productive engineer’s time will be spent on research, locating, applying, and transferring information” [Eide et al. 2002]. From the abovementioned information, it could be argued that that reverse engineering does have a rightful place in the traditional design process and thus EREA could also be considered an exercise in design.

1.2.7 Cognitive Enablers of Educational Reverse Engineering Analysis

In a reverse engineering analysis, rediscovering the original designers' specifications to understand the product under study is prone to iterations of trial and error, since the path to the final set of reverse engineered specifications is strongly based on handling conjectured design information along the way. There are indeed pieces of information at the highest level of abstraction such as comments, descriptions or committed design decisions that cannot be retrieved or recreated through a reverse engineering analysis, however, this shouldn't be considered a bad thing by itself since in educational reverse engineering analysis it is fine to assume, speculate and put forth educated guesses about the ununderstood parts of a product's design, in fact dealing with uncertainty in this kind of educational activities can later mirror the experiences that will be had in professional life.

Surprisingly; and in regard to the handling of uncertainty, conjectures and assumptions in analysing other people's designs, studies such as those conducted by [Kuffner & Ullman. 1991] uncovered that up to 90% of the design decisions made to come up with a finished product, could be derived by unrelated designers by experience alone; and even that at the students' level, published results by author Kang indicated how when undergraduate students were asked how a thermostat worked during cooking (when doing a first time, disassembling exercise on a rice cooker) there was an 87.5% of correct responses about its operation, [Kang. 2011], this kind of results then, support the idea that educated assumptions and conjectures can also help identify the relationship between components and functions during the development of a product dissection activity.

1.2.7.1 Drawbacks of the Practice of Reverse Engineering

It is the intention of this collection of resources to provide an unbiased, comprehensive view on the topic of educational reverse engineering and thus acknowledge any of its potential pitfalls; reverse engineering someone else's design for example, is hard and time consuming; it depends on the collection of information and on putting forward educated guesses to infer the design process and design rationale of a subject system, and as such, the analyst has to deal with information unavailability and uncertainty, and given that to date there is no unified methodology for doing reverse engineering, it means that the resulting analysis will be strongly dependant on the domain knowledge and expertise of the reverse engineer in turn; because of this, reverse engineering can be a long difficult process prone to cycles of trial and error where a successful end can be hardly guaranteed. If on top of that we consider that the need for reverse engineering is usually misunderstood, then it helps explain why it carries societal pressures and fears of infringement on regular product customers who usually lack the competence or the desire to reverse engineer their purchased products. Beyond all these operational drawbacks though, there are more fundamental ones, which concern the intellectual traps in the practice of reverse engineering, and which are explained next:

1. Attachment to Known Solutions

Authors [Pahl et al. 2007] state that "Because the only systems to be analyzed in a reverse engineering exercise are those that have some bearing on a new problem as a whole or on parts of it, this type of analysis could be called a way of collecting information, and thus a systematic exploitation of proven ideas, or of experience" and although this is helpful for finding a first solution concept and as a starting point for further variations of a design, they also state that "This approach carries the danger of causing designers to stick with known solutions instead of pursuing new paths." This is at first sight, the most obvious drawback of educational reverse engineering, it is however easily avoided with a proper method and pedagogy for the conduction of it, for example, one that forces students to come up with product and process improvements of their own and in relation to the product just analysed, or one that takes extra care not to induce negatively perceived attitudes of reverse engineering analysis to professors and students (e.g. creative laziness). The pedagogy later suggested in Resource 6 of this collection of resources intends to tackles those issues and challenges both, instructors and students to make the most out of existing resources.

2. Analogies and Teleological Reasoning

It is author [Ritchey. 1991] who has provided the best explanation about how this trap works, he claims that an initial stage before a solid knowledge about a product under study is achieved, implies the formulation of explanations based upon something other than the structural facts (e.g. Ad hoc internal properties) in order to remedy for the lack of clear knowledge about a system and its inner processes. Specific conceptions familiar to our previous experience arise then, in two possible ways (analogy and teleology) to force the system's internal properties to match our current level of understanding, with this though, he states, we risk introducing arbitrary conceptions into our explanation of the product under study, leading us to unusable final results or at least to a lack of reliable feedback to keep us investigating on the right track.

Analogies as described by [Ritchey. 1991] imply comparing and likening the system's components under study to other mechanical components or processes from our past experience; whereas teleology on the other hand means attributing the system's components under study, a purpose or utility vis à vis other components. Author Ritchey emphasises that the use of analogies and teleology is useful and should not be rejected if used in a proper and cautious way, and that means "emphasizing the conditions that must be met to account for what the organ accomplishes and discarding any notions not essential to the explanation that have arisen solely through the use of analogy or teleology" [Ritchey. 1991]

2.1 Post hoc Rationalization

Reflection after a reverse engineering analysis might develop into post hoc rationalization (a logical fallacy stating: "Since that event followed this one, that event must have been caused by this one"). The memories of the reverse engineering analyst then, must be jogged in order to reveal the real development history of a product, rather than a sanitised version of it. A potential solution for this cognitive trap is that the reverse engineering analysts (engineering design students in this case) try to also acquire background knowledge about the product and processes under analysis. This type of rationalisation then, is perhaps the clearest manifestation of teleological thinking.

3. Undetected Dead-ends

A reverse engineering analysis may not reveal the dead-ends the original designers faced, as such, the revealed process may be incomplete. Possible solutions for this scenario include taking extra care to identify such circumstances and explore plausible alternatives (e.g. By studying prototypes or similar problems) across domains (e.g. Benchmarking).

4. Idealised Design Processes

A careless reverse engineering analysis can lead to explanations that do not reflect the actual and redundant trial and error processes of design but instead present an 'idealized process' that eliminated them; and while this might be seen as something positive cf. [Kawakami et al. 1996] the approach followed in the methodology suggested in this collection of resources though, is to make those trials explicit, authors [Mulet & Vidal. 2008] for example, stated that "Despite the excellent results obtained by designers, most design tasks are still carried out by trial and error or by adopting the easiest or the most obvious solutions due to the pressure of the market and limited resources" the approach followed in this collection of resources then aims to help students to realise what worked for others, what didn't, and why.

In the end, it is also the goal of the methodology and pedagogy for educational reverse engineering analysis presented later in Resources 5 and 6 of this collection of resources, to avoid or at least to minimize in students these cognitive traps and operational drawbacks, while still acknowledging that the continuing professors 'supervision throughout the work sessions with the students will also play an important role in avoiding them.

1.2.8 Validity of Reverse Engineering as an Academic Subject in Design Education

Didactical analysis of an academic subject, as suggested by Dahlgren is "the science whose topic is the planned support of learning to acquire formation in an academic subject" [Dahlgren. 1990], in this regard authors [Dahlgren. 1990] and [Grimheden.2006] propose that a didactical analysis of a subject can be based on four categories or questions, as seen in Figure 1.9 below

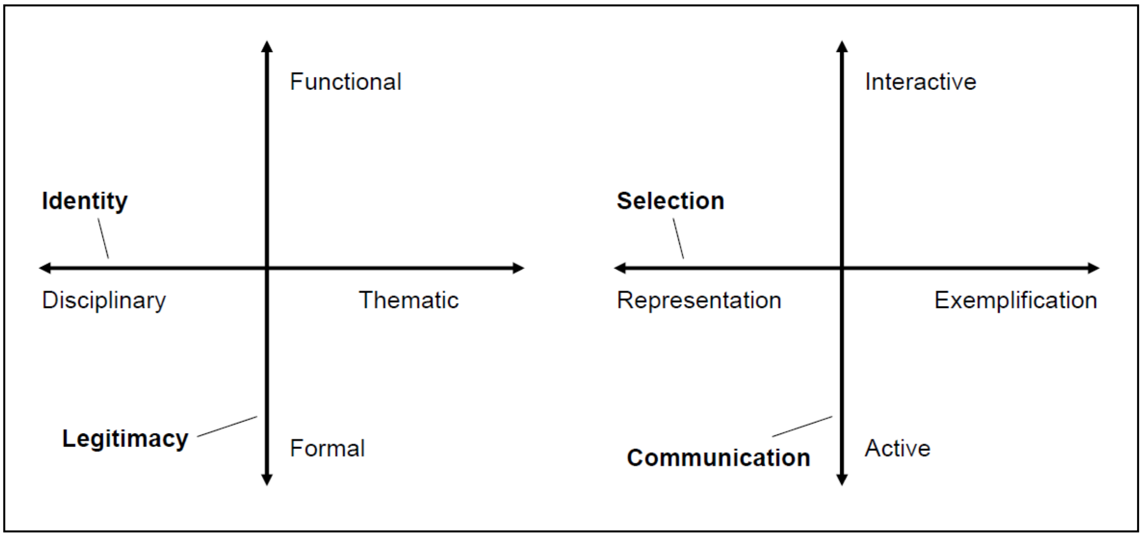

Figure 1.9 The Four questions of Didactical Analysis, Source: [Grimheden.2006]

The first question is concerned with the identity of the academic subject to answer the question "What is?", and its subsequent classification either as disciplinary or thematic. In the case of educational reverse engineering and according to an analysis of its literature and the findings on the area, the identity of reverse engineering as an academic subject can be identified as "Thematic" meaning that it is a relatively newly created subject that originates from a theme, and that as knowledge evolutes it'll move forward in its classification. In comparison, “Disciplinary” subjects are those already consolidated areas of knowledge such as mathematics or chemistry.

The second question is that of legitimacy, that is about the questions “Why should it be taught?” which is connected to “The relationship between the actual outcome of the educational efforts and the nature of the demand that is put upon the student’s abilities by society, or by industry”, [Dahlgren. 1990], in this sense reverse engineering’s legitimacy can be considered “Functional”, meaning that the functional aspects of reverse engineering deal with those skills that are not commonly acquired in textbooks or lectures but are developed with hands-on exercises, laboratory experiments, and by trial and error. The “Formal” aspect then, is the one that deals with formal knowledge such as that found in textbooks intended to be read and understood by students.

The third question concerns the method of selection or “Which elements should be taught?” which deals with how the content is delivered to the students, either representatively giving a broad perspective over the entire subject with students being taught knowledge and principles in general, or by exemplification in which the subject is exemplified rather than represented. For educational reverse engineering then, the content is delivered in an “Exemplified” way, meaning that only the method for educational reverse engineering is studied but to a much greater depth, expecting that the resulting knowledge and skills can be carried over to facilitate learning of other similar methods.

The last question is that of communication and it relates to the question “How should it be taught?” it could be either actively, meaning that teaching is considered an action and the teachers always ask themselves how they should act before the subject, the students and so on. Or it could be taught interactively meaning that the interaction teacher–student is based on feedback from the students and insight into the learning processes of the individual students. Reverse engineering then, is taught “Interactively” in the sense that student’s feedback and a profound interest in the student’s cognitive processes exist while the experiments conducted are also of paramount importance to reverse engineering. Table 1.8 then, summarises the results to the didactical questions.

Didactical Question	**Result**
Identity	Thematic
Legitimacy	Functional

Selection	Exemplification
Communication	Interactive

Table 1.8 Didactical Analysis of Reverse Engineering as an Academic Subject

In the end, the results from a didactical analysis on the subject of educational reverse engineering are useful in positioning and validating it as a subject worth teaching and of practical value in engineering education.

1.2.8.1 Pedagogical Viability of EREA

Author Dalrymple in [Dalrymple. 2009] and [Dalrymple et al. 2011] stated that although D/A/A activities were utilized in the engineering curriculum at institutions around the nation (referring to the USA), and that their value as pedagogical tools was primarily supported by highly descriptive and favourable accounts of curricula and possible learning outcomes by reviews from instructors and students such as: [Brereton et al. 1995]; [Hess. 2000],[Hess. 2002], [Otto et al. 1998], [Sheppard. 1992a], and [Wood et al. 2001] in order to test, and conclusively attribute the claims about the benefits of D/A/A activities and identify what their unique contributions to pedagogical practice might be, more formal tests were required and experimental evidence was needed since among previous reviews and studies, relatively few had compared participants performing D/A/A activities to a control group doing more traditional activities. A similar claim was made by authors [Simpson et al. 2011] who stated that “the effectiveness of integrating product archaeology into product dissection activities in engineering design education need to be tested and further evaluated”, author Dalrymple then, felt that there were limitations in the literature concerning the pedagogical viability of D/A/A activities given that:

- The systematic analysis of the pedagogical benefits of DAA activities was a relatively recent phenomenon, [Dalrymple. 2009]
- In her view most of the research methods that had been employed were not capable of providing the evidence needed to evaluate the unique allowances of D/A/A activities with respect to motivation or learning (her research is focused on these two attributes)

And so she set out to answer questions such as:

- What type of knowledge can students gain from engaging in D/A/A activities compared to more traditional laboratory activities?
- Is D/A/A more motivating than traditional instruction?

- How does the knowledge gained from engaging in D/A/A activities support subsequent performance on other engineering materials?

Her research thus, employed experimental designs to measure and compare the motivation and transfer elicited by D/A/A activities by engaging students in such activities and comparing them to a control group engaged in other traditional activities that did not involve object disassembly, and so she conducted two quasi-experiments as part of a first-year engineering laboratory, where a D/A/A activity that required students to disassemble a single-use camera and analyze its components to discover how it worked was compared to a control group doing more traditional activities on measures of motivation and learning (a GMA, step-by-step laboratory activity in the first experiment and a lecture method of instruction in the second experiment, that included the learning, analysis, and suggestions for modification of a Fujifilm ™ disposable camera). She believed the current engineering education literature revealed the potential of DAA activities to produce good outcomes on both measures, but lacked experimental evidence so she hypothesized that students who engaged in the D/A/A activity would be more motivated and would demonstrate higher frequencies of transfer than the control group (Transfer (of knowledge/learning) indeed, is the ability to extend what has been learned in one context to new contexts, [Bransford et al. 2000], or from one product design to another, [Sidler-Kellog & Jenison. 1997], and is considered a major goal of formal education since the context of learning usually differs from the context of application, [Perkins & Salomon. 1992], in this sense the ability to produce "Transfer" is one the major added values that reverse engineering can bring to design education)

In Dalrymple's both experiments then, over forty percent of the students that engaged in the D/A/A activity demonstrated the ability to transfer the knowledge gained about the functions of the camera's components and their interconnectedness and describe an approach for modifying the camera that involved the adaptation of an existing mechanism to add new functionality. She reported that such exhibition of transfer was significantly greater than the frequency of transfer yielded by the comparative traditional activities and that further post laboratory surveys also indicated that the D/A/A activities elicited significantly higher levels of motivation than the step-by-step laboratory (the Guided Morphological Analysis) and the direct instructional method (the lecture), cf. [Dalrymple. 2009].

The findings in Dalrymple's research, provided experimental support for the views of other researchers that studied the incorporation of D/A/A activities (under this or other similar names) in an engineering curriculum such as the previous studies done by

[Bedard Jr. 1999]; [Hess. 2000], [Hess. 2002], [Lamancusa et al. 1996], [Ogot. 2002], [Ogot & Kremer. 2006], [Otto et al. 1998], [Sheppard. 1992a] or [Wood et al. 2001] her findings also reinforced the outcomes of former studies of motivation associated with D/A/A activities such as those by [Carlson et al. 1997] and [Okudan & Mohammed. 2008] and in the end and although plenty of studies existed before her work, her experiments comparing reverse engineering-like activities against traditional instruction provided definitive proof of their benefits in education specially in the areas of transfer and motivation, and she also published later on that ” intellectual and physical activities such as Disassemble/Analyze/Assemble (D/A/A) activities elicit significantly higher ratings of learning, enjoyment, and perceived helpfulness than traditional instruction”, [Dalrymple et al. 2011] and even raised the possibility that learning general engineering design principles and becoming a better design engineer may require the specific knowledge of components and mechanisms that D/A/A experiences seemed well suited to offer, [Dalrymple et al. 2011].

1.2.8.2 Teaching Approach of Educational Reverse Engineering Activities

The purpose of EREA in engineering design education is not to substitute the traditional teaching of relevant topics with this type of activities, or even to expect students to learn the same after using them, EREA as presented here, are a complementary tool for existing teaching practices, and the approach to teaching through them doesn’t even focus on the technical topics of a typical engineering design programme but rather on the competences that students of engineering design are expected to develop during their college years and for which EREA can serve a suitable vehicle for their acquisition. Regarding the activities themselves, it can be said that they are geared towards an instructor-assisted team learning rather than a self-directed learning by students, in this way, students can benefit not only from their professor’s experience but also from a teamwork setting where information gaps can be filled by the efforts of a pool of students contributing towards a unified goal, this topic is further explored in Resource 6

1.2.8.3 Educational Reasons to Reverse Engineer a Consumer Product

EREA have a decidedly academic focus and are mostly performed with the purposes of scholarship, teaching and dissemination in mind, Table 1.9 below lists such possibilities to provide an overall view of the different uses of them documented so far in engineering education.

Number	Reason

1	To anchor the knowledge and practice of engineering
2	To develop curiosity, proficiency, and manual dexterity
3	To increase students' motivation and retention in engineering
4	To couple engineering principles with visual feedback
5	To provide starting points for design proposals, kinaesthetic memory triggers or thinking props
6	To identify relationships among engineering fundamentals and product design.
7	To increase awareness of the design process
8	To teach competitive assessment and benchmarking
9	To help trigger improvement ideas and innovation
10	As a lawful way to acquire know-how about manufactured products
11	To learn about a specific product
12	As an opportunity for the fostering of academic networks among universities
13	To teach and gain experience in forensics engineering

Table 1.9 Educational Reasons to Reverse Engineer a Product, Expanded by the Author from: [Simpson et al. 2008]

1.2.8.4 Uses of Educational Reverse Engineering at the College Level

Table 1.10 below lists the areas of education that have been supported so far by reverse engineering and similar approaches, and that have been found as part of the research leading to the creation of this collection of resources, namely:

Aerospace Engineering	Biomedical Engineering	Civil Engineering	Computer Aided/Assisted Design	Computer Engineering	Computer Science
Design and Manufacture	Design and Reconversion of Machines	Design Life Cycle	Design Technology	Electrical Engineering	Electronic Systems Cost Modelling
Emotionally Durable Design and	Engineering (General)	Engineering Design	Engineering Graphics and Design	Engineering (Introduction to)	Engineering Management

Sustainable Design					
Engineering Physics	Engineering Science	Industrial and Systems Engineering	Industrial Design Engineering	Industrial Engineering	Industrial Technology
Interface and Interaction Design	Manufacturing / Concurrent Engineering	Mechanical Design	Mechanical Design and Manufacturing	Mechanical Engineering	Mechatronics and Robotics Engineering
Mechatronics Design	Product architecture, Platforms and Commonality	Product Design	Rapid Mechanical Design	Technology & Information Management	

Table 1.10 Areas where Reverse Engineering has been used at the College Level

1.2.8.5 Reception in the Engineering Design Community of Similar Approaches to Reverse Engineering

As seen in Table 1.2 above, educational reverse engineering shares certain goals and concepts with professional forensic engineering but the available tools and goals of the implied analyses are what determine the differences among them. Still, forensic experience and its usefulness in education has been presented to the engineering design community already, for example at the keynote speech of the 2005 International Conference on Engineering Design by Professor Hales [Hales. 2005] who presented the following conclusions, that are also of relevance to the practice of educational reverse engineering, namely:

1. Since learning from our mistakes is a helpful way to improve our design skills, learning from the mistakes of others can be almost as helpful and is a lot less expensive
2. When mistakes occur there is a natural tendency to try to minimize their negative effects and the extent to which the details are made public, thus limiting the opportunity for everyone else to learn how to avoid making the same mistake in the future
3. A way to learn from other people mistakes is for those involved in failure investigations to describe what went wrong in such a way that a lesson can be learned even without making all the details public

4. Forensic engineers have access to a rich source of learning material but they are often so constrained by confidentiality and legal issues that too much of the history is masked or skewed for anyone to learn much from it
5. In an oral presentation it is possible to show more of the story simply through pictures, and thus the lesson can be learned without the need for a formal written document

Based on the above mentioned conclusions and on the similar goals and methods of forensic and educational reverse engineering analysis, it can be argued that reverse engineering is also a valid and valuable educational experience for engineering design students to have.

1.2.9 An Introduction to Commercial Reverse Engineering

Commercial reverse engineering activities are those that have economical rather than educational goals in mind. A strong effort to separate academic from commercial reverse engineering activities has been made from the onset of this research but still, an explanation of how they compare to each other is a common request. After all, as far apart as they could be, it would still be safe to assume that at least some of the experiences in the commercial areas of reverse engineering have at certain points in time gone into the area of academics, research and teaching.

Commercial reverse engineering then, is an activity that helps engineers learn about the state of the art in industry and that acts as a trigger for the gathering of specific pieces of information of an often immediate need. A commercial reverse engineering analysis though, requires a considerable amount of resources, intellectual work, cognitive skills and experience to accomplish its associated tasks (e.g. Devising ways to analyse a product in case it features technical protections; extracting high level abstractions from the physical evidence of a product, searching and reconstructing missing pieces of information, etc.), what's more, if the results obtained from a reverse engineering analysis are ever going to be incorporated into a new product, this will require a de facto traditional process of "forward" engineering until a successful product results. Reverse engineering thus, is actually so time consuming and resource intensive that market destructive product clones are not created this way, if the necessary information is available somewhere else reverse engineering will be generally avoided.

In conventional (forward) engineering design, the designer knows the functions that cause a solution to achieve its goal, it all comes down then to creating the form, that is the physical embodiment that will exist and that will eventually deliver the function; it can be said that forward engineering goes from the function to the form. Conversely, in reverse engineering the form is already known and from there the functions, and ideally the goals of the system will eventually be known, it can be said then, that it goes from the form to the function as seen in Figure 1.10 below

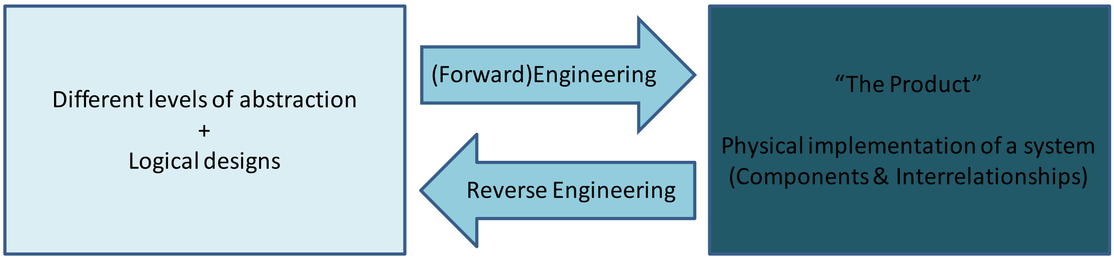

Figure 1.10 Comparison of (Forward) Engineering to Reverse Engineering

However, function and form are completely independent attributes. Forms can be seen by the naked eye but functions cannot be inferred from it without the necessary knowledge to contextualize the form's intended operations. E.g. the dynamic behaviour and use of a boomerang cannot be inferred without the necessary contextual information about the object or as authors Sato and Kaufman state "How products or serviced are used does not identify their functions. A book may make and excellent door stop, but the function of a book is not to "prevent movement"" [Sato &Kaufman. 2005]. Author [Shooter. 2008] for instance exemplifies the inter-relation of form and function from perspectives of reverse engineering and design as shown in Figure 1.11

Figure 1.11 Relationship of Form and Function in Reverse Engineering and Design, Source: [Shooter. 2008]

This concept is easier seen in archaeology and ancient technology studies where the exact use of ancient artefacts cannot be derived from its form alone. Examples of this include, the Saqqara bird at the Museum of Egyptian Antiquities in Cairo, Egypt seen in Figure 1.12 which has been potentially identified either as a sort of throwing stick used for hunting because of its streamlined shape or also as ceremonial object because of its falcon appearance and its significance in Egyptian mythology.

Figure 1.12 The Saqqara Bird, Source: [Wikimedia Commons. 2011]

Or the rattlebacks a.k.a. Celtic stones shown in Figure 1.13 which can be made to spin on its axis in a preferred direction, but whenever spun in the opposite one; they'll become unstable and they'll stop and start reversing its spin towards the preferred direction. This dynamic behaviour is not apparent from observation alone and because of its ununderstood behaviour in ancient times it was believed to be used for divination purposes.

Figure 1.13 Celtic Stone a.k.a Rattleback, Source: [Wikimedia Commons. 2006]

Educational reverse engineering activities then, differentiate from their commercial namesakes in their hands-on approach that allows them to test and experiment the subject system with all senses cf. [Wood & Wood. 2000] and thus, better tackle form and function conundrums given that design methods can later be used too to hypothesize current functions, and help conceptualize new functions and/or solutions to the current form.

1.2.9.1 Commercial Reverse Engineering as a Trigger for Industrial Development

Given the technological advances of countries where the practice of reverse engineering has been acknowledged, the question whether reverse engineering or even imitation is a necessary phase in industrial development arises; what's more, do practices such as imitation help to internalize the state of the art of a given field? It would seem so, since imitation is actually still widely practiced in western companies as part of their innovation process; but before nations or companies can even begin to innovate they must know what the state of the art is and what the competition is doing, of course, to be able to get this knowledge, intellectual; technical and material tools to access and process the latest technologies have to be acquired first, before any original improvements or adaptations can be suggested. History of modern science shows that once this innovation capability is acquired the nations and companies' time to apply for intellectual property protection will come.

When speaking about the value of reverse engineering as a trigger for innovation in industry author [Kodak. 2008] for example, stated about innovation that "The reverse engineering process brings the essence of an innovation under an organizations finger tips. In effect, this is a new chance to recapture a position in a lost market and this quality makes the reverse engineering effort almost as valuable as the innovation itself. Now, the possibility of capturing at least part of the business success of the original innovator exists and perhaps more. The "more" part is of interest for the business savvy reverse engineering planner."

In modern times we have seen that patent licensing and competitive intelligence are two controlled means to spread technology where reverse engineer has played a role in spreading innovation and technology helping companies to stay competitive. There has been a notorious shift in technology from Europe and North America to developing countries, best represented by the growth of the electronics industry in Asia in countries with a long tradition in buying western products, taking them apart and copying them, as author [James. 2009] pointed out

Japan and South Korea indeed, are two representative countries that have benefited their technological and industrial base through a planned acquisition, assimilation and eventual re- export of technologies from all over the world. Japanese companies searched, absorbed and devoted R&D efforts to any technologies they could benefit from, adapting them to their specific market requirements, improving them and then exporting them back not only to developing countries but often to the original exporting countries [Herbig & Jacobs. 1997], in fact, the South Korean technology road map 2002 edition, mentions that before their current innovation in science and technology phase an imitating phase (1960s ~ 1970s) in their developmental process on national technological ability relied on imitation of developed countries' technologies where "Technologies in maturity were accumulated through reverse engineering as a means of industrialization" [NTRM. 2002]. Figure 1.14 shows and excerpt of such report where the imitating phase were reverse engineering was claimed to have been used is put in chronological perspective against their national technological goals.

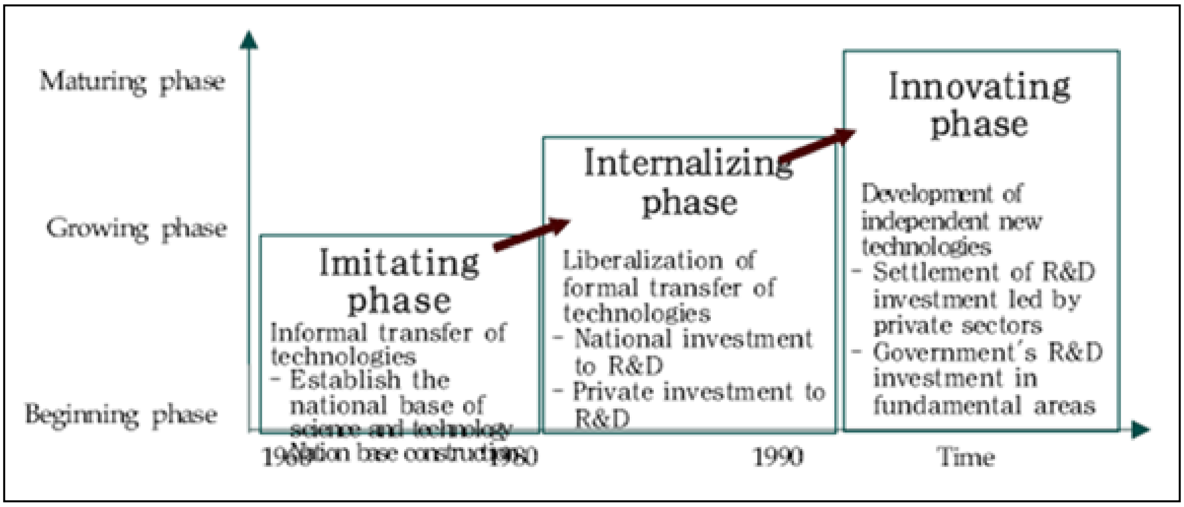

Figure 1.14 The Developmental Process of Korea's National Technological Ability, Source: [NTRM. 2002]

Reverse engineering in Korea has indeed helped the technology level of the country to advance and this process of movement from low technology to high technology and the attendant change in learning of skills and capabilities is represented in the Figure 1.15 shown below

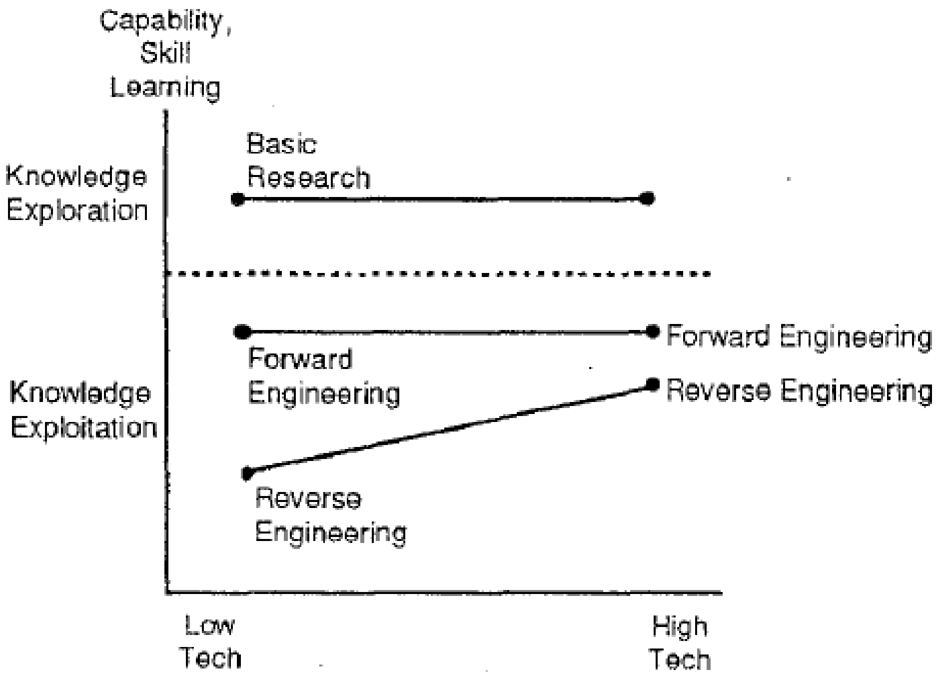

Figure 1.15 Movement from low Technology to high Technology, Source: [Methe. 1995]

Other Asian countries such as Japan, Korea, Taiwan, India, China, Singapore, and Malaysia now showing the same trend have achieved self reliance through acquisition of foreign technologies, for them reverse engineering has been an activity that has helped them not only understand advantages and disadvantages of foreign competing products but also to acquire technologies and trigger industrial development. Staying ahead of the competition then, is a full time expensive investment for companies but reverse engineering helps Asian companies in keeping pace with the competition. When referring about the industrial development of India for example, author [Mitra et al. 2006] stated that "The change from being a country of reverse engineering experts to a country that develops its own products from ground up has started for sure". Korea; Japan and the case of India are least the three countries from which easy-to-find, published research confirms that reverse engineering has taken place in recent times

Educational reverse engineering activities then as presented in this collection of resources, try to mimic this development process seen in industry, expecting that students exposed to these techniques can eventually acquire and develop abilities that can help them in their professional design careers.

1.3 Resource Conclusions

Educational reverse engineering activities come from a long tradition of approaches that intend to investigate a subject system and then with whatever analytical and technical tools available try to come up with an understanding of it, this process though is never straightforward and thus, a team effort and the integration of resources from multiple sources is usually the best way to tackle a reverse engineering effort; the rewards though are well worth it, and even authors such as [Otto & Wood. 2001] believe that reverse engineering activities can improve engineering design education since they can offer a better paradigm for it by allowing for a modern learning cycle of experience; hypothesis, understanding, and new design execution.

Author Dalrymple on her side, has also stated that “there is an undeniable need to identify and implement pedagogical practices that motivate students as well as facilitate learning that can be applied and adapted to new contexts and support future acquisition of related knowledge and skill” [Dalrymple. 2009], as seen from the wealth of topics covered in this resource then, reverse engineering can be considered indeed a valid subject of academic research in design education and thus, its study and exploration can help fulfil the author’s recommendations.

In the end, it could be said that the available knowledge about a product under analysis may not be absolute and not represent the final truth, however, it can be trusted to be valid within its area of application and thus, use it as a stepping-stone for further progress and acquisition of knowledge., indeed there is no substitute for judgement acquired though experience and educational reverse engineering activities can help bring new opportunities for learning to students of engineering design.

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RESOURCE 2: REVERSE ENGINEERING AND LEARNING

2.1 Resource Introduction

This resource introduces the reader with the mechanisms and conditions that explain the connection between the hands-on activities inherent to EREA and the associated cognitive processes that allow the students' acquisition of abilities related to the practice of engineering design

2.2 Pedagogical Framework of EREA

Broadly speaking, the learning-by-doing pedagogy model falls under constructivism which aims to facilitate learning, as opposed to traditional instructor-based teaching which falls into objectivism, in this sense, educational reverse engineering activities require the application of concepts and techniques from different sources in a synthesis effort that integrates real world-like skills, and thus, the knowledge acquired from a reverse engineering course aims to answer not only what a concept and technique is but also how and why it is applied. On a more strict sense though, the preferred learning environment for EREA is CBE (Competence Based Education) which is an institutional process that moves education from focusing on what academics believe graduates need to know (teacher-focused), to what students need to know and are able to do in varying and complex situations (student and/or workplace focused), it is a process that is centred on outcomes (competencies) that are linked to workforce needs as defined by employers and the profession and for such reasons EREA are better understood and more clearly seen in such framework, however, EREA are by no means exclusive to it, after the consideration of simple tradeoffs (e.g. Length, depth of analysis, etc.) they can be, and are indeed used under different educational frameworks such as Course/Objective/Topic-based teaching curricula.

2.3 Cognitive Processes and the Construction of Knowledge in an EREA

Students use three different perception modes to learn, namely: Auditory, kinaesthetic, and visual, the three modes can be combined but a preference for one of them is usually developed and indeed, the preferred perception modes in students have been found to affect the way students learn, cf.[Wankat & Oreovicz. 1992]. Kinaesthetic experiences in education for example, include touching, smelling, feeling or testing while handling real products in the laboratory. Visual experiences which are the preferred mode for engineering students cf. [Anderson. 1991] on the other hand, are those that help to process information through graphical solution methods; plotted equations, photographs, computer diagrams, field trips, videos of manufacturing processes, or observation of the actual product. Auditory experiences then, are those which are the most common in education since they are related to traditional lectures and printed material, and in fact reading and writing are considered a visual representation of auditory processing techniques; cf. [Wankat & Oreovicz. 1992].

According to author Stice and based on data from a study at the Socony-Vacuum Oil Company, [Stice. 1987] the more perception modes are used to acquire and process information, the better the learning and retention can be, as show in Table 2.1 below.

Visual perception mode	**Auditory perception mode**	**Kinaesthetic perception mode**	**Learner's Retention**
	√ (Reading)		10 %
	√ (Hearing)		26 %
√ (Seeing)			30 %
√ (Seeing)	√ (Hearing)		50 %
	√ (Saying)		70 %
	√ (Saying)	√ (Saying)	90 %

Table 2.1 Learning retention vs. Perception modes, After: [Stice. 1987] and [Wankat & Oreovicz. 1992]

Although from the results shown above, it could be inferred already that traditional auditory teaching styles should be complemented whenever possible with visual and kinaesthetic experiences (specially considering that visual learning is the preferred style for most students [Anderson. 1991]) other researchers have also set out to investigate what methods and practices can help maximise a student's instruction.

Authors Lamancusa and Rosen for example, assert that "doing the real thing" and "simulating the real experience" have the highest chance to retain what has been learned, as seen in Table 2.2 below

Method	**Retention percentage**
Doing the real thing	90

Simulating Real Experience	90
Teaching One to One	90
Giving a Talk	70
Participation in Discussion	70
Seeing it Done	50
Watching Demonstration	50
Looking at Exhibit	50
Watching Movie	50
Looking at Picture	30
Hearing words	20
Reading	10
Lecture	5

Table 2.2 Knowledge Retention versus Method, After [Lamancusa et al. 1999] and [Rosen, S. 2010]

Similar research in education then, has also revealed that traditional lecturing results in the lowest students' retention of content material in comparison to other methods of learning as showed in Figure 2.1 below

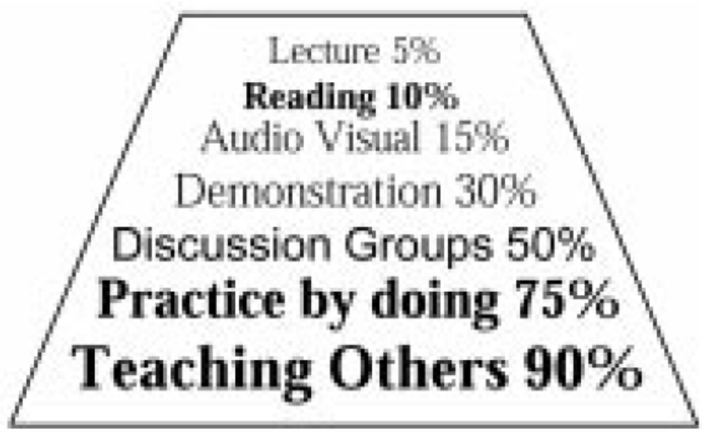

Figure 2.1 Increasing Student Learning as a Result of Teaching Technique, Source: [Wang. 2004]

Last but not least author [Athey. 2008] also reports the situations in which people learn the most as shown in Table 2.3 next

Learning Percentage	Situation
67%	When working together with a colleague on a task
22%	When doing own research
10%	When a colleague explains something personally
2%	Through a textbook

Table 2.3 Learning Percentage against Situation, after [Athey. 2008]

From the myriad of results shown above, it can be concluded that educational reverse engineering activities with their inherent team and hands-on approach are an appropriate instructional method to incorporate all perception modes to the content of traditional engineering design lectures and thus help students to retain information from them.

2.3.1 The Kolb's Learning Model and its Relation to Educational Reverse Engineering Activities

Learning in EREA cannot be understood without first explaining Kolb's cycle which has been historically linked to such activities to explain and even justify how they work in education. The Kolb's model, [Kolb. 1984] is a learning theory developed by author David Kolb that is based on two dichotomies perpendicular to each other, one dichotomy being Active Experimentation (AE) against Reflective Observation (RO) and the other being Abstract Conceptualization (AC) against Concrete Experience (CE), these dichotomies are presented in an orthogonal diagram in a way that a circular model traversing the four elements of the dichotomies can be seen, these four elements are actually considered by Kolb as steps toward learning and the complete learning cycle is shown below in Figure 2.2

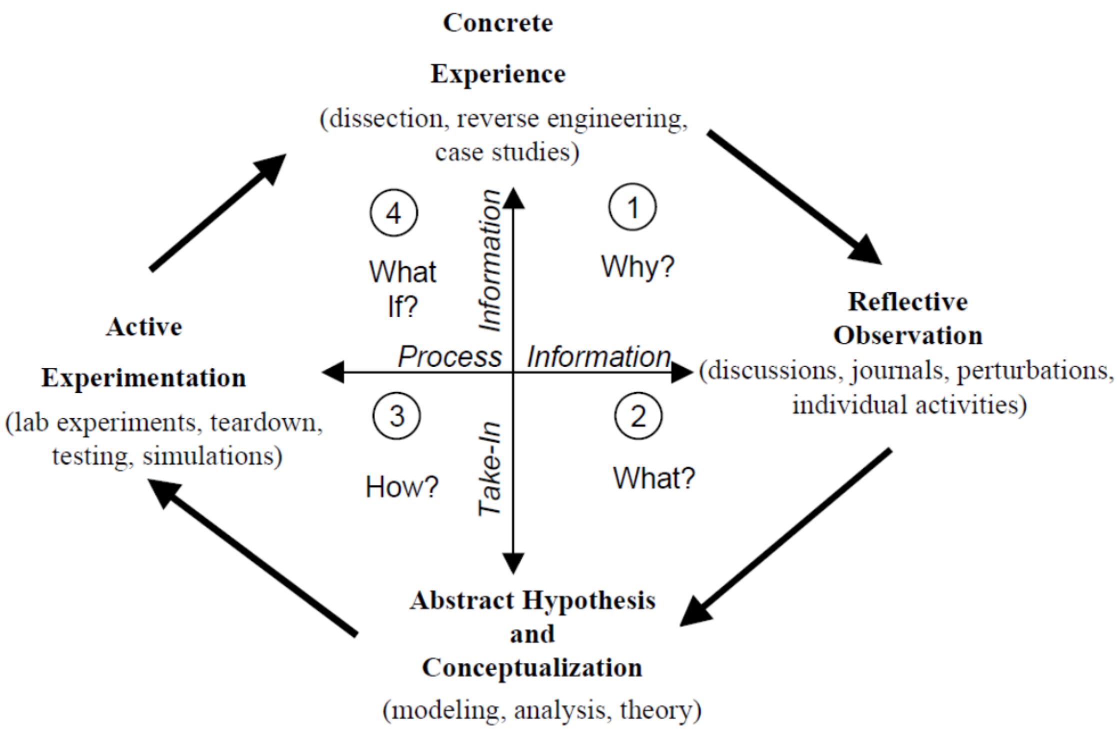

Figure 2.2 Annotated Kolb's Model of Learning Superimposed with Suggested Activities for each Quadrant, [Wood et al. 2005] also Published by [Aziz & Chassapis. 2008]

A summary of the characteristics of its components dichotomies then, is shown next in Table 2.4

Dichotomy	**Description**	**Dichotomy Elements' Characteristics**
Active Experimentation(AE) vs. Reflective Observation (RO)	People's preference to transform experience into internalised knowledge	Active Experimentation: People like to get things done and see results Reflective Observation: Examination of ideas from several angles before taking action
Abstract Conceptualization (AC) vs. Concrete Experience (CE)	How people take in and understand information	Abstract Conceptualization: Preference for logical analysis, abstract thinking and systematic planning Concrete Experience: Preference for specific experiences and personal involvement, particularly with people; Tendency to be non-systematic

Table 2.4 Dichotomy Elements in Kolb's Learning Cycle, After: [Wankat & Oreovicz. 1992]

Although in practice, students tend to favour certain operation modes, the learning cycle suggested by Kolb requires all four steps to be experienced to allow for a thorough learning experience, the preferred learning cycle then, usually starts at the concrete experience end where information is firstly acquired (although the cycle can be actually entered at any of the four steps depending on the previous knowledge of the person); later this information, is internalized and transformed by reflective observation as a second step, the third step then, is the abstract conceptualization (e.g. Generalisations and deductions of global phenomena) needed to perceive the information that was changed by the reflection in the previous step, and thus, the fourth step comes when the learner processes the information actively and does something with it in the final step (e.g. Validating it through testing). The learning cycle though, can be experienced several times in a sort of spiral cycle depending on the complexity of the information, and the spiral may even extend through time (e.g. From college years to professional practice) as the person delves deeper into the study material. In practice though, and as stated by authors [Wankat & Oreovicz. 1992] "students often take short-cuts and employ only one or two stages in the cycle which results in significantly less learning".

Author [Stice. 1987] for example, and in complement to the information presented above in Section 2.3, also calculated the retention of knowledge against the number of stages employed from Kolb's cycle, and an excerpt of such results is showed in Table 2.5 below.

Operation Mode	**Knowledge Retention**
Abstract Conceptualization (AC)	20 %
Reflective Observation (RO) + Abstract Conceptualization (AC)	50 %
Concrete Experience (CE) + Reflective Observation (RO) + Abstract Conceptualization (AC)	70 %

Concrete Experience (CE) + Reflective Observation (RO) + Abstract Conceptualization (AC) + Active Experimentation(AE)	90 %

Table 2.5 Knowledge Retention against Stages Employed, [Stice. 1987]

Once some findings such as the ones presented above were known the use of the Kolb's learning cycle to develop courses in engineering education began and it was studied by a other researchers, such as McCarthy [McCarthy. 1987] or [Stice. 1987] himself to extensively modify and expand the Kolb learning cycle to apply it to the teaching of a variety of topics, including engineering education. A sample approach to the teaching of engineering with Kolb's cycle in mind making use of all the stages for a better knowledge retention is shown next in Table 2.6

Sequence	Delivery	Operation mode
1	Lecture	Reflective Observation (RO)
2	Thinking about the ideas recently exposed to	Abstract Conceptualization (AC)
3	Homework	Active Experimentation(AE)
4	Live demonstrations or laboratory experiments	Concrete Experience (CE)

Table 2.6 Sample Approach to Teaching using Kolb's Learning Cycle, After: [Wankat & Oreovicz. 1992]

In practice though, authors [Wankat & Oreovicz. 1992] have long stated that most college education is geared towards abstract conceptualization , since memorization of a lecture is considered only as Reflective Observation (RO) and homework alone is considered to be Active Experimentation(AE), even in more recent times authors such as [Campbell. 2003] report that in practice, the content-driven approach to teaching focuses mainly on the first two steps of Kolb's cycle which has prevented the students from gaining much in the way of the mechanical intuition (to achieve familiarity with machines and devices), but still as authors [Wankat & Oreovicz. 1992] originally stated, long term learning is enhanced by planned (or even unplanned) complementary use of the other stages throughout a number of active learning experiences during college years (i.e. Summer jobs or team projects) that allow students to acquire much needed concrete experiences.

Findings from other researchers on the application of Kolb's model in the teaching of engineering have also state for example that the Kolb model "swings the pendulum of learning engineering from an emphasis of generalization and theory to a balance with all modes of learning", [Stice. 1987], to what authors [Wood & Wood. 2000] contribute by stating that since engineering becomes equally focused with hands-on activities "Without this approach (hands-on), we have no concrete experience to ground our learning and build a solid understanding. (and) Nowhere is this truth more pronounced than in machine design. (since) The grounding in current machines helps nurture our interest for understanding the way things work and for making devices work better."

From the characteristics about EREA presented already, it can be argued that they can help fulfil the four stages of learning, suggested by Kolb (specially the concrete experience and active experimentation stages) and thus help improve the instruction of students of engineering design

2.3.1.1 Students' Roles During an EREA

For inherently hands-on projects such as those based on reverse engineering, authors [Leek & Larsson. 2007] have advised a team approach, not only because working in groups brings additional dimensions of experience which can be useful for future engineers but also because projects often take place in team-form too; besides, given that reverse engineering activities provide students with Kolb's experiential learning experience, the student are assumed to take the roles described by author [Lenoir. 2001], namely "The Student as Learner", "The Student as Observer", "The Student as Assistant" but most importantly "The Student as Practitioner" which means that at this level, students are involved in an activity that helps them synthesize material together from a wide variety of previously taken courses.

2.3.2 The Data, Information, and Knowledge Triad in EREA

Authors [Ahmed et al. 1999] provide a relationship between the data, information and knowledge triad based on the awareness and interpretation of it as seen on Figure 2.3 below, The different stages of an educational reverse engineering analysis as will be later shown in Resource 5 follow a sequential and accumulative approach that provides students with the contextualization needed to link the three of them to end up in a state where knowledge can be generated through the contextualization, and subsequent interpretation of the data generated during a reverse engineering analysis .

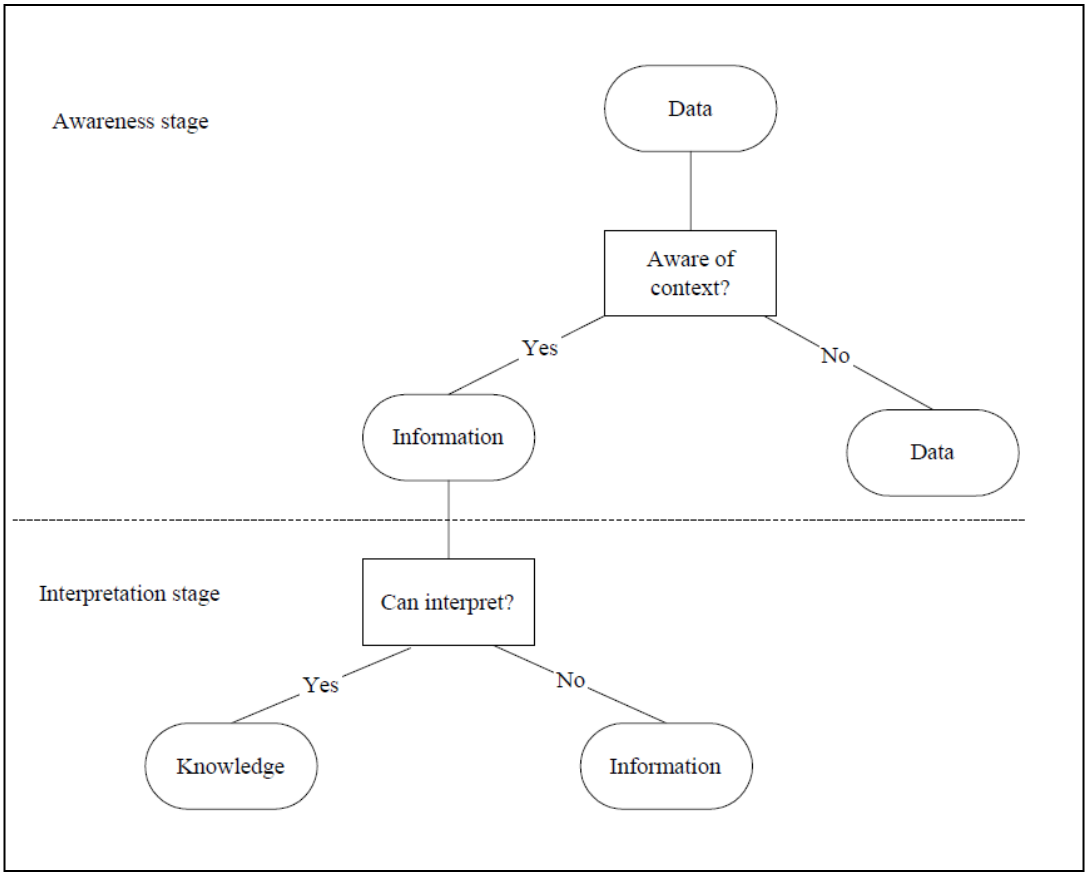

Figure 2.3 Data, Information and Knowledge Relative to the Potential User. Source: [Ahmed et al. 1999]

In this regard, Author [Brereton. 2004] also states that learning during hands-on activities arises from negotiating between abstract (e.g. Lists of requirements, sketches, and scale models) and material representations (e.g. Pieces of hardware) and that hardware helps to enhance it. Figure 2.4 below provides a graphical representation of such model

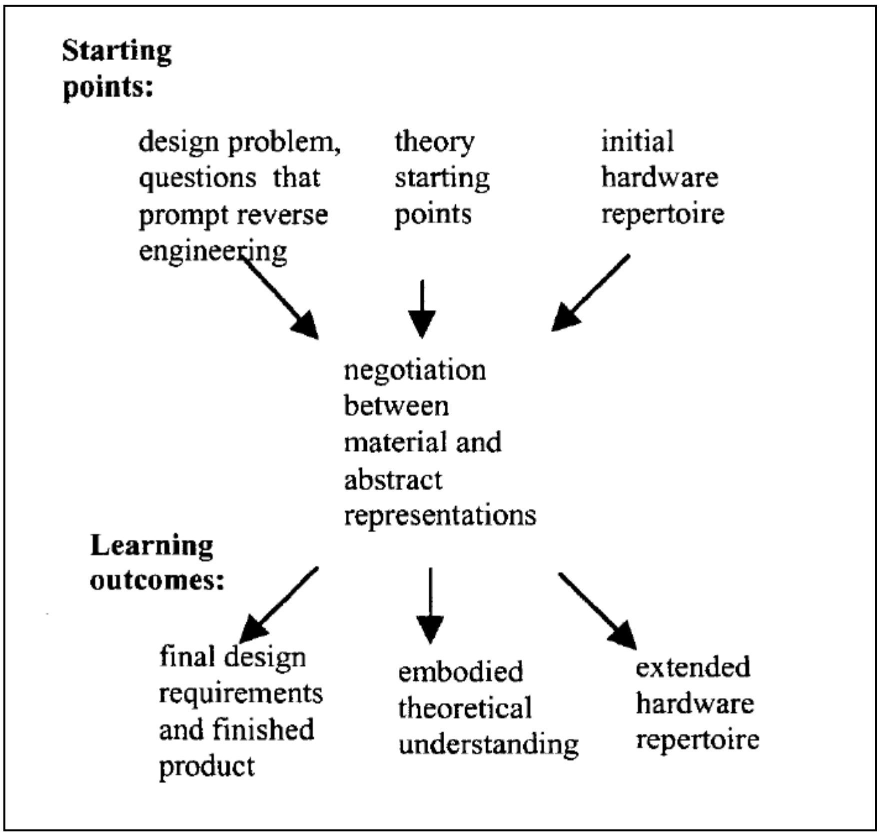

Figure 2.4 Model of Learning through Designing and Reverse Engineering, Source: [Brereton. 2001]

Educational reverse engineering activities because of the sequential, methodological approach they propose, help provide the students with an opportunity to turn raw data from tests and printed specifications into usable information which is later turned into knowledge after operating and improving the product under analysis.

2.4 Cycle of Students' Acquisition and Development of Competences through EREA

The reason to focus on competences for the evaluation of the achievements of an EREA is summarized in author Winterton's statement in the sense that "One of the key virtues of focusing on knowledge, skills and competences, is that these relate to learning outcomes or outputs irrespective of the routes of acquisition involved rather than on learning inputs." [Winterton et al. 2006]

A student's acquisition and development of competences suited to the area of engineering design then, is one of the top goals of the methodology and pedagogy presented in this collection of resources, such task is favoured in this document through the student's participation in Educational Reverse Engineering Activities (EREA) but for participant educators, a basic structure that clarifies how to go from the analysis of an existing product to the students' actual application of competences is required, in order to justify the inclusion or strengthening of EREA in an existing engineering design curriculum.

Figure 2.5 below provides an overall view of how the design rationale embedded in a consumer product can be retrieved by students and how the required analysis of it can be turned into a synthesis process through a methodology that combines verified information with educated guesses. Such figure is comprised of a series of stages linked by causes and effects that start from a common engineering process where a product designer's rationale is generated in order to attain a final product, which in turn becomes the starting point of a reverse engineering analysis and ends up in a situation where students make use of the competences acquired during the process.

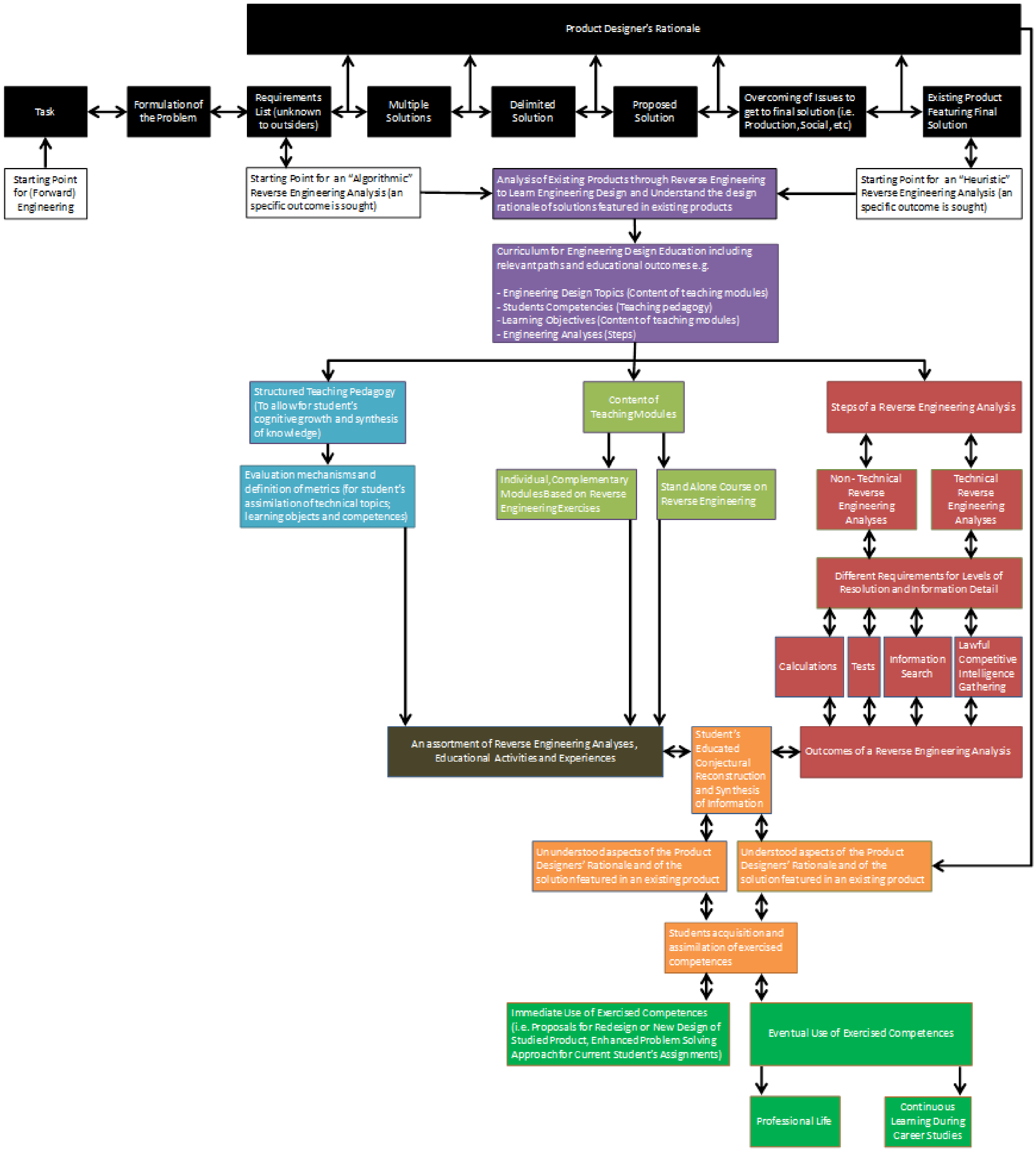

Figure 2.5 Cycle of Student's Acquisition and Development of Competences through EREA

Figure 2.6 below then, shows a simplified version of the same graph that summarises the levels at which the relationships occur and for which an explanation starting from the top to bottom levels follows:

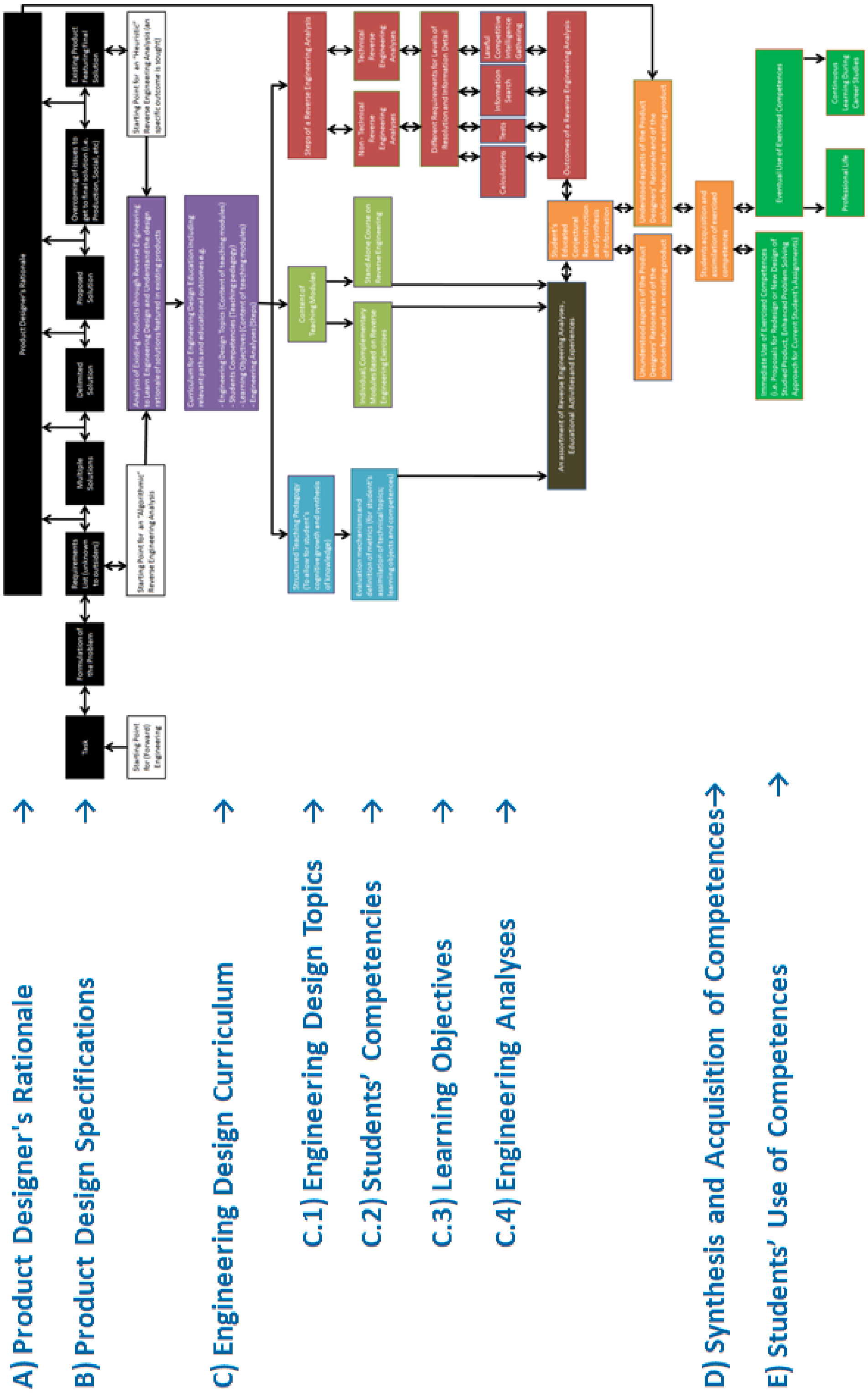

Figure 2.6 Levels at Which Students Acquire Competences through EREA

A. Product Designer's Rationale:

The graph intends to portray how a product designer's rationale (e.g. Constraints, specifications, assumptions, trade-offs, domain knowledge, etc.) changes and accumulates throughout the stages of a regular design and manufacturing process, this experience gained by the designer which is not usually documented or available to outsiders does complement the information about the product under analysis found in public records (e.g. Patent documents, repair manuals) and the analyst's own experience in testing it to come up with a definite understanding of it. The acquisition of the original designer's rationale (initially unavailable to the reverse engineer) is the target of the methodology presented in this research and the enabler that will allow the student to contextualise simple data into information and then into usable knowledge when the opportunity arises.

B. Product Design Specifications:

This level shows from left to right the typical design process of a consumer product which is the test bed chosen in this collection of resources for the execution of EREA; in this level we can also see the potential entry points to a reverse engineering analysis which can be either at the requirements list stage or at the represented embodiment of a design solution.

An algorithmic (or brute force) approach such as the one favoured in the guided example presented here in Resource 7 can be considered an analysis that intends to explore all aspects of a product and takes as a starting point all necessary categories from a typical requirements list to start analysing each one of them, an "heuristic" approach on the other hand has as entry point the actual physical product from which a specific aspect of it will be explored, this approach is used in commercial reverse engineering for example or when new information has become available that allows a previously ununderstood feature of a product to be analysed again.

C. Engineering Design Curriculum:

This level makes explicit the resulting curriculum for engineering design education, that will include the analysis of existing products through reverse engineering, as one of the aids that will help students to learn about engineering design and to help them understand the design rationale of solutions featured in existing products, such curriculum (or methodology at the very least) will feature three relevant paths and associated educational outcomes that will consider the technical and pedagogical aspects of reverse engineering and that will assist in achieving its expected educational goals, the paths are briefly mentioned below and are further explained across several resources of this collection of resources, namely:

C.1 Engineering Design Topics (e.g. Contents of teaching modules (or methodology stages) that highlight reverse engineering and related activities)

C.2 Students Competencies (e.g. A suitable teaching pedagogy that includes the use of hands-on activities)

C.3 Learning Objectives (e.g. Chosen in accordance with the areas where reverse engineering activities can bring an added value to engineering design education)

C.4 Engineering Analyses (e.g. Steps of the method that will increase the technical and non technical understanding of the product under analysis)

In the same figure, an overview of the three abovementioned paths can be seen, where in order to unify an assortment of reverse engineering analyses; educational activities and experiences that together make up the EREA one has to consider not only an appropriate teaching methodology and associated evaluation mechanisms, but also the actual content of the stages of the methodology for EREA and the way they will be delivered (e.g. A standalone course on reverse engineering as done in this collection of resources)

Regarding the actual outcomes of a reverse engineering analysis, one will also have to consider the different requirements for levels of resolution and information detail, requested by the educators and depending on the proficiency of the target students.

D. Synthesis and Acquisition of Competences:

A common challenge that the reverse engineering method proposed in this collection of resources intends to ease is that reverse engineering activities so far, have focused heavily on a dissection stage where the product parts are analysed according to the detail level required by the instructor in charge, however this research is focused on the area of Engineering Design overall and so, if the results from this research project are to be used by engineering design professors, the analysis stage of a reverse engineering activity must be complemented with a synthesis stage that takes into account the particular characteristics that engineering design education has, thus bringing actual benefits to the designing abilities of the students.

In the method presented here then and when reaching this level, students will have gone already through a sequence of orderly, accumulative tests and tasks that will have increased their understanding of why the product under analysis is the way it is, even then though, there will always be ununderstood elements of the system under analysis which will have to be later revisited whenever new information or analysis tools become available, once a reasonable effort has been done though, the reverse analysis has to stop and the knowledge gained (through a permanent cycle of analysis- synthesis) becomes an asset for the participating students.

E. Students’ Use of Competences:

Because of the way the reverse engineering methodology has been planned for this research, there will be an immediate need for students to exercise their newly acquired competences either through the proposals for redesign or for a new design of the studied product, however it is also expected that such competences can be later used as they keep progressing throughout their career studies.

Alternatively, Figures 2.7 and 2.8 below provide a complementary view on the mechanisms in place during an EREA that make students acquire and develop capabilities from the analysis of a consumer product. Figure 2.7 below shows all the levels involved in the acquisition of competences through an EREA starting from the -product life phases- level of a product at the bottom of the figure and all the way up to the student’s learning level. The white coloured boxes shown on the right side of the figure indicate the link between all the levels and can be thought of as the result of all the items shown to the left of them in the same row.

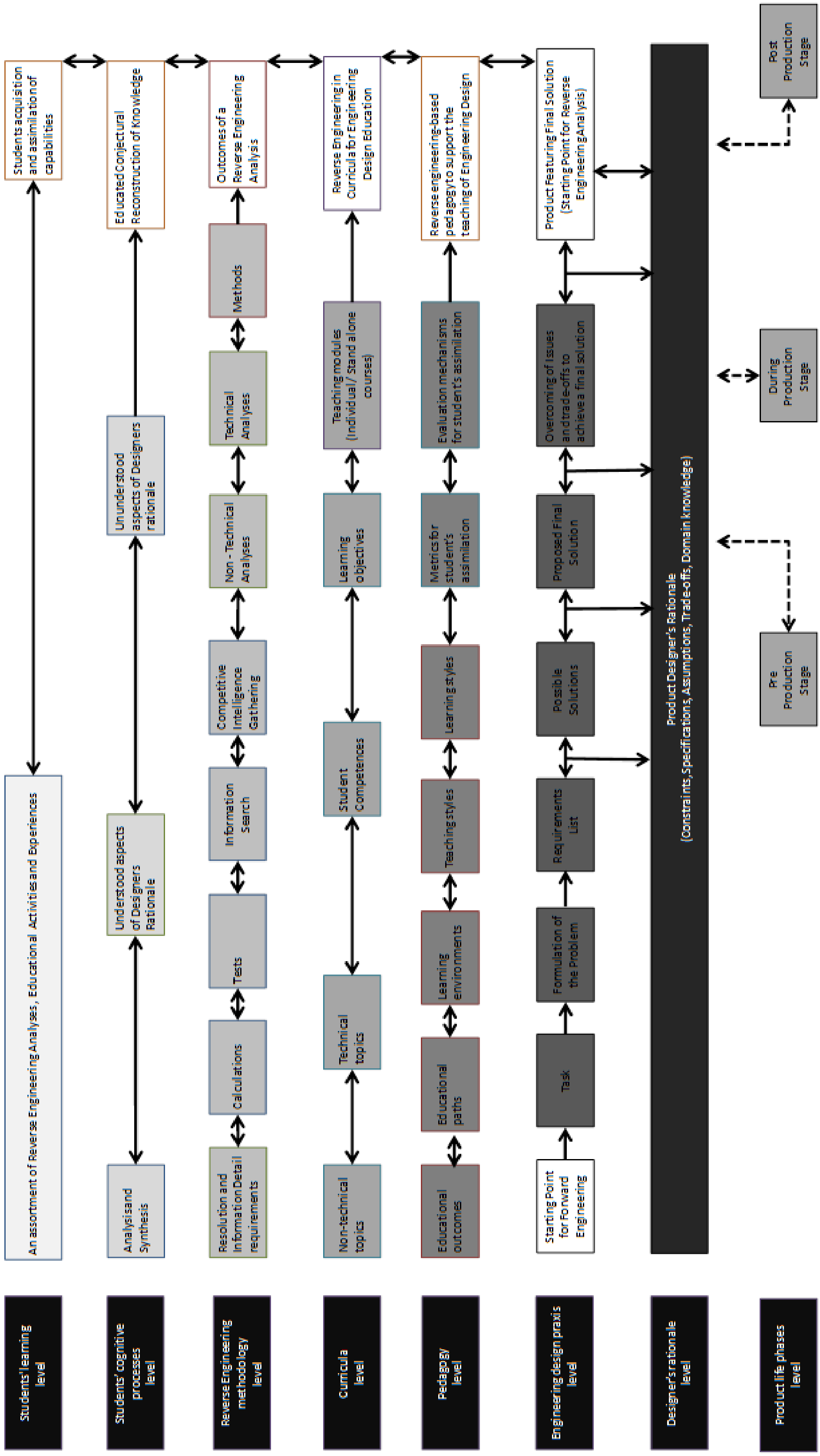

Figure 2.7 Levels Involved in the Acquisition of Competences through Reverse Engineering Activities

Figure 2.8 shown below then, depicts a simplified version of the relationship between the levels involved in typical educational reverse engineering activities and the expected outcomes from them

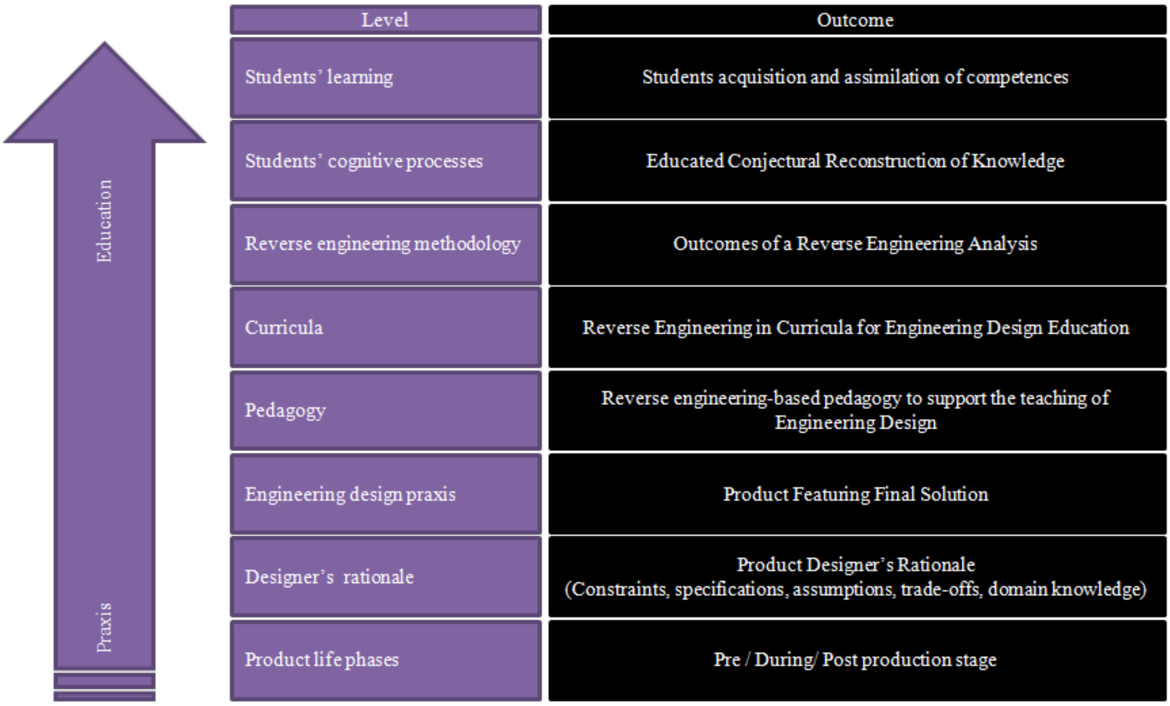

Figure 2.8 Levels and Corresponding Outcomes Involved in Educational Reverse Engineering Exercises

From the information presented above it can be concluded that a proper method for educational reverse engineering analysis that considers the different aspects that contribute to a student's learning can indeed become the vehicle for the acquisition of competences that are relevant to the practice of engineering design and that will be later shown in this collection of resources in Resource 5

2.4.1 Comparison of Competences Exercised in an EREA against those in a Conventional "Forward" Engineering Design Exercise

Many questions arise concerning the differences between forward and reverse engineering-based exercises; the best way to answer this question is perhaps by illustrating a comparison of them by showing their typical events, competences and results. However, it is important to realize in the first place what the desirable or rather expected competences engineering design students should have at the end of their career studies; Plenty of research about it exists, for example that of the reasonably expected areas of competence of a university graduate by [Meijers et al. 2005] in Figure 2.9 below

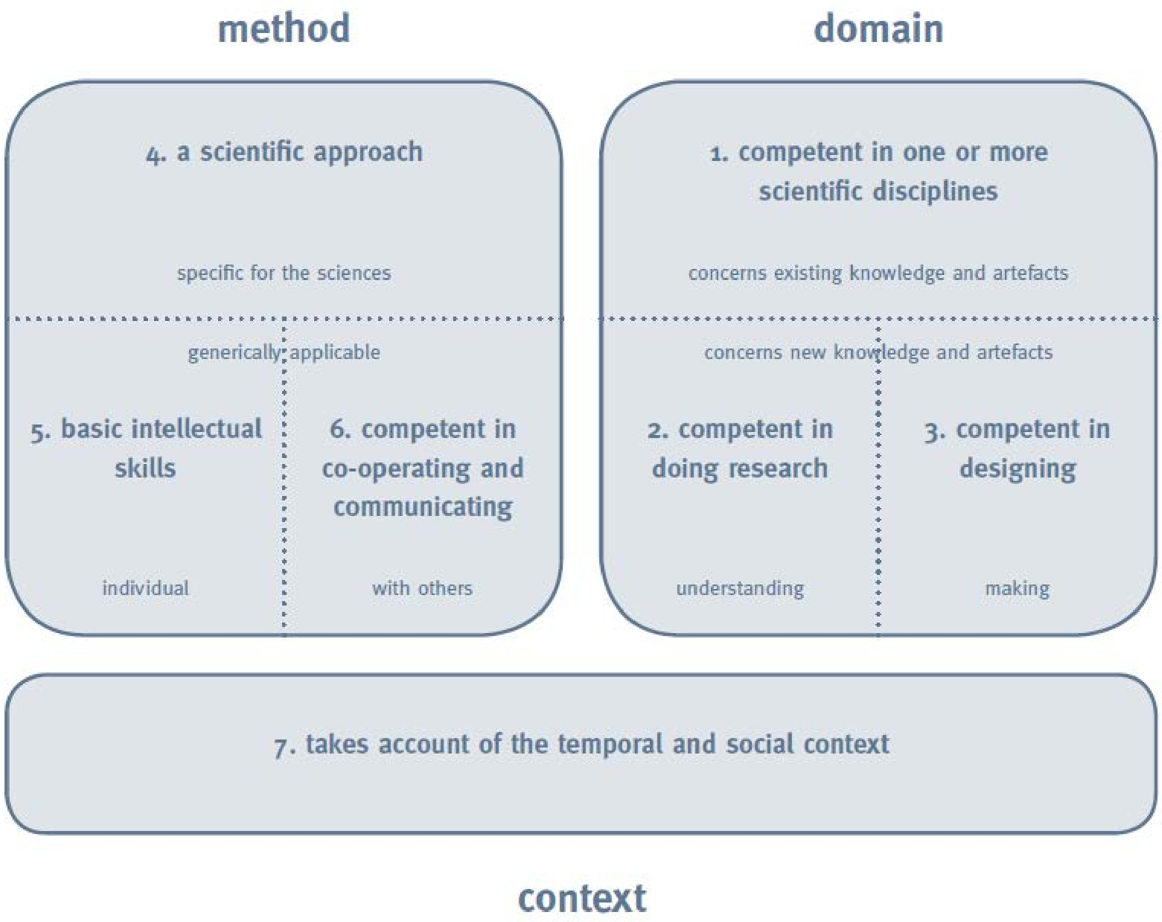

Figure 2.9 Reasonably Expected Areas of Competence of a University Graduate, Source: [Meijers et al. 2005]

Table 2.7 however shows the specific competences desired from Engineering Design students according to [Calderon. 2010a], namely:

Competences	Learning Objectives
Teamwork	Participate effectively in groups or teams
Information Gathering	Gather Information, using various sources and techniques, Including analysis
Problem Definition	Define problem, including specific goal statement, criteria and constraints
Idea Generation	Utilize effective techniques for idea generation
Evaluation and	Utilize critical evaluation and decision making skills and techniques,

Decision Making	including testing
Synthesis	Combine information together from pre-existing elements in a different way, in a new pattern or proposing alternative solutions
Implementation	Implement the design to a stage of usefulness to prospective clientele
Communication	Communicate at all stages of development and implementation of design solutions

Table 2.7 Desired Competences in an Engineering Design Student and Measurable Learning Objectives, [Calderon. 2010a]

With the previous competences then, students can have a credible chance to succeed in their career studies and can also serve as a baseline for further growth during their professional careers.

Table 2.8 shown below shows an example of a typical (forward) engineering design exercise, detailing the events common to any engineering design process, the competences required to succeed in them, and what they lead to in terms of educational outcomes and practical results.

Events	Competences Required	Leading To…
1. Define a need; express as a goal	Problem Definition Teamwork Communication	Definition of the Problem, Including Specific Goal Statements
2. Establish design criteria and constraints	Problem Definition Information Gathering Teamwork Evaluation and Decision Making Communication	Acknowledgement and delimitation of constraints, Understanding of the open ended nature of problems, Recognize importance of problem definition
3. Evaluate alternative designs	Evaluation and Decision Making Idea Generation	An iterative approach that employs evaluation of proposed solutions repeatedly in the design process
4. Build a prototype of	Implementation	Achieve familiarity with the design

best design	Teamwork	
5. Test and evaluate the prototype using the design criteria	Evaluation and Decision Making Teamwork Implementation	Management of time and other resources as required to complete the project
6. Analyze test results, make design changes, and retest	Synthesis Evaluation and Decision Making Teamwork	Self- assessment of design proposals and also learning to follow instructions provided by others in implementation
7. Communicate the design	Communication Teamwork	Presentation of the development and implementation of a solution

Table 2.8 Example of Events and Practiced Competences in a (Forward) Engineering Design Exercise

Table 2.9 below then, shows an example of a reverse engineering exercise detailing the same aspects as those of a traditional (forward) engineering exercise (Note: The example follows the suggested methodology for reverse engineering analysis that is later explained in Resource 5 of this document)

Events	**Competences Required**	**Leading To**
1. Task Clarification	Problem Definition, Idea Generation	Goals and span of the exercise
2. Product Procurement	Problem Definition, Information Gathering, Evaluation and Decision Making	Selection of product to cover expected theory principles and effects
3. Team Selection	Evaluation and Decision Making, Communication	Assembly of people to undergo the reverse engineering activity
4. Data Collection	Information Gathering	Acknowledgement of the positioning of the chosen product
5. Product Performance Test I	Evaluation and Decision Making	Achieve familiarity with the chosen product and its design
6. Product Disassembly	Information Gathering, Idea Generation, Implementation	Increase of awareness of the product under analysis
7. Product Analysis	Analysis, Information Gathering, Idea Generation,	Understanding of inner workings as well as external

	Evaluation and Decision Making, Communication	factors influencing the design of the product under analysis
8. Product Reassembly	Evaluation and Decision Making	Hands-on experience and validation of past stages
9. Product Performance Test II	Evaluation and Decision Making, Information gathering	Confirmation of understanding of the requirements for the product to keep working even after a destructive analysis
10. Knowledge Synthesis	Synthesis, Idea Generation, Communication	Generation of knowledge and acknowledgement of the product's design "suitability" to accomplish its objectives
11. Redesign Suggestions	Implementation, Synthesis	Presentation and assessment of improvement proposals and rational and theoretical foundations behind them, Acknowledgement of current design constraints
12. Conclusions	Synthesis, Information Gathering, Idea Generation	Situational awareness of the product (historical timing, design, production), Understanding of the open ended nature of problems in design
13. Results Dissemination	Communication	Presentation of the findings
14. Project Closure/Follow Up	Implementation, Synthesis, Communication, Idea generation , Information Gathering	Tracking of the project and search for ideas to improve it

Table 2.9 Example of Events and Practiced Competences in a Reverse Engineering Exercise

From a comparison between the tables above and the exercises they represent with their different steps, practiced competences and fundamentally different goals, it can be seen how EREA are a complement not a substitute of traditional design engineering projects or existing design pedagogies; this is an idea also shared by author [Wu. 2008] who stated that mechanical dissection "doesn´t replace traditional design pedagogies, but instead complements them"

Part of the added value EREA can bring to engineering design education then, comes from their suitability to reinforce engineering concepts through hands-on experiences and help exercise most of the expected competences considered important for an engineering design graduate, because of this, the two types of exercises should not be considered as competing ones, but rather be chosen or even combined according to their suitability towards the goal educational goal in mind.

2.5 Gender, Prior Experience and Motivation in EREA

With regard to the effects of gender, prior disassembly experience, and motivation in students, the studies in the area of D/A/A Activities by Authors [Dalrymple et al. 2011] found in their test population that men reported significantly more prior experience in disassembling artifacts than women, also they found that males had a higher perceived competence on D/A/A activities than females. However, no other significant relationships was found among the variables (gender, prior disassembling experience and motivation) and despite the abovementioned findings the actual results from their study indicated that none of these perceptions or relationships actually accounted for any significant variability in responses for students in a D/A/A activity, in this sense the authors reported that women's inexperience or lower perception did not put them at a disadvantage and students of both genders performed equally on the measure of learning and transfer from D/A/A activities, based on this, and on the statements by the researchers themselves, their results "help reduce concerns about potential novelty effects related to the D/A/A activity both because many participants had previously experienced D/A/A activities and because prior experience with D/A/A did not show a significant relationship with transfer or motivation".

2.6 Resource Conclusions

Much research has gone into the study of the cognitive processes that allow for the students' learning and construction of knowledge with or without the aid of physical objects ; still an indicative representation of what the most relevant findings for the area of educational reverse engineering is presented in this resource and from it, one can see that EREA are integrative, comprehensive activities that help students learn with all their senses and thus have memorable educational experiences that comply with current recommendations in the field of education, after all and as stated by author [Hoffman. 2006] when referring to hands-on activities "As much as you think you know, nothing beats picking up the parts, feeling them, weighing them, and knowing the processes that made them."

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RESOURCE 3: MISCONCEPTIONS ABOUT REVERSE ENGINEERING

3.1 Resource Introduction

Given the different goals, methods and stakeholders commercial reverse engineering activities have in relation to their educational counterparts, a major effort has been done during the creation of this collection of resources to focus only on the educational aspects of reverse engineering. However, given that EREA are sometimes unfairly marred by the misconceptions and negative perceptions their commercial counterparts have, the information presented in this resource intends to debunk some of the myths of commercial reverse engineering and explain at the same time how they affect the educational aspects of it.

3.2 Negative Associations of the Term "Reverse Engineering"

The term "engineering" is positively seen as the creation of something beneficial, whereas the term "reverse engineering" suffers a negative connotation often associated with illegal acts, this connotation is mostly derived from the use of the term in criminal counterfeiting or software hacking practices and thus, by sheer simplification the idea has spread that reverse engineering is not legitimately linked to technical advance under any circumstance. Indeed the term "reverse" rather than implying the concept of a bidirectional data exchange between physical and conceptual domains is understood as an opportunistic misappropriation of existing information. It's been only in recent times though, that in commercial environments, little by little reverse engineering starts being associated with the positive production of new products or the variation of old ones. For example, a publication by the Gale group states that "reverse engineering used to be viewed as a not-so-ethical process of copying successful designs by OEMs but with less design capability than the originators. But since then, reverse engineering has come to be viewed in a more positive light because it speeds up and simplifies many developmental procedures for OEMs. Today, it is in almost universal use because it enables OEMs to be more competitive across several disciplines", [The Gale Group, 2002].

Back to the academic domain, it should be mentioned that the idea to complement the teaching of the engineering design process with reverse engineering activities was met with reticence when first presenting the research proposal that led to the creation of this collection of resources. Initial, exploratory studies showed that both, an idealized view of the design process and a criminalisation of the term "reverse engineering" had led some educators to believe that reverse engineering could have the potential to promote bad habits in design. The following list summarizes some of the misconceptions and misunderstanding found about educational reverse engineering and that are addressed in this resource:

- Disassembling a product you have legally purchased is illegal
- Reverse engineering is always employed to violate copyrights
- Pursuing, sharing or obtaining knowledge through reverse engineering is unlawful
- Reverse engineering is the same as espionage
- Reverse engineering activities promote bad habits in design

If not properly understood then, educational reverse engineering activities might be a cause for ethical concern since they could be thought to be only one step away from infringement of the law; this is far from truth and especially so for this collection of resources which is decidedly focused on the educational aspects of reverse engineering. Professor and reverse engineering author Tim Simpson for example, stated in an interview that reverse engineering has long been upheld as a legitimate way to reveal a product´s trade secrets and that "as long as you´re not trying to reproduce it or make it yourself, you´re not infringing on anybody´s copyright or intellectual property", he also mentioned that taking something apart doesn´t provide all the information needed to recreate it and that "we can measure a part and see what the final fabricated dimensions are, but we don´t know what the tolerances are. We can take a guess at what the material is, but we don´t know exactly." [Wu. 2008], such statements add to the legitimacy of educational reverse engineering and help debunk the misconceptions surrounding reverse engineering in general.

3.3. Lawfulness of Reverse Engineering as an Educational Practice

Commercial and educational reverse engineering activities are of a very different nature, their goals and purposes vary and how they are seen by intellectual property law differs completely. The academic activities are those carried out by members of educational institutions, and involve the disassembly, analysis and potential publication of results obtained through the analysis of a product for educational purposes.

From the information presented already in this collection of resources it can be understood that although certain post-reverse engineering actions in commercial environments could infringe intellectual property laws at some point, as far as education is concerned, the relationship between EREA and existing patent and copyright laws is bond through the following principles: “First sale doctrine of patent law” as seen in [Quanta Computer, Inc. v. LG Electronics, Inc. 2008]; “Fair use” as seen in [United States Copyright Act. 1976], and “Fair dealing” as seen in [Copyright, Designs and Patents Act. 1988], they can be understood as the legal framework that allows EREA to be used in the analysis and criticism of patented products for research, private study and academic purposes and that backs ups the educational nature of the reverse engineering analysis and the publication of its results. A short overview of them and their main characteristics is presented next:

A. The First Sale Doctrine of Patent Law:

The first sale doctrine states that the first unrestricted sale of a patented item exhausts the patentee's (or intellectual property owner) control over that particular item which is the subject of intellectual property rights; in educational reverse engineering it means that whenever a product embodying a patented invention is bought, the purchaser acquires the right to use it and becomes generally free to experiment with his purchase without fear of patent liability, this includes disassembling it and studying how it works as this doesn’t not involve making or selling the invention, still, even if afterwards, the person were to make a patented invention, it could be claimed to have been done “to satisfy scientific curiosity” inspired by the initial product and he/she could still maintain an “experimental use” defence against patent infringement. This concept was once, informally called as the principle of “You bought it, you own it" by Lohmann, F. from the Electronic frontier Foundation [EFF. 2007]

B. The Fair Use Principle of Copyright:

Fair use is a doctrine mentioned in the United States Copyright Act of 1976 regarding a limitation and exception to the exclusive rights granted by copyright law to the author of a creative work, that allows limited use of copyrighted material without acquiring permission from the rights holders for purposes such as criticism; comment, news reporting, teaching (including multiple copies for classroom use), scholarship, or research, [United States Copyright Act. 1976]

In educational environments, the first sale doctrine of copyright law provides educational exemptions so copyrighted works can be used in teaching environments. Section 110(1) of the Copyright Act exempts from infringement liability “the performance or display of a copyrighted work in the course of face-to-face teaching activities by a non-profit educational institution in a classroom or similar setting." [United States Copyright Act. 1976], it also, "exempts from liability the transmission of a performance or display of a copyrighted work if the performance or display is a regular part of the systematic instructional activities of the non-profit educational institution; the performance or display is directly related and of material assistance to the teaching content of the transmission; and the transmission is made primarily for reception in classrooms or similar places or by persons to whom the transmission is directed because of their disabilities" [United States Copyright Act. 1976] and [Lehman. 1995]

In cases of controversy, fair use is assessed against a four factor test for infringement of copyright, the points included are:

The purpose and character of the use, including whether such use is of a commercial nature or is for non-profit educational purposes

- The nature of the copyrighted work
- The amount and substantiality of the portion used in relation to the copyrighted work as a whole
- The effect of the use upon the potential market for or value of the copyrighted work.

Of relevance to EREA is that an educational analysis of a product and further publication of results obtained thereof would fall under the category of criticism, comment, teaching, scholarship and research as legitimate reasons to perform reverse engineering.

C. The Fair Dealing Principle of Copyright Law:

Fair dealing is considered a set of limitations and exceptions to the exclusive rights granted by copyright law to the author of a creative work, it is a concept found in many of the common law jurisdictions of the members of the Commonwealth of Nations and although different and not as flexible, it is considered a parallel concept to the United States copyright law's doctrine of fair use.

The copyright office of the University of Melbourne in Australia for example, states that in certain circumstances, some works may be used if that use is considered to be 'fair dealing'. There is no strict definition of what this means but it has been interpreted by the courts on a number of occasions by looking at the economic impact on the copyright owner of the use. In cases where the economic impact is not significant, the use may count as fair dealing, [Patent Office. 2012]. A commonly agreed definition is that fair dealing is an enumerated set of possible defences against an action for infringement of an exclusive right of copyright that allows the limited use of copyrighted materials for certain purposes without requiring the permission from the copyright owner, (where) fair dealing is only valid for certain purposes, such as research; study, criticism, review, parody, satire, reporting news, judicial proceedings or professional advice, after: [UCO. 2011].

For research or study purposes for example, one can copy ten percent of the total number of pages or words (if the work is not paginated) or one chapter of the work, whichever is greatest, one can also for example, copy one article from a journal issue, magazine or newspaper or two or more articles from the same issue if they are for the same research or course of study. To copy other types of materials such as artistic works; films, sound recordings, computer programs, software, games, unpublished material more than ten percent or one chapter of textual material, one can consider if the use is "fair and reasonable" under the following conditions, [UCO. 2011]:

a. Why you are copying the work
b. The nature of the work
c. The possibility of obtaining a copy within a reasonable time at an ordinary commercial price
d. The effect of the use upon the potential market for, or value of, the work
e. If only part of the work is copied, the amount and substantiality of the part in relation to the whole work.

In such cases, the provision only applies to material being copied for your own research and study and one does not need to be enrolled in a formal course of study, fair dealing for research and study also applies to self-directed study and research and one must acknowledge any material used.

In cases of criticism or review on the other hand, one can use either the whole work, if needed, or a part of it. In the specific case of the Australian Copyright Council for example, "criticism and review involves making a judgment of the material concerned or of the underlying ideas" which means one is unlikely to be able to use material as an example or to illustrate a point under fair dealing for criticism or review. The provision then, also applies if the critique or review is being published, presented at a conference or made available online and one must acknowledge any material used. In summary, under fair dealing, educational analysis and other activities can be defended against potential accusations of copyright infringement and just as the fair use principle, fair dealing allows for the educational use of copyrighted material under certain circumstances, c.f. [D’Agostino. 2008].

Fortunately, in academic environments the perception of reverse engineering keeps improving and even authors such as [Barr et al. 2009] have stated in regard to the rightfulness of reverse engineering as a tool in education that “It should be noted that, for student projects, reverse engineering is a legitimate activity. Determining “how something works” is not stealing someone’s ideas, but rather is a beneficial way to enhance the learning process of engineering design for the novice” , the authors then end up by declaring that “Mechanical dissection has been promoted for many years as an acceptable activity for engineering students” such conclusions are in line with the ones expressed in this document and it is expected that the perception of educational reverse engineering keeps improving over the years, should the reader needed more information on this topic Table 3.1 below lists the information needed to access the “Freedom to Tinker” website which promotes among other things the right of citizens to experiment with their devices

Name of the Resource	Associated webpage	Description / Notes
Freedom to Tinker	http://www.freedom-to-tinker.com/	A website managed by the University of Princeton's Centre for Information Technology Policy in the USA that focuses on issues related to legal regulation of technology, and especially on legal attempts to restrict the right of technologists and citizens to tinker with technological devices.

Table 3.1 Information on the Regulation of Citizens' Rights to Tinker with Their Devices

From the information presented in this section then, it should be understood that EREA fall under good faith, fair use, fair dealing and other exemptions usually available to educational institutions and that provide the legal framework for educational reverse engineering activities to exist.

3.4 Major Misconceptions and Misunderstandings Regarding the Practice of Reverse Engineering

Because misconceptions and misunderstandings about reverse engineering activities still float around, the following ones (and their ramifications) have been selected as those with the greatest importance for clarification in benefit of potential adopters of EREA, namely:

- Supposed easiness
- Market unfairness effects

- Disdain for intellectual property laws
- Innovation hampering, invention weakening

A number of statements from actual results found in published literature have been collected in an effort to provide a clearer, unbiased view about what reverse engineering activities really are and thus, try to portray a favourable view of them that helps improve their acceptance as a valid tool in the teaching of engineering design, and to try to reduce their perceived association to questionable practices that contribute to the disinformation about them.

Authors Pamela Samuelson and Suzanne Scotchmer conducted an extensive research on the law and economics of reverse engineering where they debunked many myths concerning not only reverse engineering as an intellectual activity itself but also about its impact in economy and innovation. This collection of resources has gone through their seminal publication "The Law and Economics of Reverse Engineering" [Samuelson & Scotchmer. 2002] to collect the most significant statements mentioned there that help debunk misconceptions and misunderstanding surrounding the reverse engineering practice and that are also relevant to the engineering education field covered in this collection of resources. Tables 3.2 to 3.6 shown below then, list common misconceptions about reverse engineering and are contrasted against actual documented facts.

A. Reverse Engineering and its Perceived "Easiness":

Reverse engineering is sometimes thought to be a careless, easy way to take what has been done already, in a speedy, risk-free manner; this misconception is wrong since reverse engineering is indeed a complicated process. Table 3.2 lists the perceived myths about reverse engineering's easiness against what has been actually published in Samuelson & Scotchmer's study [Samuelson & Scotchmer. 2002].

Misconception	Facts, Quoted from: [Samuelson & Scotchmer. 2002]
Reverse engineering is an easy activity	Reverse engineering can be extremely difficult and is generally costly, time-consuming or both.
Innovation and secrets are visible to the open eye and are there for the taking by freeloaders	
Reverse engineering is a	Second comers to a market have to go through a four stage process before they introduce reverse engineered products for

speedy process	sale. The first stage involves a firm's recognition that another firm has introduced a product into the market that is potentially worth the time, expense, and effort of reverse engineering. In some markets, recognition happens very rapidly; in others, it may take some time, during which the innovator can begin to recoup its R&D costs by selling its product and establishing goodwill with its customer base. The second stage begins when a second comer obtains the innovator's product and starts to disassemble and analyze it to discern and find of what and how it was made This stage may be costly, time-consuming, and difficult. The third stage is implementation where the know-how obtained during the reverse engineering process is put to work in designing and developing a product to compete in the same market. This may involve making prototypes, experimenting with them, retooling manufacturing facilities, and reiterating the design and development process until it yields a satisfactory product. It may be necessary to return to the reverse engineering stage again if it becomes apparent in the implementation phase that some necessary know-how eluded the reverse engineer the first time. Information obtained during reverse engineering may, moreover, suggest possibilities for additional product innovation that will be investigated in the implementation stage, for these reasons, the second comer's implementation stage may take considerable time and require significant expense. The fourth stage is the introduction of the product to the market. How quickly the new product will erode the innovator's market share and force the innovator to reduce prices to be competitive with the new entrant will depend on various market factors.
Companies performing reverse engineering are lousy and careless	American industry lost a substantial share of the market for random access memory chips to Japanese competitors whose superior quality control made their chips very competitive.

Table 3.2 Misconceptions in Reverse Engineering Regarding its Perceived "Easiness", After: [Samuelson & Scotchmer. 2002]

B. Reverse Engineering and Market "Unfairness":

Though at first sight reverse engineering practices might appear harming to market health, it is actually quite the opposite since they contribute to force market innovation and continuous competition; reverse engineering in industrial contexts serves as a way to transfer knowledge to second comers and acquire some of the know-how embedded in innovative competing products while still aiming to learn anything that might lead to further innovation. Given that reverse engineering is a costly; lengthy, resource intensive process where the acquired know-how takes time to reimplement and materialize into a completed, fully tested product, first comers will be protected long enough from horizontal competition to recover R&D expenses and establish a customer base. Thus, in order to maintain their advantage, innovators are pushed to come up with a better product thereby benefiting customers as a whole.

Reverse engineering then, is one of the forces promoting competition and constant innovation, for example, first comers could if they wished so, license their technologies to second comers as a means to acquire additional income and market power, or they could even voluntarily disclose and share some information. Reverse engineering per se has not a market destructive effect of its own as it is normally conducted behind closed doors, post-reverse-engineering activities on the other hand have the potential to erode first comers' advantage and deprive society of the benefit of follow-on innovation but only if somehow a way to expedite the reverse engineering process were ever found. In practice, continuous innovation and changes of technology provide the leading advantage to innovative companies and reverse engineering of old products does not seem to harm innovative companies since they've had enough time to recover their R&D expenses by then. In this context, it is very important to distinguish reverse engineering (as a driver for follow-on innovation) from plain copying which does not lead to any kind of innovation; does not promote the development of knowledge-based tools, or the advancement of the state of the art at all.

Table 3.3 below lists the perceived myths about reverse engineering's market "unfairness", against what has actually been published in Samuelson & Scotchmer's study [Samuelson & Scotchmer. 2002].

Misconception	**Facts, Quoted from: [Samuelson & Scotchmer. 2002]**

Reverse engineering is a market destructive practice	Either costliness or delays can protect the first comer (companies , manufacturers, innovators, etc) long enough to recoup its initial research and development (R&D) expenditures
Reverse engineering damages innovators	Innovators are usually protected by one or all of the following reasons, the costliness of reverse engineering, the human resources required to perform it, and the lead time due to difficulties of reverse engineering imposed by technology gaps (this latter functions as a short-lived intellectual property right)
Publication of information obtained through reverse engineering erodes an innovator’s ability to recoup its R&D expenses because the innovation will no longer be secret.	Reverse engineers do not generally publish their discoveries, instead maintaining the discovered information as their own trade secret.
Reverse engineering always erodes innovative firms’ market	For some consumers, a firm’s reputation for innovation or quality service will make its product attractive even if second comers eventually copy it, to the extent there are switching costs associated with the product (e.g., owing to a steep learning curve in how to use it), the innovator may also benefit from “lock-in” of its initial customers and those who later value the innovator’s product because others are using it and portray a strong brand image.
Reverse engineering does not yield any economic benefit to first comers	The reverse engineer’s purchase of a competitor’s product to reverse-engineer it, does contribute towards recoupment of the innovator’s costs; this may be trivial for mass-market goods but not for specialized, expensive, long lifecycle machinery
First comers can’t benefit economically from competitors	During both the reverse engineering and the implementation stages, the innovator may decide to license its know-how to the second comer. Over time, the innovator’s willingness to license may increase, especially if it has reason to think that certain second comers are making progress toward developing a competing or improved product. The second comer’s willingness to take a license may decline as its expenditures in reverse engineering and redevelopment rise and as it perceives these efforts to be bearing fruit; yet a license from the innovator may become attractive if fine details of implementation elude the

	reverse engineer.

Table 3.3 Misconceptions in Reverse Engineering Regarding its Perceived "Market unfairness", After: [Samuelson & Scotchmer. 2002]

Additional examples of positive views about reverse engineering's effects in the market can also be found, for example in "The Pocket Scope" newsletter who published for example, that "reverse engineering is a common and recognized practice, particularly in computer software, and is extremely important to technological advancement. IEEE-USA defines reverse engineering as the discovery by engineering techniques of the underlying ideas and principles that govern how a machine, computer program or other technological device works", they also ended up stating that "ultimately, the greatest benefits from reverse engineering are reaped by the public at large", [McManes, 2005].

C. Reverse Engineering and its "Disdain for Intellectual Property Laws":

Reverse engineering is wrongly equated with counterfeiting rather than with exemplification and inspiration. Counterfeiting itself, is associated to a lack of effort and creativity, and counterfeiters for example, have no need to understand how a product works in order to copy it, this is especially true if all they are aiming for, is the reproduction of geometrical features or the overall appearance of a product, and while some superb counterfeits could exist, the trend for forgers is to provide independent contributions to the counterfeited product to a minimum. Lawful competitors on the other hand, come up with a new implementation of a reverse engineered specification that is at least different enough to the original design as to avoid copyright infringements, most likely, they'll go even further in the development, as to consider it a new product. While counterfeiting for commercial profits is a questionable practice, copying should not be instantly equated to counterfeiting or any other criminal activity, the actual process of copying a product, in all fairness, is indeed a difficult, time-consuming process whose set of skills necessary to achieve a successful outcome are commonly overlooked or even scorned. What's more, legitimate copying for the purpose of self-education should not reproduce flaws in the source design since a critical analysis to the original design should run parallel.

Imitation and learning from competitors, products and processes in professional practice occurs from formal and informal exchanges between colleagues, suppliers and designers at a number of different venues (e.g. congresses) and in fact authors [Patel & Pavitt. 1995] also report that reverse engineering is indeed the main method of learning from competitors' product technologies. Counterfeiting and piracy on the other hand, are multidimensional topics of research far outside the scope or the goals of this collection of resources and commercial reverse engineering activities should not be equated to them since under certain circumstances they are a perfectly legal and common tool in product design. Table 3.4 below lists the perceived myths about reverse engineering's "Disdain for intellectual property laws" against what has actually been published in Samuelson & Scotchmer's study [Samuelson & Scotchmer. 2002].

Misconception	**Facts, Quoted from: [Samuelson & Scotchmer. 2002]**
Reverse engineering is a practice against patents and copyrights	Patents and copyrights encourage individual effort by personal gain and make public welfare advance through the talent of inventors; Reverse Engineering aims to become a tool for motivated inventors to expand their sources of inspiration and understanding.
Reverse engineering breaches trade secrets	The owner of a trade secret does not have an exclusive right to possession or use of the secret information. Protection is available only against a wrongful acquisition, use, or disclosure of the trade secret, as when the use or disclosure breaches an implicit or explicit agreement between the parties or when improper means, such as trespass or deceit, are used to obtain the secret, reverse engineering then, has always been a lawful way to acquire a trade secret, as long as the acquisition of the known product is by a fair and honest means, such as purchase of the item on the open market. It can be said, though, that since there is no time limit to trade secrecy protection, reverse engineering is the principal way in which a trade secret enters the public domain.
Scientific researchers cannot use patented inventions without authorization	The "experimental use" privilege allows a researcher to use a patented invention without permission from or compensation to the patent owner. However, such a use must be "merely for philosophical experiments, or for the purpose of ascertaining the sufficiency of the [patented invention] to produce its described effects." If the purpose of the research falls outside these parameters, the "common law" experimental use privilege is inapplicable, and the researcher may face liability for patent infringement.
Manufacturing firms' main protection of intellectual assets are patents	Empirical studies of manufacturing firms over a long period demonstrate that such firms typically rely more on lead time than on patents as the principal source of protection for their intellectual assets. Semiconductor firms particularly have historically relied on lead time and secrecy far more than on patents to protect their intellectual assets. It is also possible to build products that are difficult to break down and copy, hardware components can be

	encapsulated to make non-destructive disassembly almost impossible; components can be mislabelled; custom parts can be used; “locks” (often implemented in software) can be added. In any sort of complex product, non-functional features can be added to create a “fingerprint” on any illegitimate copy, forcing copyists to invest in real reverse engineering efforts. Additionally, the length of time a first comer leads a market can be referred to as “lead time” it is determined among other things on how long a competing second comer will take to find a non infringing improvement to the product analyzed. In practice this becomes the effective patent life which may be shorter than the statutory patent life.
Trade secrets are always expensive and difficult to develop.	Some trade secrets may have been serendipitously developed at low cost yet are difficult to reverse-engineer, while other expensive and time consuming innovations may be impossible to hide in the final product. Still, some commentators contend that “inventiveness often correlates with difficulty of reverse engineering, with the result that the more inventive the product, the longer its inventor enjoys the so-called ‘first mover advantage,’ and the more profit he/she earns. A further consideration is how difficult or easy it is to detect whether another firm independently developed the same or a similar innovation, or engaged in reverse engineering to discover it. Reverse engineering, after all, tends to occur behind closed doors”
Laws are the same everywhere	In some countries, parasitic copying such as that conducted by a plug-mould process is illegal as a matter of unfair competition law

Table 3.4 Misconceptions in Reverse Engineering Regarding “Disdain for Intellectual property laws”, After: [Samuelson & Scotchmer. 2002]

D. Reverse Engineering, “Innovation hampering” and “Invention weakening”:

While there might be an impression that reverse engineering somehow suppresses the desire for innovation and new invention on the people that practice it, reverse engineering is in fact a trigger for innovation, not only can it be assumed that many people have found inspiration disassembling all sorts of products, but it can also be seen how older engineers and scientists developed their skills with hands-on hobbies and by disassembling machinery at hand. It is indeed in the attitudes of some of the most famous innovators such as William Hewlett and David Packard (Developers of test equipment and computers); Stephen Gary Wozniak and Steve Jobs (founders of Apple Inc.), Richard Stallman (Initiator of the free software movement) and Linus Torvalds (Initiator of the Linux kernel) who were known for being hardware hackers and shared a deep passion for technology where it is easier to see that disassembling existing products (a key feature of reverse engineering analysis) can at the very least, help increase the sources of inspiration of motivated innovators. Reverse engineering then, is not only about disassembling products but also assembling them, modifying them and building new ones.

Tables 3.5 and 3.6 list the perceived myths about reverse engineering's "Innovation hampering" and "Invention weakening" against what was actually published in Samuelson & Scotchmer's study, [Samuelson & Scotchmer. 2002].

Misconception	Facts, Quoted from: [Samuelson & Scotchmer. 2002]
Reverse engineering does not contribute to innovation	In 1989 the U.S. Supreme Court decision on the Bonito Boats, Inc. v. Thunder Craft Boats, Inc., case characterized reverse engineering as "an essential part of innovation," likely to yield variations on the product that "may lead to significant advances in the field" and stated that "the competitive reality of reverse engineering may act as a spur to the inventor" to develop patentable ideas. Even in the cases where reverse engineering does not lead to additional innovation, the Bonito Boats decision suggests it may still promote consumer welfare by providing consumers with a competing product at a lower price. [Bonito Boats, Inc. v. Thunder Craft Boats, Inc. 1989]. Reverse engineering then, does incentive to engage at the very least in follow-on innovation.
Innovation is not worth it if products are going to be reverse engineered anyway	Because reverse engineering generally takes time (time to decide the product is worth figuring out, as well as time to actually do the engineering and bring the product to market), the first inventor enjoys a period of exclusivity in which to recapture the costs of invention; build a reputation, and establish a base of loyal customers. Furthermore, the copyist is not quite a free rider because reverse engineering is generally expensive, thus after the secret is discovered, the parties compete on a fairly level playing field. It can be said then, that innovation has outpaced patent effectiveness.

Table 3.5 Misconceptions in Reverse Engineering Regarding "Innovation hampering", After [Samuelson & Scotchmer. 2002]

Table 3.6 shown next then, list some common misconceptions about reverse engineering, invention and new design.

Misconception	Facts, Quoted from: [Samuelson & Scotchmer. 2002]

Reverse engineering hampers original inventions	The following excerpt is taken from “Edison a Biography” by [Josephson. 1959] “When the devices of others were brought before him for inspection, it was seldom that (Edison) could not contribute his own technical refinements or ideas for improved mechanical construction. As he worked constantly over such machines, certain original insights came to him; by dint of many trials, materials long known to others, constructions long accepted, were ‘put together in a different way’—and there you had an invention.”
Reverse engineered products can’t themselves inspire competition	Existing technologies are usually reinvented rapidly once it becomes known to the others that the technology available to do so is possible.

Table 3.6 Misconceptions in Reverse Engineering Regarding “Invention weakening”, After [Samuelson & Scotchmer. 2002]

As stated already, the actual facts in response to the myths listed on the left column of Tables 3.2 to 3.6 above were compiled and contextualized for this collection of resources from the work by authors [Samuelson & Scotchmer. 2002] whose original publication remains the source that helps debunk the myths about reverse engineering activities.

In the opinion of author Sheri Sheppard, co-director of the Centre for Design Research at Stanford University, “The reality is that very little design is actually new design”, [Wu. 2008], to what she also adds the statement that “Very good designers have this catalogue in their brain of stuff, of mechanisms, of devices, of machine elements.” [Wu. 2008], from these statements and from the characteristics of EREA it could be argued that they can also help students build a mental parts’ catalogue which they can order from in future design tasks. Author Sheppard’s reasoning thus, is in line with the goals of the promotion of reverse engineering activities in engineering design education as a way to actually improve the student’s design abilities.

3.5 Misconceptions about the Relationship between Reverse Engineering and Creativity

Reverse Engineering is usually criticised as a process that hinders creativity in students; if poorly understood, reverse engineering can be mistaken for plain copying and be associated to laziness or lack of creativity. In industrial contexts for example, imitators can be seen as potential parasites benefiting from other companies’ efforts in developing products and services. Imitation itself is often seen as a shallow activity devoid of intellect and initiative that prevents the development of new knowledge; however this is a naive, idealized vision probably stemming from models of innovation that assume a linear relationship between basic scientific research and industrial superiority which authors Bessant and Francis have found not always to exist, [Bessant & Francis. 1999].

Reverse engineering in fact, should be understood as discovery; contextualization, and technical proficiency, it is indeed an exercise in synthesis which integrates not only technical knowledge but also doses of creativity and hard work. Analyzing a product then, is not an easy task and requires deep concentration to find out what conditions led to given results. Reverse engineering is comprised by a number of steps and considerations that far from hindering creativity actually expand it by allowing students to increase their awareness of the design process as well as their sources of inspiration, and are even an opportunity to exercise their cognitive skills, for example when analyzing other's successes and failures in design. The building of one's technological capabilities from the achievement of others thus, should at least be credited with the generation of learning; with an effort in product development, with potential innovation, and should be disassociated from criminal counterfeiting and intellectual infringement activities that don't involve creation of knowledge but rather monetary benefits.

The search for inspiration from analogies or other's experiences then, is a surely element of the innovation process. For example, solutions in engineering design are the product of experimentation and integration of knowledge from different disciplines, reverse engineering thus, tries to tear apart the rational for these solutions and has the potential to identify weaknesses and improve existing solutions by consciously combining new ideas and methods.

Authors [Sato & Kaufman. 2005] state for example, that in Japan "Comparative analysis tends to stimulate creativity. Engineers are sensitive to differences. If they lag competition, they want to overtake. If they lead, they want to maintain that lead" comparative analysis thus, is indeed a key step in a reverse engineering analysis and Sato and Kaufman's statement might contribute to the explanation of why reverse engineering was so successful in Japan and in Asian countries overall

It is true however, that resorting to known preferred solutions might somehow exclude the most efficient ones for a given task, however, this trait is well known in designers notwithstanding their level of experience; authors [Pahl et al. 2007] have stated in this regard, that designers tend to minimize their work effort and favour certain solutions because of their individual talents and experience. Still, the actual selection of known solutions also has the following advantages as published by authors Pahl & Beitz too:

1. Avoidance of unfeasible solutions and waste of time
2. Quick concretization of a solution starting from a similar one

Conversely, selecting known solutions has the following disadvantages, Source: [Pahl et al. 2007]:

1. Designers' tendency to remain in their area of expertise
2. Fixation on solution ideas that are less suitable in principle
3. Failure to recognise other better solution principles

As authors [Pahl et al. 2007] state, these are existing traits already known in designers, and because reverse engineering actually tries to overcome such disadvantages, it is only unfair to conclude that reverse engineering is the actual origin of these traits, a more comprehensive effort in teaching pedagogies though, is in fact needed to reduce the effect of the abovementioned disadvantages.

The relationship between reverse engineering and creativity then, is often misunderstood even at the fundamental level, on the one hand, research in brain science states that the essence of human brain activity is not a passive processing of stimuli from the outside world, but the active creation of contexts [Mogi. 2003]. On the other, creativity cannot be forced to happen from one moment to the next. Thus, reverse engineering in this sense, can arguably help students to expand their awareness and sources of information for a better contextualization of their research and findings.

The following list by [Khandani. 2005] compiles characteristics of creative people which can be consciously developed by committed people:

- Curiosity and tolerance of the unknown to not be afraid of what is not understood.
- Openness to new experiences.
- Willingness to take risks, knowing that they may be misunderstood and criticized by others.
- Self-confident and not afraid to fail.
- Ability to observe details but also the whole picture
- No fear to tackle complex problems with their own abilities and experience if possible
- Ability to concentrate and focus on the problem until it's solved

From the findings of past researchers presented here already, and from the experience in developing this collection of resources it can be stated that none of the above mentioned points conflicts in any way with the skills and requirements needed to perform an educational reverse engineering analysis and thus creativity should be understood as much more than a systematic application of rules and theories to solve a problem. Author Khandani for example, stated that “Psychological research has found no correlation between intelligence and creativity”, people are creative because they make a conscious effort to think and act creatively. Everybody has the potential to be creative. Creativity begins with a decision to take risks”, [Khandani. 2005] and so the argument that reverse engineering per se can hinder students’ creativity cannot be sustained.

3.5.1 EREA, Teaching and Development of Creativity

Neither reverse engineering nor another teaching tool can on its own teach everything a student needs to know, reverse engineering isn’t a panacea that can be used to teach everything an engineering design curriculum needs, still and in order to answer questions about how reverse engineering can help with the teaching of creativity , this document resorts to the paper “Teaching Creativity in Engineering” by [Liu & Schönwetter. 2004] and to the research by authors [Treffinger et al. 1994] where creativity is said to emanate from problems, thus making the practice of problem solving a suitable approach to gain creativity. For such purpose, it is suggested in this collection of resources to follow the creative process and systematic pathways of problem-solving and creative learning model proposed by [Treffinger et al. 1994] since it is a powerful tool for an instructor to stimulate and develop creativity in engineering students. This model then, consists of three hierarchical levels, namely:

1. Learning and using basic thinking tools
2. Learning and practicing a systematic process of problem solving
3. Working with real problems

EREA as presented in the methodology of Resource 5 and the pedagogy of Resource 6 mostly support levels two and three, regarding level two for example, students learn from this document a methodology for educational reverse engineering analysis that is based on previous ones that other researchers have used to solve problems and thus, through the explanations provided in this collection of resources students can also learn from the work of others. The objective of level three then, is to improve the students' capability of and effectiveness in handling real-life problems and challenges for which authors [Liu & Schönwetter. 2004] have stated before, that students must experience first-hand through hands-on unsolved problems such as those that reverse engineering exercises can provide.

Other researchers on the topic have also documented the use of reverse engineering or similar activities to support the teaching of creativity, among them for example, author [Kodak. 2008] cites Prof Edward Crawley by stating that the professor “suggest a number of approaches to stimulate creativity. The list is extensive, but he prioritizes reverse engineering, benchmarking and patent search for creativity exercises”, other authors such as [Dalrymple et al. 2011] quote Professor Hess from the Department of Engineering at the College of New Jersey who described a D/A/A activity incorporated in a manufacturing processes course, as “the instructor’s fire keg that lights the imaginations of the engineering students,” [Hess. 2002]. In the end, it could be said that further studies to link creativity and EREA are needed, but at least the information provided in this resource can serve as a starting point from which to continue researching on the topic.

3.6 Reverse Engineering in Support of the Innovation Process

Although limited occurrences have been found in published research specifically linking educational reverse engineering to support the innovation process, two of them can be cited here; the first one by author [Kodak. 2008] who stated that “Just like the inventive genius who determines the next innovation by testing the system to its limits, a prolific reverse engineering will do the same to uncover the innovation”. The second one, comes from an article by [Conti. 2006] in the “Hacking and Innovation” issue of the magazine of the Association for Computing Machinery magazine suggesting that innovation can arguably benefit from hardware hacking (which is a context similar to reverse engineering) and states that computer science “should pay serious attention to the hacking community and its passion for pushing the limits of technology and its role as a counterbalance to its misuse”. As it will be explained in the next section though, where reverse engineering can leave a longer lasting mark is in its ability to support the creation of incremental innovation designs.

3.6.1 Suitability of EREA to come up with Incremental Innovation Designs

Authors [Benedicic et al. 2005] state that innovations can be divided into two larger groups, incremental and radical. Incremental innovations are an ongoing process of change, they are being introduced all the time within a company but they have no revolutionary impact on the structure of the company or the market. Radical innovations on the other hand, can happen on products; processes, or services, and trigger changes that affect the current technical solutions and markets. They state that radical innovation meets the following criteria:

1. It brings an entirely new set of performance features.
2. It causes a five times or greater improvement in the existing performance features.
3. It causes a significant (thirty percent or greater) reduction in costs.

To come up with radical innovations such as those suggested by [Benedicic et al. 2005] as a result from one educational reverse engineering activity done by students while still learning engineering design may not be that realistic to expect, in fact, such kind of innovations may well be outside the expectations of any other educational experience had during the full length of undergraduate studies. What educational reverse engineering activities could trigger though, are post reverse engineering design works and incremental innovations in the form of follow-on innovation (e.g. Derivative applications, add-ons, spare parts, attachments, etc.). Sometimes when teaching students about innovation and creativity, educators might believe that asking students to come up only with new ideas every single time is the right way to go, and while as an ideal goal this might be true and commendable to teach, in industry, innovation works in a different way, it is just as the Goldfire © innovation software homepage used to claim "Innovation is not just reserved for the glamour of breakthrough products and disruptive technologies. In fact, the most common innovation task that companies must do is to improve something that already exists. There is simply no disgrace to incremental improvement. Innovative solutions applied here, can reap enormous benefits in driving high-quality revenue, product reliability, and process efficiency", [IMC. 2011].

Author [Cross. 2008] for example, published Figure 3.1 seen below to show the opportunity areas for product development considering the associated risks, from it, it can be seen how incremental improvement of a current product has its rightful place in product development just as much as product innovation does.

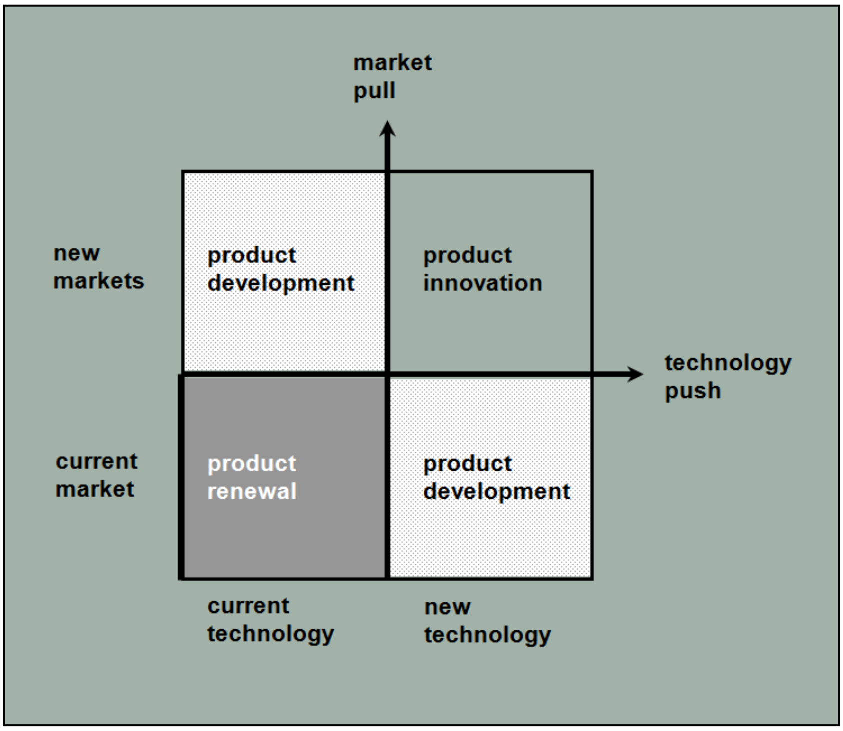

Figure 3.1 Product Development: Opportunity Areas, from low risk to high risk, Source: [Cross. 2008]

Authors [Sato & Kaufman. 2005] have stated that "Although the payback for new products is better than for improvement of existing products, the latter must not be abandoned. Existing products have a market that is constantly changing. Cost reduction and value adding improvements of existing products require constant attention to keep up with aggressive competitors and technology advancements, and to maintain or improve market share and sale". In product development then, exposure to a variety of situations and systems' functionality can trigger inspiration which is in turn useful for exploration and discovery of new solution spaces in the natural and artificial domains, more often than not, existing systems are routinely used for inspiration and reverse engineering exercises aim to enhance this without hindering the creativity of students, the methodology for educational reverse engineering analysis presented here in Resource 5 actually includes a stage for the suggestion of improvements to the product under analysis thus complying with the recommendations of renowned authors Sato and Kaufman.

To sum up it can be said that progress is not only about breakthrough innovations but also about the accumulation of small steps, innovation then ,not only benefits from both huge and small steps, but it's also a multifactorial process that when materialized into a radical product it effectively changes the rules of the game, unfortunately only a small percentage of the design projects end up being radically innovative, which helps support the belief that incremental innovation has indeed a legitimate place in design projects and it suits much better the goal of EREA to be a complement not a substitute for other traditional teaching approaches in engineering design.

3.7 Benefits of Replicating Typical Commercial Reverse Engineering Activities in an Academic Exercise

Although the approach to educational reverse engineering is different to the commercial one, the suggestion of improvements to the product under analysis is a major stage of the educational methodology, the merits of such stage if replicating a purely commercial approach as an academic exercise and the actual benefits stemming from it are discussed below:

In a commercial environment or because of competitive intelligence purposes the reasons to reverse engineer a product can range from:

a. Making a surrogate product
b. Cloning a product
c. Developing an improved derivative of the original product or
d. Creating a complete new product

In academic environments though and specially so in the approach to reverse engineering presented in this document, the ultimate goal of an academic reverse engineering analysis is to understand a product; its inner workings, why it exists, what it needs to fulfil, how it does that, what technologies it might contain, what its socio-economical impact could be and ideally to be able to predict what comes next to the market or in a technological roadmap.

At the "Redesign Suggestions" stage of the reverse engineering method used in this collection of resources; it is asked from students to come up with improvements to the product just analysed to the best of their understanding or come up with ideas for an original design fulfilling the same or similar needs that the product analysed attains. However, asking students to replicate a commercial approach (mainly options a and b of the ordered list shown above) as a purely academic exercise is left to the criteria of the professors in charge and the benefits of such approach are contextualized here.

It is believed in this collection of resources that "playing catch-up" may be a valid initial goal in academic environments too, specially until students grow in the understanding and mastery of technologies, since the ability to create a substitute or even a cloned product based on the one under analysis could still bring some value to their education.

For example, creating a surrogate product means creating a fully functional substitute that fulfils a given set of requirements while using available, proven, known components. Additionally, while creating this substitute, students could even attempt to produce a cheaper, more environmentally and manufacturing friendly surrogate product profiting from the current technologies and processes available at the time of the reverse engineering analysis, while at the same time generating a full clear set of original blueprints rather than trying to recover old ones.

Cloning a product or making a direct copy of the one under analysis, which is another possibility, can still provide students with valuable experience and understanding of the design subjects involved, for example, having detailed information about a product, such as the schematics or the data obtained through a reverse engineering analysis, not only satisfies the general curiosity about a product's structure but it is also educational to be able to see the details on how components, mechanisms or circuits have been implemented; even in a worst case scenario the students would have to revisit the technologies used in the product at the time of its original design and production which might be nowadays old, obsolete or dependant on currently unavailable components ,it would be interesting for them then, to see how solutions were implemented, because while the theory behind the solutions might be well known , the actual implementation is trade craft know how, where experience might trump knowledge and play a more important role. Seeing the actual product and knowing the theory behind, can only expand the understanding of the subject under study; besides as patents expire over a period of time, no intellectual property conflicts could arise from copying an old product if it ever were to be commercialized by the students.

On the other hand and as it is usually the case in an EREA, if the intention is to create an improved derivative of the product under analysis, the new modernized specifications in the new solution would make it an original work and the new blueprints and components would enable students to improve the product or add additional capabilities which could eventually end up making a complete new solution over the original product. In fact simultaneous reverse engineering analyses and the development of new specifications and upgrades are common in industry.

Finally, if initial the goal were to create a complete new product, an EREA would still be useful in setting the foundations for the creation of the new product since the actual (forward) engineering process needed to come up with a new product (real or imaginary) that comes after the educational reverse engineering method is already well understood, researched and documented and thus this doctoral research mostly considers out of its scope.

As seen above then, taking a commercial approach to try to replicate what is done in competitive intelligence laboratories for commercial gain but with a specific goal to learn from the process can also bring benefits for students of engineering design.

3.7 Resource Conclusions

Although creativity and innovation are highly desired traits of a design engineer, the mechanisms to develop them need to be properly contextualized so reasonable expectations about the specific contributions EREA can make towards their growth can be set.

In trying to clarify misunderstandings about creativity itself, author [Jirousek. 1995] stated for example, that a common misunderstanding equates creativity with originality “when in point of fact, there are very few absolutely original ideas”; she also stated that most of what seems to be new is simply a bringing together of previously existing concepts in a new way. Other authors such as [Pahl. 2005] stated that “It is accepted at face value that “novelty” is the prime measure of creativity. (and) We also know that novelty in design often occurs as a result of transfer of data, either inspired or rigorous, from outside the field of original expert knowledge. However to date we lack both simple explanations and appropriate tools for teaching the process of creative knowledge transfer to designers”, [Pahl. 2005]. Concerning misconceptions about innovation itself, and in trying to demystify economical success through innovation alone author [Kodak. 2008] stated that “innovation alone does not guarantee business success” and that “there is more to commercial success than an earth shattering innovation”. These past statements intend to show that expectations from EREA and from any other teaching tool for that matter, should always be properly contextualized so the actual added value new teaching approaches can actually bring is properly appreciated and understood so other researchers can also replicate it and benefit from it.

Still, and for the field of education it could be said that EREA do try to help students enhance their innovation and creativity traits by putting them in touch with multiple sources of inspiration from past and existing solutions relevant to the challenges they face. This resource then, has been included in this collection of resources to help engineering design professors form an opinion about the impact EREA could have in their students’ traits of innovation, creativity and invention and see if they find it worthy giving them a try under their existing teaching practices.

RESOURCE 4: BENEFITS OF REVERSE ENGINEERING

4.1 Resource Introduction

Despite being highly rated activities by engineering students and the fact that authors such as [Kutz. 2007] already consider the industry-specific learning and pedagogical benefits of reverse engineering as "obvious" it is important nevertheless to present potential adopters with the documented benefits that make EREA a viable tool in the teaching and learning of engineering design. The findings published by previous authors on the topic and those new ones resulting from the research leading to the writing of this collection of resources are highlighted, contextualized and discussed in this resource.

4.2 Documented Benefits of Educational Reverse Engineering Activities

Product dissection activities have been utilized already in a variety of engineering learning environments and their value as a pedagogical tool has been primarily supported by the published works of pioneering researchers in the area such as: [Sheppard. 1992a]; [Brereton et al. 1995], [Otto et al. 1998], [Hess. 2000], or [Wood et al. 2001] who have provided already, information about their respective course objectives; instructional approaches, outcomes, reviews, and the impressions of students and instructional staff while using them. In order to organize all available information though, other authors such as [Simpson et al. 2008], [Shooter. 2008] and [Dalrymple et al. 2011] have compiled lists of their uses and benefits, and also published historical accounts of the development of product dissection activities that have successfully engaged engineering students in their learning.

Tables 4.1 to 4.8 below, cover and explain those major categories of findings and benefits and present the reader with several claims that are related either to the practice or study of EREA. In such tables, the left columns categorise the documented benefits and claims; the central column provides a summarized explanation about the context in which the claim is stated, and the right column lists the representative researchers confirming the claimed results that show how EREA helped students. Namely:

A. Claimed Benefits of the Study and Practice of EREA in Relation to Industrial Practices:

Documented Benefits	Context	Source

Category	Claim		(First source is the main supporter of the claim and the rest have claimed similar ones)
Industrial	Similarities with industrial practices	Self-descriptive	[Kutz. 2007], [Otto & Wood. 2001]
	Better understanding of the contexts of reverse engineering	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Knowledge of trends and recent developments in key technologies	After the teardown of several common products one can notice the recent developments and trends in some key technology areas and perhaps make educated predictions on future hardware development	Findings from this research project

Table 4.1 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

B. Claimed Benefits of the Study and Practice of EREA in Relation to its Pedagogical Suitability:

Documented Benefits		Context	Source (First source is the main supporter of the claim and the rest have claimed similar ones)
Category	Claim		
Pedagogical Suitability	Value as Pedagogical Tool	Self-descriptive	[Dalrymple. 2009];[Brereton et al. 1995], [Hess. 2000], [Hess. 2002], [Otto et al. 1998]

			, [Sheppard. 1992a], [Wood et al. 2001]
	Overall learning enhancement	Self-descriptive	[Otto & Wood. 1996], [Carlson. 1995], [Kresta. 1998], [Aglan. 1996], [Catalano. 1996]
	Positive effect on learning through the combination of multimedia and hands-on	The authors report how the effectiveness of hands-on materials depend on the type of content the student is attempting to master and in cases where the material is abstract, the addition of hands-on experiences seems to provide an increase in learning potential	[Cooper. 1996], [Regan & Sheppard. 1996], [Sheppard & Regan. 1995], [Behr. 1996]
	Useful to teach a number of subjects (e.g. competitive assessment and benchmarking)	Self-descriptive	[Marchese et al. 2003], [Jorgensen et al. 1996]
	A touch of realism in the students' education	Self-descriptive	Findings from this research project
	Opportunity to experience professional practice situations	Author Dalrymple claims that "D/A/A activities show potential to provide the experience of "being an engineer;" providing experiences where students are encouraged to apply their knowledge to solve complex problems".	[Dalrymple. 2009]
	Exposure to other domains	It is said that Genrich Altschuler, the developer of TRIZ, (Theory of inventive problem solving), found out that in average, it takes about thirty years for a discovery in one field to appear in another [Savransky, 2000].	[McCartor, 2005]

		Author McCartor pointed out about Altschuler that "He stripped the context away from function to speed the process" by following that line of thought then, useful analogies can be drawn. McCartor for example also mentions that "Yoghurt and paint are both thixotropic fluids, which are fluids that become thinner the faster they are stirred. By thinking in terms of pouring a thixotropic fluid instead of thinking in terms of yoghurt or paint, it is easy to carry the means for pouring yoghurt over to pouring paint or vice versa" In this sense EREA ease the exposure of ideas and solutions from one situation to the next by familiarizing students with real life scenarios that might otherwise have been out of reach, thus complementing their education and benefiting from findings in other domains while at the same time helping students to keep their minds open to new ideas and remain creative.	
	Increase of student's positive perception towards dissection activities with reported greater workload sharing, team satisfaction and team viability	After introducing a dissection and redesign activity in an introduction to engineering design course authors Okudan & Mohammed reported such benefits with respect to the impact on students' design performance	[Okudan & Mohammed. 2008]

Table 4.2 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

C. Claimed Benefits of the Study and Practice of EREA in Relation to the Learning of Design:

Documented Benefits		**Context**	**Source (First source is the main supporter of the claim and the rest have claimed similar ones)**
Category	**Claim**		
Learning of Design	Helps students identify relationships between engineering fundamentals and hardware design	In authors' [Brereton et al. 1995] study for example, the identification of relationships between torque and power was achieved when analyzing a drill and evidence was provided to support this claim in: -Video (video studies and in situ ethnography) - Instructor Observations	[Brereton et al. 1995], [Brereton. 1998], [Hess. 2000],[Hess. 2002], [Lamancusa et al. 1996]
	Supports design learning	Evidence was provided to support this claim as: - Survey Data (Student perceptions) - Instructor Observations	[Burton & White. 1999]; [Devendorf et al. 2007],[Okudan & Mohammed. 2008], [Otto et al. 1998], [Wood et al. 2001] ; [Ogot et al. 2008]
	More self confidence with regard to disassembly of common products and devices	Self-descriptive	[Goff & Gregg. 1998]
	More interest in engineering	Self-descriptive	[Goff & Gregg. 1998]

	and design		
	Seeing engineering and design as fun, challenging, and rewarding activities	Self-descriptive	[Goff & Gregg. 1998]
	Application of a rich, diverse base of knowledge and experience to understand fundamental concepts	The authors found that dissection and design activities improved the understanding of fundamental concepts, in an apparent contrast to the clean restricted context in which most students learned about concepts in analytical classes or even routine laboratory experiments.	[Brereton et al. 1995]
	Provision of encapsulated design experiences	Author Samuel Andrew found out that his approach to the teaching of engineering design through ‘Make and Test’ projects which shares a hands-on approach with EREA provided the claimed benefits.	[Andrew. 2006]
	Experience with design synthesis	Author Samuel Andrew found out that his approach to the teaching of engineering design through ‘Make and Test’ projects which share a hands-on approach with EREA provided the claimed benefits.	[Andrew. 2006]
	Knowledge of the stages of the life-cycle of a specific design	Such knowledge can help unify dispersed knowledge and tie together courses that normally are perceived by students as unrelated	Findings from this research project
	Reuse information learned	It is reported that “little domain expertise is reused from the past” [Blessing & Chakrabarti. 2009] but in this sense, reverse engineering helps revisit old designs and designers thus keeping experiences and knowledge documented and alive	Findings from this research project
	Dissemination	Presentation of findings and results to	Findings from this

	of know-how that can lead to new and improved products	varied audiences	research project
	Creation of opportunities to redesign products	Because of the stages comprised in the method for reverse engineering analysis students get opportunities that help them exercise their skills in redesigning products (e.g. to increase quality or reduce costs)	Findings from this research project
	Allowance for new designers to build on the efforts of the original designers	After analyzing how others have solved design problems and constraints	Findings from this research project
	Opportunities to learn from past mistakes	EREA encourage students to find potential flaws in the original designer's logic	Findings from this research project
	Integration of new technologies into old designs	EREA encourage students to suggest or improve existing products in light of new technologies or information	Findings from this research project
	Opportunity to learn about design functions	Authors Wood, J. and Wood, K; state that by studying and dissecting machines (e.g. consumer products), the physical components may be directly experienced with all senses and then design methods may then be used to hypothesize current functions, and conceptualize new functions and/or solutions to the current configuration.	[Wood & Wood. 2000]
	Awareness of how consumer products are designed and marketed	According to author Wu, though reverse engineering exercises students get to see the products "through the eyes of the consumer while finding out at the same time that the same external function can be gotten with different mechanisms	[Wu. 2008]

		inside. When disassembling families of products, such as coffeemakers and single-use cameras, students can see how they are very similar inside, sharing the same basic structure and only with different features added"	

Table 4.3 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008]; [Dalrymple. 2009] and [Dalrymple et al. 2011]

D. Claimed Benefits of the Study and Practice of EREA in Relation to the Learning of Engineering Fundamentals:

Documented Benefits		**Context**	**Source (First source is the main supporter of the claim and the rest have claimed similar ones)**
Category	**Claim**		
Learning of Engineering Fundamentals	To couple engineering principles with significant visual feedback	By providing the opportunity to engage in hands-on activities. Evidence was provided to support this claim as: -Instructor Observations (mostly by author Barr at the Mechanical Engineering department at the University of Texas at Austin in the USA)	[Barr et al. 2000], [Lamancusa et al. 1996] ; [McKenna et al. 2008]
	To anchor knowledge and practice of engineering in the minds of students	Self-descriptive	[Sheppard. 1992a]; [Lamancusa et al. 1996], [Brereton. 1998]
	Gained understanding of how things work &	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]

	problems of engineering		
	Learning of how things are manufactured, fastened, etc.	After dissecting and observing how a product is made	Findings from this research project
	Improvement of drafting skills	Authors Sidler-Kellog and Jenison have stated in a study done to analyse reverse engineering in the design process that "students have tended to develop better sketching and drawing skills when they are interested in the objects they are working with" since they reported an "increased student interest in learning the graphics concepts introduced in this course when they can apply the techniques to real world situations"; Drafting is indeed one of the activities comprising an EREA	[Sidler-Kellog & Jenison. 1997]
	Learning of technical topics	In the words of author Wu "Reverse engineering exercises help students to learn how to measure performance, make drawings, sketches and to communicate technical information"	[Wu. 2008]

Table 4.4 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

E. Claimed Benefits of the Study and Practice of EREA in Relation to the Development of Personal Traits:

Documented Benefits		Context	Source (First source is the main supporter of the claim and the rest have claimed similar ones)
Category	**Claim**		
Development	Development	Such traits are considered desirable in	[Beaudoin & Ollis.

of Personal traits	of curiosity, proficiency, and manual dexterity (three desirable traits of an engineer)	an engineer and can be encouraged through learning-by-doing activities. The evidence provided to support this claim was presented mainly as: - Course Evaluation Data - Instructor Observations By authors Beaudin and Ollis at the North Carolina State University in the USA	1995]; [Hess. 2002], [Sheppard. 1992a]
	Learned how to work in a team	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Not afraid of taking things apart anymore	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Allowing students to find out "on their own" how to take products apart	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Learning how to use various tools	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Paying close attention to every step in the laboratory, in order	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Learning how to put product back together after disassembling	Reported value created through participation in product dissection laboratories	[Goff & Gregg. 1998]
	Enhancement of team problem solving	Author Samuel Andrew found out that his approach to the teaching of engineering design through 'Make and Test' projects which shares a hands-on approach with EREA provided the claimed benefits.	[Andrew. 2006]
	Enhancement	Author Samuel Andrew found out that his	[Andrew. 2006]

	of students' sense of success and self-belief (Growth of self confidence)	approach to the teaching of engineering design through 'Make and Test' projects which shares a hands-on approach with EREA provided the claimed benefits.	
	Establishment of student to student relationships	Because of the cooperative nature of EREA, they provide opportunities to establish student to student mentoring relationships.	Findings from this research project
	Interest in learning	In a study done to analyse reverse engineering in the design process, authors Sidler-Kellog and Jenison reported "an increase in interest in learning as they take possession of their product. Many teams perform beyond expectations and turn in reports that exceed the requirements provided to the students"	[Sidler-Kellog & Jenison. 1997]

Table 4.5 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

F. Claimed Benefits of the Study and Practice of EREA in Relation to Cognitive Development:

Documented Benefits		**Context**	**Source (First source is the main supporter of the claim and the rest have claimed similar ones)**
Category	**Claim**		
Cognitive Development	Increase of motivation and potentially improving retention	Achieved in part by giving students early exposure to functional products and processes (through dissection activities), and introducing such experiences early in the students' academic careers. Evidence	[Carlson et al. 1997], [Hess. 2002]

		to support this claim was given as: - Course Evaluation Data - Experimental nature	
	More engagement in the learning process hence retaining more	Self-descriptive	[Goff & Gregg. 1998], [Andrew. 2006]
	To provide starting points for design proposals, kinaesthetic, memory triggers, or thinking props	Self-descriptive	[Simpson et al. 2008]
	Enhancement of conceptual thinking	Author Samuel Andrew found out that his approach to the teaching of engineering design through 'Make and Test' projects which shares a hands-on approach with EREA provided the claimed benefits.	[Andrew. 2006]
	Enhancement of attention to detail	Author Samuel Andrew found out that his approach to the teaching of engineering design through 'Make and Test' projects which shares a hands-on approach with EREA provided the claimed benefits.	[Andrew. 2006]
	Learning transfer	According to author Dalrymple "Reverse engineering and product dissection, more broadly termed Disassemble/Analyze/Assemble (DAA) activities" are instructional practices that have shown potential in motivating students, as well as facilitating the transfer of learning beyond the classroom.	[Dalrymple. 2009]
	Enhancement of long-term retention of content	Self-descriptive	[Linsey et al. 2006]

Table 4.6 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the

Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

G. Claimed Benefits of the Study and Practice of EREA in Relation to the Awareness of the Engineering Design Process:

Documented Benefits		**Context**	**Source (First source is the main supporter of the claim and the rest have claimed similar ones)**
Category	**Claim**		
Awareness of the Engineering Design Process	Increase of awareness of the design process	Achieved through dissection activities	[Otto & Wood. 2001]
	Identify relationships among engineering fundamentals and product design	Self-descriptive	[Simpson et al. 2008]
	Growth in the design process	The integration of experiences into a cohesive continuous allows the growth in the knowledge of the design process beyond the increased understanding provided in each individual course.	Findings from this research project
	Bringing field experience to the classroom	EREA can help bring some of the field experience while still being students so they increase their awareness of the process and actual practice of engineering design.	Findings from this research project
	Link between dissection and design	In Sidler-Kellog and Jenison's research for example, faculty members that regularly taught the freshman design course were also asked to comment on their perceptions of dissection projects and they observed that "students are	[Sidler-Kellog & Jenison. 1997]

		better able to identify the steps of the design process when they are asked to complete an open-ended design project later in the semester. They can focus on the necessary design steps and have less difficulty establishing criteria and constraints for their new problem" and thus, "it appears that the dissection project is an effective introduction to design" [Sidler-Kellog & Jenison. 1997]	
	Filling of deficiencies in traditional design courses	In the courses at the University of Texas at Austin; The Massachusetts Institute of Technology and the United States Air Force Academy, reverse engineering was reported to be a critical step in the redesign process, and was incorporated in all their design courses, it was documented that reverse engineering helped fill the common deficiencies found in design courses, i.e., lack of hands-on opportunities that are interesting, intriguing and provided a platform that facilitated the integration of math, science and analytical skills with design	[Otto et al. 1998], [Wood et al. 2001]
	Existence of other solutions in design	Authors [Blessing & Chakrabarti. 2009] reported that at the concept generation stage of the design process designers seldom generate more than a few concepts, one of the reasons being a lack of awareness of (partial) solutions in other designs or domains; In this sense then, reverse engineering experiences can raise the designers' awareness of the existence of partial solutions while still being students thus helping them to consider a wider range of concepts that should not only help generate more innovative ideas but also to evaluate these using a wider set of relevant criteria.	[Blessing & Chakrabarti. 2009]

Table 4.7 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

H. Claimed Benefits of the Study and Practice of EREA in Relation to a Graduate's Career Path:

Documented Benefits		**Context**	**Source (First source is the main supporter of the claim and the rest have claimed similar ones)**
Category	**Claim**		
Career Path	Job Opportunities	After graduation, and because of the experience acquired during EREA, engineering design students could eventually provide professional reverse engineering services to established companies since they could outsource this sort of projects to a specialist thus keeping in-house personnel in their own design projects with the added benefits for both parties.	Findings from this research project

Table 4.8 Documented Benefits of Reverse Engineering and Similar Activities in Engineering Education, Expanded and Arranged for this Collection of Resources from the Works by [Jensen & Bowe. 1999]; [Simpson et al. 2007], [Simpson et al. 2008], [Shooter. 2008], [Dalrymple. 2009] and [Dalrymple et al. 2011]

From the assortment of tables listed above one can see that some of the core concepts of engineering design education can be taught through the exercise of educational reverse engineering activities, indeed authors such as [Simpson et al. 2007] have already stated that the interest in such hands-on activities and the "learning by doing" opportunities they provide has increased not only because the intellectual and physical experiences they give to students, but also because they have been successfully used in the past to help students learn.

4.2.1 Benefits at the Organizational Level of Introducing Educational Reverse Engineering Activities

Apart from the benefits shown above from Tables 4.1 to 4.8 for students participating in EREA, their introduction can also bring benefits to educators and host universities as explained below. Namely:

A. Benefits to Faculty:

- If a reverse engineering activity involves multidisciplinary analyses; the interaction among students and professors from other university departments can increase, and could lead to a greater coordination, integration and sense of community of the faculty

B. Benefits to the Department or the University:

-The prominent display in departmental hallways of successful reverse engineering projects can help to capture the interest of students and teachers from other departments, and also from the general public. This could increase the understanding of reverse engineering and of engineering design, and make students consider a continuous career in engineering.

-Positive feedback from the students' side regarding reverse engineering activities can increase the department and the university's opportunity to publicly and concretely demonstrate the value of the education the students are receiving. Authors [Jensen et al. 2003] for example, stated in their research that the reformulating of their existing design classes to include a reverse engineering/redesign component "has led to substantial improvements in course ratings" including "an immediate jump of 16% in student's ratings on the `intellectual challenge and encouragement of independent thought' and a 13% increase in the student's perception of the instructor's concern for their learning"

C. Benefits to Industrial Clients:

-Industrial sponsors or donors of equipment for dissection can gain a greatly enhanced exposure among students and the general public.

- Students with reverse engineering experience could present their skills to recruiters from benchmarking and competitive Intelligence companies.

-Additional to the benefits to faculty and host institutions, reverse engineering projects can also help to foster cooperation from research groups at partner universities or local companies. The study of the design principles materialized into existing products, and the potential to produce improved derivative products for example, are just two of the ways EREA can open venues for industrial collaboration and applications where existing industrial requirements could be handed to students to find a suitable solution.

The results presented in this section then, intend to present the reader with those documented benefits EREA have and that could be of relevance to the teaching of those interested in giving EREA a try.

4.3 Strongest Elements Educational Reverse Engineering Activities can add to the Teaching of Engineering Design

EREA are not a panacea for the teaching of engineering design, and for that matter, unfortunately no approach is; however they do bring unique learning experiences and add value to the teaching of it by helping students acquire and develop a given set of competence elements; abilities, skills, and attitudes to help raise their awareness of the design process; expand their sources of inspiration, and understand the impact of the designer's actions within the life cycle of a product. This section presents the reader with the compendium of those strongest elements where EREA work as a suitable vehicle to bring engineering design students a given competence element or learning objective into their education; such results are expected to guide professors and curriculum developers adopting EREA or the most representative aspects of them to better plan their learning activities and expected educational goals. In order to provide concrete evidence about which of the learning experiences unique to reverse engineering can add value to the teaching of engineering design and how; it is needed then, not only to acknowledge first what the experiences associated to reverse engineering actually entail but also to know what the desired/expected competences from engineering design students are, so the suitability of the specific learning experiences to achieve those competences can be evaluated; measured, analyzed and its results contextualized.

A number of studies have been conducted already to outline the competences and elements expected from studying and practicing engineers in general (and design engineers in particular) and that ensure a proper performance on the situations typical of their praxis, such type of research involves the interaction with practicing engineers; students; professors, cognitive psychologists, representatives from industry, as well as the definition and agreement of the involved parties on a variety of concepts such as competence, knowledge and skills. Table 4.9 below shows the lists of representative studies of that kind that were chosen for examination on “A Comparison of Competences Required in Reverse Engineering Exercises Versus Conventional Engineering Exercises and its Relationship to IPMA's Competence Baseline”, [Calderon. 2010b] which was one on the papers written along this collection of resources and that supported the creation of the content for the individual resource presented here. The items analyzed in those studies then, can be thought of as a comprehensive description of engineering practice pointing both to the human behaviour and the intellectual aspects of it. Such mix of papers and studies, intended to portray a manageable yet accurate picture of the competences of engineering design students and practitioners, both in their field and in the broader context of engineering and project management, which was chosen as an exemplary and common career path.

Name of Study	Reference
1. Trevelyan's Knowledge Descriptors	[Trevelyan. 2008]
2. ABET's Engineering Program Outcomes	[ABET. 2010]
3. Expected Qualities in a Design Engineer	[Sheppard & Jenison. 1996]
4. Taxonomy of Engineering Competencies	[Woollacott. 2009]
5. CDIO Syllabus	[CDIO Council. 2010]
6. TIDEE's Design Process Competencies	[Calkins et al.1996]
7. Desired Attributes of an Engineer	[Boeing University Relations. 2010]
8. Saeema's Categorization of Knowledge-Process	[Saeema. 2007]
9. ICB – IPMA Competence Baseline Version 3.0	[Caupin et al. 2006]

Table 4.9 Representative Studies on Engineering Design Competences, After [Calderon. 2010b]

The first step in such analysis was to acknowledge what the learning experiences of EREA actually entailed, so in order to come up with an unified understanding of the characteristics of EREA (e.g. Steps; areas of impact, methods, inherent cognitive processes, benefits, etc); a thorough analysis of existing literature was done, from which among other deliverables a comprehensive definition of what EREA were was obtained (shown here in Section 1.2.1); as well as what the reported benefits of them were (shown here in Section 4.2), and where they had been successfully used in the past (shown here in section 1.2.8.4), these results were all noted down and documented so they could be later presented for discussion and feedback to experienced professors and practitioners. All of the resulting information representing the understanding of what EREA were then, was later also evaluated against every individual item; learning objective and competence element included and recognized in the studies mentioned in Table 4.9 above as a desired/expected competence of an engineering design practitioner/student (206 elements in total) through a Likert-like suitability scale developed to rank and measure the correlation degree and suitability of EREA (and their potential) to achieve such competences. Such method which followed a cardinal approach, according to the definition by [Roozenburg. 1995], ranked alternatives by quantifying judgement of the effectiveness of the alternatives and the importance of the criteria on an interval scale, and was instrumental in coming up with the results shown further below in Table 4.10.

Higher Order Categories	**Suitable To:**
Engineering Design Process	Learn from previous designs for similar products
	Generate and evaluate alternative ideas and solutions when dealing with whole products or whole assemblies
	Document group activities, achievements, ideas, data, and other information in personal design journals
	Evaluate project information as to its relevance and values, matching local problems to the big picture
	Utilize appropriate design steps in solving open ended problems.
	Improve the knowledge required to define specific components including technical drawings and specifying manufacturing requirements
	Improve the knowledge required to analyze and verify a design
	Acquire the knowledge required to set up any necessary tests and be able to challenge results from a formal analysis
	Familiarize with documentation techniques to ensure a design complies with standards and legislation
	Practice the Managing of requirements and assessing the risk of these requirements not being achieved for each component
	Acquire the knowledge required to integrate the function of a component with other component or assemblies that share the function
	Practice investigative and diagnostic work to identify problems that could be applied to major quality failures for example
	Improve a design from a particular perspective, e.g., cost or quality, not necessarily employing a formal Design for the X method or tool

	Practice all kinds of engineering work (e.g. General, specialist, mixed with other work, non-engineering-specific work, etc.)
Engineering Practice Awareness	Raise awareness of the impact of engineering solutions; processes, methods and tools in a global; economic, environmental, and societal context
	Acquire a basic understanding of the context in which engineering is practiced along with a knowledge of contemporary issues in engineering
Systems Approach	Get a multi-disciplinary; systems, products & technology perspective
	Practice the design of a system, component, or process to meet desired needs within realistic constraints (e.g. economic; environmental, social, political, ethical, health, safety, manufacturability or sustainability)
	Think with a systems orientation, considering the integration and needs of various facets of the problem
	Understanding issues of importance to product success, including other engineering fields, e.g. psychology, aesthetics, etc.
	Practice the conceiving, designing, engineering ,implementing and operating of systems in the enterprise and societal context
Product	Ensure the physical integration and component interfacing of products so they fit together properly
	Represent the internal operation of machines and physical systems in several ways
	Define a product's complete list of parts and materials
	Find applications of products
	Operate the product
	Maintain; repair, remediate and modify products
	Disassemble and reassemble a product
	Know the failure modes of a product, find failure symptoms and signs of "trouble" with the product and use diagnosis methods for it
	Improve the value of products

Technology	Understand time and cost issues related to (rapid) prototyping of ideas
	Create new concepts and build up real hardware through hands-on technical work; basic machining, programming, construction, repair and technical work in the laboratory
	Provide product reviews by checking, testing and diagnosing problems
Information Collection	Improve information retrieval by locating required technical information in large amounts of mostly irrelevant written documentation
	Exercise resourcefulness to access relevant sources of information; engineering expertise, know-how and skills at all stages of the design process through the use of a variety of resources such as interviews to potential sources, effective database searches ,observing, questioning, etc.
Design For X	Improve knowledge not only of design strategies for the achievement of economic; neat, well structured, designs but also of the considerations for the product from its manufacture to its end of life (e.g. inspection, release, monitoring components for wear limits, service, etc.)
Assembly	Acquire knowledge of how the product will be assembled and of the assembly plans
Manufacturing	Get an understanding of design and manufacturing processes
Materials	Acquire knowledge of components' materials
Inter-Personal Interactions	Cooperate with other people in support of effective teamwork
	Perform the different team roles included in effective teamwork
	Coordinate and evaluate processes that affect team performance
	Communicate effectively in native and foreign languages
Adaptive Dispositions	To think critically; creatively, independently and cooperatively
	Engage in self-evaluation and reflection
	Promote self-development through experimentation, knowledge discovery and life-long learning
	Exercise personal and professional skills and attributes of written, oral, graphic and listening types.

Cognitive Development	Exercise skills in both right-brain and left-brain thinking
	Determine what type of analysis is appropriate in support of synthesis, evaluation and decision making
	Identify when analysis will provide insight into the quantification of a design or into the strengths/weaknesses of it
	Improve engineering reasoning and problem solving
	Familiarize with brainstorming, mind-mapping, visual thinking and kinaesthetic thinking
	Exercise analytical and conceptual thinking
Creativity	Exercise creative and intuitive instincts

Table 4.10 Strongest Elements Educational Reverse Engineering Activities can bring to Engineering Design Education (Rephrased as Action Verbs and Sorted under Fourteen Higher Order Competence Categories)

In summary, Table 4.10 above lists those elements expected from an engineering design student that can be acquired and exercised via EREA with a high degree of success, a conclusion reached based not only on their strong suitability rating resulting from the method used in this study to evaluate and rank them but also by independent confirmation through other researchers' documented experiences and published materials on the topic (cf. Tables 4.1 to 4.8). The table above then, can be considered as the compendium resulting from this research that best describes the elements that EREA can help tackle in engineering design education and that aims to present an accurate view of what EREA can best do in engineering design education. It is not implied here though that it is only through EREA that such elements can be acquired, only that EREA due to their nature, strongly fit the elements listed in Table 4.10 when considered as learning outcomes.

From the results seen in Table 4.10 then, it can be concluded that among all possibly expected competences of an engineering design graduate, EREA in their technical nature tend to rank better on those items dealing with the technical aspects of engineering design, while those "soft skills" competences related to behaviour and management, don't rank well enough as to consider EREA the only alternative to acquire and exercise these capabilities in students.

4.4 Added Value of Reverse Engineering Activities in Design Education

EREA are comprehensive, integrative activities that can bring new experiences to those that try them, from a students' perspective the added value EREA can bring to engineering design education comes from:

- The opportunity to engage in an exercise that simulates the type of practical experiences and knowledge developed by designers in real life projects; EREA
- The potential to exercise students/instructors/practitioners interaction through the exchange of experiences during a project and its preparation
- Getting early in career studies, the opportunity to acquire and develop, through interesting and engaging activities, some of the abilities required to lead a successful career in engineering design.

From the instructors' side what constitutes the added value from EREA is:

- Their suitability to exercise most of the expected competences of an engineering design curriculum
- Their ability to keep students interested and engaged in the activities; which can help them acquire new knowledge and learn on their own
- Their ability to produce "Transfer"
- Their suitability to reinforce engineering concepts through hands-on experiences

The different experiences EREA can bring to the learning of engineering design can complement the regular teaching of it and thus give students other type of experiences that are very close to those found during the actual praxis of design.

4.5 Resource Conclusions

In general, it can be concluded that reverse engineering activities in education help engineering design students to acquire and develop a set of abilities that raise their awareness and proficiency of the engineering design process, and they do so by enhancing the students' ability to learn from their predecessors in the safety of an educational setting that helps them understand the technologies they work with in order to gain confidence and practice in them. Listed next though are some specific conclusions regarding the benefits of four specific aspects of EREA, namely:

A. Educational Setting:

- EREA provide realistic; complex, hands-on experiences that can be safely repeated in a classroom until a desired goal is attained. The reinforcement and repetition of key information; as well as the free exchange of ideas, test results, and improvement proposals by all participating students helps to level differences in status, experience and knowledge among students.

B. Cognitive Development:

- It is clear that design engineers do not stop learning when they finish their studies, much of their learning actually comes while practicing design in their professional careers; by bringing that same practice to the classroom, EREA can help improve the lifelong learning experience of students of engineering design

- Reverse engineering activities help students to reason on multiple levels and look at problems from multiple perspectives, because of this, students can eventually have access to the reasoning rules in design and know how and when to break them

C. Potential Ramifications of EREA:

- Comparing similar technologies and solutions from different manufacturers thus catching up with the changing technologies relevant to an engineering design curriculum may indeed lead to academic or even commercial opportunities when suggesting improvements to the product under analysis

Breakthroughs may eventually come from students with good training and experience and thus, EREA as well as other educational tools that could bring benefits to their education should be tried and tested, in this regard the information presented in this resource has been compiled so potential adopters of EREA can get an overview of the latest findings in the area.

RESOURCE 5: A PROPOSED METHODOLOGY FOR REVERSE ENGINEERING ANALYSIS IN ENGINEERING DESIGN EDUCATION

5.1 Resource Introduction

A definite methodology for the educational reverse engineering analysis of consumer products that unifies all relevant fields of engineering design does not exist, there are however, tailored methodologies for the dissection of products in education such as those proposed by authors [Sheppard. 1992a]; [Lamancusa et al. 1996], [Otto & Wood. 2001], [Durfee. 2008] or [Lewis et al. 2011] shown here in Table 1.3. However, the varied differences among them justify the continuous research on the topic while still being possible to benefit from them by using them as a baseline for complementing research.

An approximation to that comprehensive, sought after methodology for the area of engineering design is proposed in this resource and it is one that is comprised of proved and tested analytical tools common to the subject area (e.g. Technical systems analysis, DfX analyses, engineering tests, etc.) as well as comprised of methodological tasks arranged in a such a way that allow for the sequential, accumulative analysis of a subject system (e.g. A consumer product). The methodology then, provides a natural path of progression in the analysis of consumer products for educational purposes and intends to help students understand how a given system came to be and why, while at the same time helping them to acquire and exercise relevant abilities to the area of engineering design.

The sequence of analyses and specific deliverables expected from each of the individual stages presented here, along with their contextualization and implementation of results into the field of engineering education design stem from the author's own experience in reverse engineering products as well as from the findings gotten after a thorough bibliographical analysis of other authors' experiences; approaches, rationale and published best practices in the area.

5.2 Conceptual Stages of a Proposed Methodology for Educational Reverse Engineering Analysis

The basic foundations of learning through reverse engineering analysis come from the cycle of analysis and synthesis inherent to human cognition cf. [Kant. 1781] triggered by an object of study as seen in Figure 5.1, such analysis-synthesis cycle is inseparable and it's in continuous interaction.

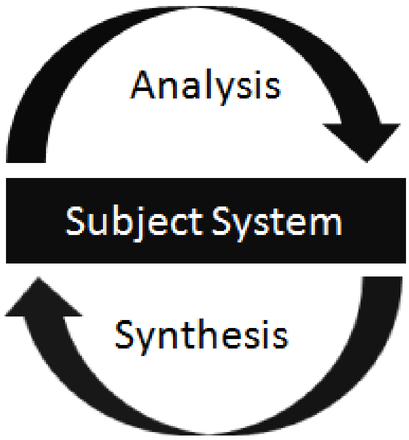

Figure 5.1 Cycle of Analysis and Synthesis while Analyzing a Subject System

Figure 5.2 below then, shows a conceptual methodology for an educational reverse engineering analysis based on said cycle comprising eight essential stages that allow an orderly analysis of a subject systems with a clear goal; start and ending of such activity.

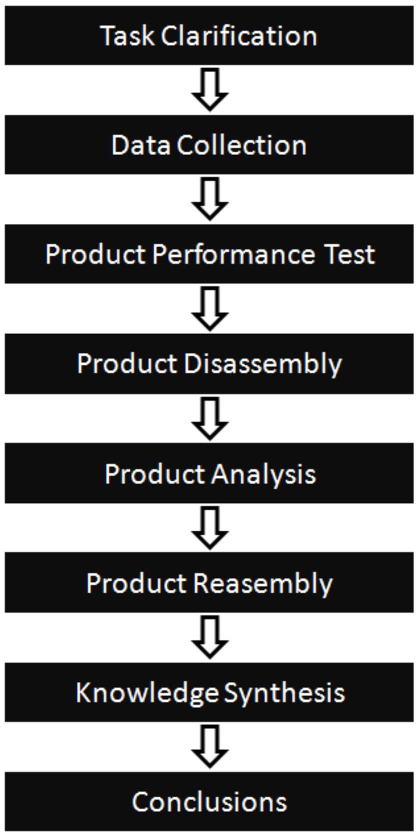

Figure 5.2 Essential Stages for an Educational Reverse Engineering Analysis

In line with the didactical approach of this collection of resources though, Figure 5.3 below shows an expanded version that comprises 14 stages that intend to reflect more accurately the real life inter-stage interactions and flows that enable a successful development of a reverse engineering analysis in an educational setting in the area of engineering design.

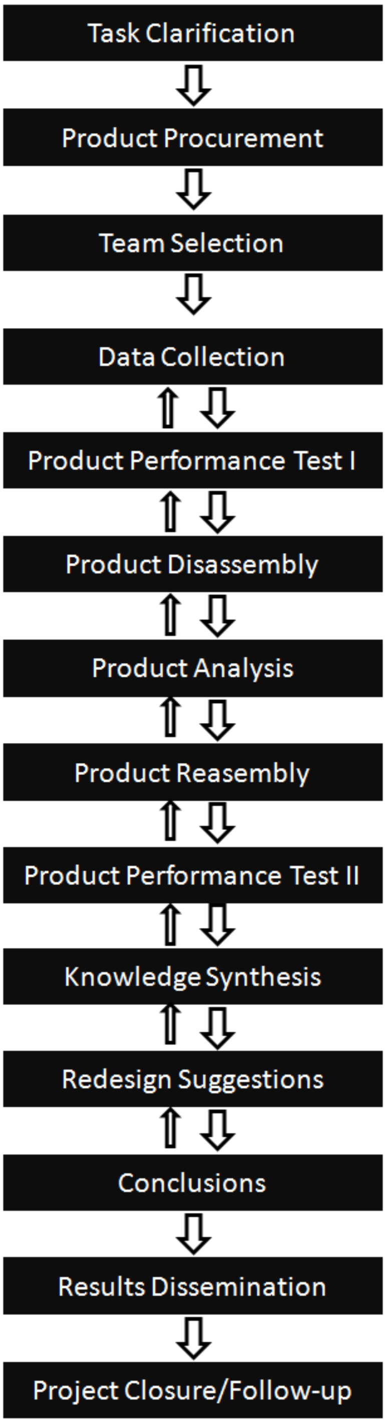

Figure 5.3 Conceptual Methodology for the Educational Reverse Engineering Analysis of a Consumer Product

Finally, Table 5.1 below shows the abovementioned methodology expanded with expected substages and deliverables, as well as the mapping of its individual stages to the phases of Kolb's cycle [Kolb. 1984] explained already in Section 2.3.1 and which is the learning model of choice in existing, published research to explain knowledge generation in educational reverse engineering.

Sequence	Stage	Substage	Representative Deliverable(s)	Stage Mapping to Kolb's Learning Model	Main Pedagogic Feature
1	Task Clarification	-.-	Understanding of the situation (e.g. Why, How, etc.)	Reflective Observation	Preparation of an EREA
2	Product Procurement	-.-	Selection of the product for analysis and the reasons for choosing it	Reflective Observation	Execution of an EREA
3	Team Selection	-.-	Assignment of roles for the execution of the exercise	Reflective Observation	Execution of an EREA
4	Data Collection	-.-	Gathering of all relevant information about the product under analysis	Reflective Observation	Execution of an EREA
5	Product Performance Test I	-.-	Understanding of performance specifications of the product under analysis	Concrete Experience	Execution of an EREA
6	Product Disassembly	-.-	Familiarization with the inner components of	Concrete Experience	Execution of an EREA

			the product under analysis and the way they achieve their functions		
7	Product Analysis	Recovery of the Product's Original Specifications	Evaluation of the product under analysis at a convenient detail	Active Experimentation	Execution of an EREA
		Digitizing, modelling and analysis			Execution of an EREA
8	Product Reassembly	-.-	Bringing of the product under analysis back to its original condition	Concrete Experience / Abstract Conceptualisation	Execution of an EREA
9	Product Performance Test II	-.-	Ensuring that the product meets the initial performance specifications	Active Experimentation / Abstract Conceptualisation	Execution of an EREA
10	Knowledge Synthesis	- Consolidation of all previous work assessing the different aspects of the subject system - Integration and organization of all available	Building of knowledge about the product under analysis through all collected data and information about it	Abstract Conceptualisation	Execution of an EREA

		information - Synthesis of all available data, information and knowledge - Contextualise of all resulting knowledge - Development of preliminary conclusions			
11	Redesign Suggestions	-Identification of weaknesses and improvement opportunities for the subject system -Suggestion of competitive, value adding changes to the subject system's design - Development and explanation of suitable improvement concepts for the subject	Improvement suggestions about the product under analysis and its associated design concepts	Abstract Conceptualisation	Execution of an EREA

		system 4. Prototyping or generation of a working model of your improvement concepts 5. Documenting and presentation of the stage findings			
12	Conclusions	-.-	Consolidation of all knowledge generated about the subject system	Abstract Conceptualisation	Evaluation of an EREA
13	Results Dissemination	-.-	Communication to interested parties of relevant information about the subject system and the findings in analysing it	Abstract Conceptualisation	Evaluation of an EREA
14	Project Closure/Follow Up	-.-	Setting of action to ensure information is not lost and reaches interested people over time	Abstract Conceptualisation	Follow up of an EREA

Table 5.1 Expanded Methodology for the Educational Reverse Engineering Analysis of a Consumer Product

One of the things that can be seen in the table above with respect to Kolb's learning cycle and its match with the sequence of the suggested methodology, is that it makes several passes or that it goes back and forth on certain steps of it, this is normal and it better reflects the real life applications of the cycle. The column at the far right of the table then, lists what the main pedagogical feature of the stage is which can be of a planning; execution, evaluation or follow up nature as explained in Resource 6

5.3 Conceptual and Procedural Explanation of the Stages of the Proposed Methodology for Educational Reverse Engineering Analysis

In the pages below, each stage of the suggested methodology will be explained to make clear the purpose; expectations, differences, deliverables and steps needed to accomplish them; each stage of the methodology indeed, is comprised of its own fitting analyses, tasks and questions and the answer to them provides a safe path to the achievement and goals set for an EREA

The individual tasks, questions and analyses to be performed on the subject system and shown further below then, are all considered standard ones in the area of engineering design and are deemed suitable for the stage where they are placed; they are however, not categorized by their specific area of knowledge (e.g. Analysis of technical systems, DfX Analysis, etc.) but rather grouped into higher order taxonomies (e.g. Analysis of: Materials; manufacturing processes, product architecture, etc.), this is in line with existing, published examples of reverse engineering and is done to remove one extra layer of complexity, so professors and students alike can more easily start a reverse engineering analysis with a lees steep learning curve; in an educational activity of this nature though, most of the results are expected to be narrative rather than numerical and their interpretation to be open depending on the experience and knowledge of the target students and the professor in turn.

The individual tasks, questions and analyses then, are placed at the stages where they better belong and intend to be of a sequential nature to convey the highest sense of order and clarity to the suggested methodology, in real life though, intra and inter stage interaction is expected to happen back and forth until a satisfactory understanding of the activity is attained, indeed even the transition between the stages themselves could be thought of as a zone of continuous transference rather than a clear cut division; this will mean two things, on one hand the cases where two or more of the stage tasks can be executed in parallel will be evident to the experienced reader, and on the other hand the completion of some tasks or the complete solution to certain questions will be unattainable at the suggested stage they are originally placed, since the expected, final result might require the tracking of flows or signals across several stages of the methodology to determine with certainty what is being looked for and thus, they should be left and retried further down the sequence of the methodology when complementing information becomes available. The decision to go ahead and consider individual, separate stages in the methodology proposed here then, was taken so students of reverse engineering give a conscious effort and properly focus on the specifics of each of the individual stages.

It is worth mentioning though, that just as the goals and levels of expectation from an EREA are set by the professor in charge, each task, question or analysis comprising the methodology here can be adapted to the specific needs of the target students, meaning for example that, any item can be chosen, skipped, rearranged or changed in the thoroughness of its execution in the methodology; and although the methodology is presented here for a maximum case scenario that covers all relevant, aspects of the reverse engineering analysis of a consumer product, professors should rest assured that just by having their students go through the core concepts of each of the stages of the methodology , their understanding of the subject system will still be enough to familiarize and learn something from it and thus have a higher chance to come up eventually with a suggested, improved version of it that isn’t that far off from and engineeringly correct and plausible redesign

Finally, it can’t be stressed enough that educational reverse engineering activities as envisioned in this collection of resources are not heavily, technically oriented where a numerical result is sought at any cost, but they are rather planned as an aid that supports the teaching of engineering design and helps students acquire and exercise design-relevant abilities in the process.

5.4 Stages of the Proposed Methodology for Reverse Engineering Analysis in Design Education

Although this resource (and the whole collection of resources for that matter) is directed to professors of engineering design the methodology shown below has been written in a style to address the one(s) executing the EREA (c.f. Undergraduate students of engineering design). Besides, the questions and tasks listed below are all of a generic nature in order fit any product under analysis, they can be seen though, specifically adapted to the example of an educational reverse engineering analysis of a Kodak™

single use camera that is later shown in Resource 7. In Resource 6 then, a suggested pedagogy on how to deliver the methodology shown in Table 5.1 above is presented to those professors of engineering design willing to give EREA a try.

5.4.1 Stage 1: Task Clarification:

5.4.1.1 Stage Purpose:

To plan the actions to achieve an understanding of the holistic context of a subject system's design by determining how it works and interrelates with humans and the environment.

5.4.1.2 Stage Tasks, Questions and Analyses:

1. Understand what you are about to do and foresee how it will be achieved

1.1 Write down the purpose, expectations and goals of the exercise

1.1.1 Establish the activity rationale: (e.g. The understanding and adequate representation of the subject system, from its detected need to its physical implementation)

1.2 Determine what constitutes a successful completion of the task

1.3 Determine the activities to perform through the activity

1.3.1 Plan for the execution of global analyses that include not only the technological aspects of your subject system but also the factors that affect its market success and customer's fulfilment (e.g. Technical; societal, safety, ethical, economical, environmental analyses, etc.)

2. Determine total duration and schedule of the activity

3. Plan for the allocation of resources needed to achieve your goal

4. Document stage findings; individual/group activities, achievements, ideas, data, and other information and explain how you performed the required steps in personal design journals

5.4.2. Stage 2: Product Procurement:

5.4.2.1 Stage Purpose:

To get a physical product from which something relevant can be learnt and a true hands-on experience can be had.

5.4.2.2 Stage Tasks, Questions and Analyses:

1. Select the subject system (c.f. A consumer product) for procurement and determine according to the characteristics of it what information in areas relevant to the learning of engineering design will be sought after and for what purpose

1.1 If needed and for purposes of contextualization of results also choose and procure a competing product or exemplary product component that aids in a comparative analysis

2. Procure the subject system(s) (e.g. Purchase or donation from sponsors)

3. If the product is still packaged, unpack it with care (e.g. Remove all seals and stickers) and record the steps and packaging materials in case you need to pack it again.

4. Inspect the product externally as a first contact with it, recognize its main function; features and form; in subsequent stages then (e.g. Performance Test I) the product will be fully experienced.

5. Start reflecting on the experiments and testing procedures for the product chosen which will be later implemented at the Product Performance Test I stage (e.g. Imagine at least two tests of a quantitative nature and another one of a qualitative one to discover how well the product performs its tasks and to characterize how it performs at different levels of inputs)

6. Prepare an initial assessment of the auxiliary tools needed for the disassembly, testing and reassembly of the subject system as well as any safety devices needed (but definitive information about this will become available at subsequent stages. Namely: Data Collection and Product Performance Test I)

7. Document product impressions; stage findings; group activities, achievements, ideas, data, and other information in personal design journals and explain how you performed the required steps

5.4.3. Stage 3: Team Selection:

5.4.3.1 Stage Purpose:

To assemble a team of people to accomplish the goal of the Educational Reverse Engineering Activity and assign roles and tasks accordingly

5.4.3.2 Stage Tasks, Questions and Analyses:

1. Devise the team skills needed to accomplish the activity’s goal and take actions to acquire them

1.1 Determine the professor’s functions to guide the activities

1.2 Determine the students’ roles in performing the activities

1.3 Plan for team members’ cooperation; participation sharing of information, communication and contribution to the project’s workload

2. Prepare a document showing division of labour and ground rules for an effective teamwork experience

3. Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution ,decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.4 Stage 4: Data Collection:

5.4.4.1 Stage Introduction:

This stage is about the collection of data that will serve as a baseline for future investigations about the subject system; to accomplish it, the tasks and questions further below are suggested and are expected to be answered by information collection alone.

5.4.4.2 Stage Purpose:

To collect all background and reference materials about the product under analysis to build information out of it and answer as many questions as possible about it before actually testing it and disassembling it.

5.4.4.3 Difference to other Stages of the Methodology:

This stage is different to the ‘Product Analysis’ one for example, in that in here the information about the subject system is obtained by information collection or indirect analysis alone without actually testing or disassembling the subject system whereas in subsequent stages further information is also obtained from its thorough physical manipulation.

5.4.4.4 Link to Other Stages of the Methodology:

There will be questions and tasks left only partially answered at the end of this stage, this is normal in reverse engineering analysis but the methodology provides ways to get further complementing information in subsequent stages (e.g. Product Performance Test I; Product Disassembly, and Product Analysis)

5.4.4.5 Students' Learning from this Stage:

Experience in information retrieval and interpretation

5.4.4.6 Stage Tasks, Questions and Analyses:

1. Prepare thorough analyses about the following areas of your subject system: (e.g. Primary needs to fulfil, Product type, background theory, description, usage environment, applications, etc.)

1.1 Assess and contextualize your subject systems' functionality

1.2 Investigate manufacturer's data about your subject system (e.g. Factory repair and service manuals; technical data handouts, published specifications, blueprints, technical journals, design catalogues, delivery instructions, design documents, design records, technical reports, CAD drawings, user manuals, brochures, online catalogues, , bill of materials , assembly drawings, parts list, etc.)

1.3 Prepare a market analysis of your product (e.g. Customers; stakeholders, surveys, benchmarking data, competition, marketing, parent company, inventor, export versions, availability, etc.)

1.4 Investigate about the Intellectual Property relevant to your subject system (e.g. Patents, licenses, norms, legal disputes involved, etc.)

1.5 Analyse the regulations applicable to the product under analysis (e.g. Applicable industry standards; codes and government regulations, statutory legislations, product liability, health and safety requirements, etc.)

1.6 Prepare a packaging and distribution analysis of the subject system (e.g. Packaging assessment; product storing, transporting, distribution and installing, visual design elements, advertising, graphic design, etc.)

2. Prepare initial analyses about the following areas of your subject system (Which will be later completed at subsequent stages of the methodology)

2.1 Document your initial impressions about the product under analysis

2.2 Prepare a technology level analysis of your subject system (e.g. State of the art in the field)

2.3 Assess the features of industrial design relevant to your product (e.g. Aesthetics, design influences, etc)

2.4 Prepare a social assessment about your subject system (e.g. Product's social context and impact on consumer habits)

2.5 Evaluate the historical timing of the product (e.g. Temporal perspective against competitors and trends, Generational nature of it meaning it is regularly updated and released to the market, etc.)

2.6 Investigate about the product's design development and history (e.g. Analysis of mock-ups, prototypes or other physical models)

2.7 Investigate about the product's manufacturing and production process (e.g. Mass production, made to order, etc.)

2.8 Prepare an ecological assessment on your product system (e.g. Reuse, recycling, etc.)

2.9 Prepare a user's safety analysis of your product

3. Study, understand and organize all background theory and gathered data about your subject system

4. Produce preliminary conclusions about the investigations associated to this stage (Note: The product has been neither fully operated nor disassembled at this stage)

5. Acknowledge how much available knowledge about the product exists and determine what further information about the product will be sought through other means in subsequent stages

6. As a last step of the stage and as an exercise in synthesis try to hypothesise and predict the product's work, functions, inner constructions and performance (e.g. Its main parameters), a task which will be properly performed and confirmed at later stages of the methodology (e.g. Product Test I)

7. Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution ,decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.5 Stage 5: Product Performance Test I:

5.4.5.1 Stage Purpose:

To develop an understanding of the functionality of the device

5.4.5.2 Stage Characteristics:

This stage is about the kinaesthetic knowledge of the subject system through its operation and testing

5.4.5.3 Stage Tasks, Questions and Analyses:

1. Prepare for product performance tests (e.g. Familiarize with the tools, measuring devices and basic safety precautions for the handling of the subject system and its testing equipment. verify if the product is safe to handle and operate, etc.)

2. Operate the product (e.g. Identify all user or product actions; determine the inputs, processes, outputs and feedback aspects of the system, the measured main performance parameters, and so on.)

3. Find out the boundaries of the main performance parameters of the product (e.g. Derive user requirements and customer needs, Evaluate its performance against competition, Attempt to discovery undocumented features of your product, Determine the maximum and minimum design parameters of your product, etc)

4. Assess the ergonomic and aesthetic considerations of the subject system (e.g. Appearance, feeling, simplicity, psychological aspects, etc.)

5. Assess the product's safety

6. Assess the product's durability

7. Develop a black box model of the subject system (e.g. Speculate about the system's internal properties and formulate hypotheses about how the system works, the functions of it and what you might find when disassembling it)

8. Consolidate, interpret, and contextualise all acquired data

9. Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution ,decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.6 Stage 6: Product Disassembly:

5.4.6.1 Stage Introduction:

This is a stage where the planning and execution of the inspection of the insides of the subject system is done in an effort to understand exactly how the product performs each of its major functions and thus achieve a better understanding of it

5.4.6.2 Stage Purpose:

To orderly access a subject system's inner assemblies and components in order to learn about its design

5.4.6.3 Major Activities from this Stage:

Setting up all resources for the disassembly; documenting, testing, measuring and controlling of the activity as well as developing hypothesis about the subject system and deciding the analyses to be executed down to an appropriate level that helps verify them

5.4.6.4 Background Information:

Most of the existing work on educational reverse engineering has been done in the area of product dissection, the ideas presented in the methodology; pedagogy and guided example of this document intend to expand on that seminal research and are based on the author's own experiences with the several aspects of the analysis and synthesis cycle inherent to an EREA

5.4.6.5 Link to Other Stages of the Methodology:

A varied number of tasks and analyses can be executed at this stage with the product in a disassembled state (e.g. those of a geometrical nature and relating to the assembly of it), however many of the analyses happening at the upcoming "Product Analysis" stage also benefit from having the product in that state (e.g. Analysis of materials and manufacturing processes involved), indeed no formal instructions to reassemble it are given in the methodology until the subsequent "Product Reassembly" stage and so it becomes necessary to keep it disassembled for several sessions/days to only reassemble it once the tasks required by the professor in charge are completed (e.g. Comparing the subject system to competitors) or a new stage in the methodology is reached; the planning of provisions for a proper storage that allows the protection of the product while still being able to pick up smoothly where you left the analysis in a previous session / day then, is strongly suggested.

5.4.6.6 Stage Tasks, Questions and Analyses:

There are no fixed guidelines for the disassembly of a product other than performing a step by step dissection that allows for a safe and traceable activity that later allows the successful reassembly and re-test of the product under analysis, the following tasks though, are presented in an order that has proved to be successful in attaining such goal in the past, namely:

1. Prepare for the disassembly process of the subject system (e.g. Select and procure the dissection tools and safety devices needed for the subject system, hypothesise about the inner workings of the product and how the various operations of it are performed; estimate how many parts are required to make the product, hypothesise on the materials and manufacturing processes of the parts you will find inside, etc.)

2. Set in place controlling and recording actions for an orderly disassembly process (e.g. Determine expected order of disassembly, access directions, orientation of product, any expected permanent deformation that may be caused by disassembly, etc.)

3. Disassemble the subject system to the agreed level of detail (e.g. Determine down to what level the subject system will be disassembled for analysis, in order to conduct supporting tests that allow the hypotheses about it to be verified or modified)

4. Generate a full set of measurements of your subject system (e.g. Materials; weights, dimensions of components, etc)

5. Prepare a full set of engineering drawings (e.g. One or two point perspective, 3rd angle projection, point and mesh clouds, etc.)

6. Create a comprehensive Bill-of-Materials (BOM) detailing relevant data about the entire subject system

7. Analyze your product’s architecture (e.g. By determining what constitutes an assembly and subassembly by following flows and signals of them, etc.)

8. Analyze the inner workings of your subject system (e.g. Identify the product components that function to allow each of the previously identified user (or product) actions of your subject system to occur)

9. Create thorough instructions for the disassembly of the subject system (e.g. Make a three dimensional computer animation that provides information about the sequence in

which the disassembly should proceed or a video providing support in disassembling the subject system)

10. Create thorough instructions for the reassembly of the subject system (e.g. Create a three dimensional computer animation that provides information about the sequence in which the reassembly should proceed or a video on how to reassemble the product under analysis)

11. Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution, decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps (e.g. Report if the dissection process of your product was destructive or non-destructive, compare what you expected to find inside the camera before and what you found during disassembly, etc.)

5.4.7 Stage 7: Product Analysis:

5.4.7.1 Stage Introduction:

This stage is about examining the product under analysis until the workings of it are known to a degree that allows the testing of hypotheses about it, to attain this, the execution of a number of design and performance tests common to the teaching of engineering design is suggested; indeed the technical analyses performed to a subject system for the purpose of a reverse engineering analysis (educational or not) have been previously devised by authors such as [Jounghyun. 1994]; [Musker. 1998], [Otto & Wood. 2001]; [Sato & Kaufman. 2005] and [Kutz. 2007] and in that sense this specific stage draws heavily on the work from past researchers and due credit is given wherever needed; however the specific mix of tasks and questions suggested below were handpicked from the findings of the abovementioned authors by following the guidelines detailing the competences engineering design students are expected to show during their studies and in their careers according to [Calderon. 2010b] where a number of papers and studies that portrayed an accurate picture of the competences of design engineers both in their field and in the broader context of engineering and project management were analysed. The items suggested for this stage then, provide a manageable yet accurate picture of what is desired to analyse about a subject system from a technical point of view while still helping students to reach their expected competence goals and professors their teaching objectives for the activity.

5.4.7.2 Stage Purpose:

To understand the actual workings and rational behind the creation of the subject system by exploring its mechanisms and component's interactions in order to confirm or revise the explanations of how things are put together and how they work.

5.4.7.3 Background Information:

For a long time, the sole technical analysis of a subject system as seen in this specific stage has been considered "reverse engineering" and indeed such stage requires special attention since it consumes most of the resources allocated for an activity of this kind. Traditional approaches to reverse engineering analysis rely on product development methods, however under the approach to reverse engineering presented in this document the rest of the stages of the methodology are equally important since they provide a comprehensive, multidisciplinary approach to what otherwise would be just a thorough technical analysis of a product, this indeed makes it a more inclusive methodology and one that is contextualized into the field of engineering design. In fact, the idea to engage in a comprehensive product analysis further beyond a purely technical analysis is an idea that has been around engineering education for a long time, author Kang, for example, suggested to research on the "global, economic, environmental, and societal issues" of a product under analysis [Kang. 2011] thus the methodology presented in this document intends to amalgamate those concerns, and complement with original results the work by previous researchers in the area.

5.4.7.4 Link to Other Stages of the Methodology:

In the previous "Product Performance Test I" stage for example, the subject system was tested as a whole as intended to be used by the customer whereas in this stage the individual parts/subsystems/assemblies inaccessible in previous stages can now be analysed from a different (e.g. Technical, scientific) perspective; additionally, it is in this stage where it is clearer that several tests are solved by a hands-on rather than bibliographical approach and thus they actually transcend their host stage, since they start early on the methodology but definite certainty of the results obtained can only be gotten at the last stages of it when further information and validation becomes possible.

5.4.7.5 Students' Learning from this Stage:

How to analyse a product from a technical point of view and to contextualize its visible data (e.g. After it is disassembled) in order to derive actual knowledge from it

5.4.7.6 Stage Tasks, Questions and Analyses:

The tasks and questions listed below are tailored not only to gain insight into the product's design but also to help students exercise their design-related capabilities, as they stand, they represent a valid but summarized version of what can be a fully fledged technical analysis, however, professors should still select from them only the analyses to be conducted by the target students, to what depth, their sequence (although a rough sequential order is provided already), and which ones to leave out according to their teaching needs, indeed no specific test is recommended over another since all of them provide relevant numerical data, it should be noted though that the answer to many of these questions and tasks by first year students might be of a narrative nature only (as opposed to a numerical one), this is normal and expected from students at the early stages of their careers.

1. Assume that some sort of design optimization strategies were considered in the design of your subject system (e.g. DfX)

2. Determine what data needs to be collected about your subject system (e.g. A full technical systems analysis of it or how the product works; its components, connections, how functions are achieved, etc.)

3. Plan the analysis of your subject system (e.g. Determine the approach to analysis (analytical vs. synthetic), Choose appropriate measurement techniques; tools, units of measure for the data to be collected, etc.)

4. Execute the analysis of your subject system down to the appropriate level to verify any hypotheses you might have about it

5. Analyse your subject system's overall construction (e.g. Structural features); compare it and contrast it to competing (older/newer) products (e.g. Mechanisms, structure and composition of objects)

6. Analyse and determine your subject system's architecture (types and examples; product modularity, modular design, clustering and functional methods, architecture-based development, etc.)

7. Asses your subject systems in terms of functionality (e.g. Embedded anti-counterfeiting measures or traps/locks against refurbishing, remanufacturing, recycling or disassembly by unauthorized entities, discuss alternative ways the product may be used or misused by customers, etc.)

7.1 Assess and document the full range of user experiences with the subject system

8. Execute a functional and systems analysis of your product and its components (e.g. System decomposition, Design Structure Matrix, Function Relation Analysis, etc.)

9. Determine the manufacturing process(es) and manufacturability of the product under analysis and provide a basic manufacturing process plan for it and its components (e.g. Identify your product parts' origins and availability (standard, off the shelf vs. unique construction))

9.1 Uncover a feasible sequence of assembly of your subject system

10. Assess and determine the materials comprising the subject system by a physical analysis and gathering of information about them (e.g. Critically appraise the choice of materials selected)

11. Assess your subject system's for compliance to DfX approaches and suggested design and usage guidelines

12. Assess your subject system in terms of quality and reliability topics (e.g. Perform a FMEA (Failure Mode and Effects Analysis))

13. Perform a life cycle assessment of your subject system

13.1 Asses your subject system's environmental design and ecodesign aspects (e.g. Perform a Life Cycle Inventory analysis of the subject system such as the one suggested by authors [Comparini & Cagan. 1998])

14. Consolidate your work analyzing the societal, technical and economical aspects of your subject system (e.g. By following authors [Devendorf et al. 2011] recommendations for the analysis of factors that influence the design of a product)

15. Confirm if the product's design complies with ethics (e.g. Social responsibility), standards and legislations of the target markets (e.g. Assess your product in terms of safety, liability, ethics and standards of practice issues)

16. Benchmark your subject system against competing or generational designs of itself (e.g. Determine what are the features of the product that make it competitive)

17. Obtain competitive intelligence data about your subject system (e.g. Comment on the impact of engineering processes, methods and tools that allow a product like the one under analysis to exist)

18. Execute a design critique of your subject system by assessing the degree of refinement of its design (e.g. Determine if the subject system was designed to meet the desired needs of the target customer within realistic constraints such as economical; environmental, social, political, ethical, health and safety, manufacturability, and sustainability ones))

19. Explore your subject system's design influences (e.g. Asses your product's main design philosophy and criteria)

20. Analyse your product's design and development process (e.g. Speculate about possible alternative solutions or trial designs undergone to come up with the current product (evaluate alternatives based on scientific/engineering principles))

21. Analyse the workers' actions in the manufacturing of the subject system (e.g. Speculate how you think they were trained and for what purposes)

22. Analyse the overall realization process of your subject system

23. Recover, develop and report potential PDS (Product Design/Data Specifications) a.k.a "Requirements List" about the product under analysis (e.g. by leveraging from author`s [Musker. 1998] research in this area and also by generating engineering functions and specifications about your subject system (as suggested among others by authors [Otto & Wood. 2001]))

23.1 Assess the performance requirements of the subject system (e.g. Function(s); appearance, reliability, environment, ex-works cost, ergonomics, quality, weight, noise, etc.)

24. Create a computer / behavioural model of your subject system (e.g. Metric ranges; simulation, optimization, spread sheet applications, example models of cost, heat transfer, stress, strength, life cycle, assembly and so on, as suggested by [Otto & Wood. 2001])

25. Research on potential diagnosing actions and strategies for your subject system (e.g. Devise diagnosing and maintenance actions and strategies for your subject system such as how to provide reparation; support, tuning, change services and so on)

26. Determine the logistics associated to the creation of the subject system (e.g. Procuring components and materials, storage, logistics, transport, etc.)

27. Consolidate your work assessing the different aspects of the market and marketing of your subject system (e.g. Assess your product's actual market success or failure)

28 Assess the varied aspects of the installation and operation of the subject system

29. Assess the relevant electromagnetic aspects of your subject system (e.g. Its interaction with other electronic devices without affecting them or the users)

30. Try to explain how your product fits as per the customer requirements based on Kano's model of customer requirements (i.e. Normal, expected or exciting requirements), cf. [Kano et al. 1984]

31. Assess if the subject system is a generational device (e.g. Products that feature cumulative system technologies such as hard drives)

32. Determine if the design of your product uses an existing spatial variation of a known principle and if so, how

33. Analyse the subject system's state of novelty/obsolescence (e.g. Think about possible scenarios that could make the subject system obsolete)

34. Document the ununderstood features of the subject system up to this point to be tackled at subsequent stages of the methodology (e.g. Propose hypothesis about your subject system to be finally tested at the "Knowledge Synthesis" stage of the methodology)

35. Validate and verify all analyses performed up to this point in preparation for the next stage of the methodology

36. Secure a sound theoretical framework to identify and explain what the subject system actually accomplishes and its solution principles

37. End the stage once a satisfactory specification of the subject system is created

38 Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution, decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.8 Stage 8 Product Reassembly:

5.4.8.1 Stage Introduction:

The purpose of this stage is twofold on the one hand it is to return (as much as possible) the subject system back to a fully functional state in preparation for the subsequent stages of the methodology and on the other it is to help students contribute towards the completion of their cycle of learning as suggested by Kolb's cycle [Kolb. 1984] via the hands-on work and visual feedback when reassembling the device.

5.4.8.2 Stage Purpose:

To return the disassembled device back to its original state in preparation for the subsequent stages of the methodology while providing students with a chance for a complementing hands-on experience with the device

5.4.8.3 Background:

Reassembling the product under analysis is indeed an integral part of an EREA not only because it makes students conscious about the consequences of careless disassembly actions but also because it is an activity that helps them learn how to keep their hands-on activity under control.

5.4.8.4 Stage Tasks, Questions and Analyses:

1. Acknowledge if before reassembling the subject system there are unusable or missing parts and plan for remediation actions (e.g. Jumping directly to Stage 10 "Knowledge Synthesis" altogether)

2. Reassemble the subject system back into a functional state in preparation for the next steps of the methodology

3. Consolidate your work on writing and refining product reassembly instructions that others could follow (e.g. For future readers of your work)

4. Research on how the subject system was assembled and on its plausible assembly plans and compare them to your own experience reassembling it (e.g. Determine what features of the product make it easy or hard to assemble)

5. Keep track of the steps required for reassembling the subject system and think about what type of machine could be (was) used to automate the assembly step.

6. Compare your disassembly and reassembly times and procedures and analyse and report the reason for the differences

7. Superficially examine the proper operation of the reassembled system in preparation for full tests of it at the “Product Performance II” stage

8. Straighten out your work space after the stage is done

9. Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution, decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.9 Stage 9: Product Performance Test II:

5.4.9.1 Section Introduction:

This stage is about testing if the subject system was successfully brought back to its original state, such action is more important than it might seem at first sight since students get a great sense of reassurance and accomplishment when proving themselves capable of restoring the product back to working conditions, it means to them (among other things) that no pieces were damaged or lost during the previous stages and it effectively confirms that the previous stages of the methodology were carried out successfully.

5.4.9.2 Stage Purpose:

To confirm that the previous stages of the methodology were carried out successfully by testing if the subject system is still fit for future users/uses of it while at the same time getting a chance to complete the sequence of learning suggested by author Kolb’s cycle, cf. [Kolb. 1984]

5.4.9.3 Background Information:

The reassembly and restart of a product helps uncover new information about it that would be very difficult to get otherwise specially in those cases where a destructive analysis has to be avoided or if the product counts with anti tampering and anti reverse engineering measures, if students had to actually defeat anti tampering measures (e.g. by not damaging the photographic film in a disposable camera by disassembling the camera in a dark environment) not only did they understand the workings of product but also learned to operate around it, effectively becoming expert users of the subject system.

5.4.9.4 Link to Subsequent Stages of the Methodology:

In terms of complying with Kolb's learning cycle, cf. [Kolb.1984] this stage gives students the opportunity to experience a stage of "Abstract Conceptualisation" and "Active Experimentation" of the published cycle (Concrete Experience -> Reflective Observation -> Abstract Conceptualization -> Active Experimentation) effectively "closing the circle" of learning suggested by author Kolb while at the same time getting the students ready for the subsequent stages of the methodology

5.4.9.5 Main differences to other stages of the methodology:

The past Product Performance Test I stage for example, was about getting concrete experience with the product whereas this Product Performance Test II stage is about closing the Kolb's learning cycle, thus complying with his advice for a complete learning experience while testing at the same time the subject system for future applications of it.

5.4.9.6 Stage Tasks, Questions and Analyses:

1. Acknowledge if the subject system can be tested at all (e.g. In case the product underwent a partially destructive analysis) and plan for remediation actions (e.g. Jumping directly to Stage 10 "Knowledge Synthesis" altogether) or else continue with the stage steps

2. Report if you attempted to adjust/improve/repair any part of the subject system during its disassembly/reassembly

3. Test the performance of the reassembled product, and compare the results to those obtained prior its disassembly

4. Describe the operational capabilities of the product after reassembly

5. Assess and report the limitations of manufacturing processes and materials chosen, in trying to achieve a given product performance

6. Report if after operating and analyzing the subject system you'd be able to detect failure symptoms or signs of "trouble" with it and why

7. Consolidate your work on benchmarking the performance of your subject system against competition

8. Store the subject system and auxiliary tools needed during the stage once it is finished

9. Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution, decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.10 Stage 10 Knowledge Synthesis:

5.4.10.1 Stage Introduction:

This is perhaps the most important stage in a reverse engineering analysis since it is here where all past data is made sense of and contextualized in the search of an understanding of how the subject system came to be and why; in fact every past stage of the methodology has brought new knowledge to the intermediate stage results of it and so it is actually at this stage when one is certain of what is actually known about the subject system and what isn't; the tasks to perform listed below and that aim to attain the understanding of the subject system can be clearly differentiated as those concerning the consolidation, organisation, synthesis, contextualization and development of preliminary conclusions from all available results obtained so far; the steps comprising this stage then, have been made individually explicit in this document in order to study them and focus on their particularities, but in real life and as mentioned already they form a continuum of actions where transitions and boundaries among them rather blur

A. Step 1 'Consolidate all previous work assessing the different aspects of the subject system'. This task is self describing and it is not only about unifying all information obtained throughout the past stages of the methodology but also revisiting any aspect of the subject system where new relevant information had become available up to this point and be worth taking into consideration to help fill any knowledge gap in the reverse engineering analysis of the subject system

B. Step 2 'Integrate and organize all available information'. The purpose of this step is to facilitate the development of a synthesis – contextualisation cycle and it is needed in this stage given that an effective reverse engineering analysis calls for the consideration of varied perspectives, domains and use of existing data from design repositories, thus strengthening the need to integrate and organize it all in semi formal data structures or major domain categories initially, but preferably at a later time in formal data structures, so that a clear arrangement is made for representing the various types of design information available so far, and where specific data can be easily found or retrieved from a structure that allows for a modular; rational, collaborative and systematic analysis to interpret and contextualize whatever data had been obtained during past stages of the methodology.

C. Step 3 ‘X. Synthesize all available data, information and knowledge’. The purpose of this step is self explanatory since there is an impending need to make sense of all data and information collected throughout the analysis stages and turn it into usable knowledge that helps uncover the history of the subject system (cf. Its design plan) and its design rationale. In fact in the reverse engineering analysis of design information, two aspects can be distinguished which in the end converge and turn out to be one and the same, one is the analysis for the purpose of understanding the inner workings of the subject system itself which includes for example, the obtaining of raw performance data; the functional analysis of it and of the manufacturing processes undergone to achieve its final form whereas the other aspect is the reconstruction of the product’s design history which is expected to yield information about the design process, its tradeoffs between design; manufacturing and production, and of course the actual rationale behind the product (e.g. Socio-economical, technical and ecological). indeed design plans and design rationales are both individual topics of research on their own right and yet the method of synthesis-contextualisation presented at this stage analyses them individually and ultimately unifies both of them and their results in an approach that is valid for the specific context and goals of an EREA thus amalgamating existing findings in the area and takings the best parts of them to suit the educational goals of an EREA. By following the sequence of tasks suggested here and covering the points they mention, the students will naturally go through a process of synthesis of all available information which is based and supported by existing theory and past examples that have taken a similar sequence of actions under similar reasoning grounds.

D. Step 4 ‘Contextualise all resulting knowledge’. This stage is about putting all knowledge about the subject system in perspective either to reinforce the already known aspects of it or to aid in the proposal of new hypotheses to solve the still ununderstood aspects of the subject system, in this sense the main tasks to develop concern the contextualization of all resulting knowledge about the subject system and the demonstration of the level of understanding about it, for example, by answering a battery of questions and tasks provided in this document and that encompass and represent the ideal of understanding to strive for, at the end of this stage

E. Step 5 ‘Develop preliminary conclusions’. The focus of this step is twofold, on the one hand it is about drawing conclusions about the progress in the knowledge of the subject system and on the other about documenting and analysing your personal impressions about the full reverse engineering process in regards to your own learning.

5.4.10.2 Stage Purpose:

To turn all data and information available about the subject system into usable knowledge that helps to come up with a reasonably comprehensive and accurate picture of its design history and rationale

5.4.10.3 Background:

Knowledge synthesis in support of analysis processes is a thriving area of research where several theories try to explain how cognition works, for such reason coming up with the analysis-synthesis-contextualisation sequence presented in this document involved the thorough examination of existing methods dispersed across varied domains in an effort to pick the findings that best suited the area of engineering design education. This collection of resources acknowledges previous research on the topic of knowledge acquisition such as that of authors:[Gruber & Rusell. 1992], [Jounghyun. 1994], [Khandani. 2005]; the research on a product's character by [Ashby. 2005]; the seminal work on reverse engineering theory by [Chikofsky & Cross. 1990], the methods for interpretation of information by [Blessing & Chakrabarti. 2009], the techniques for knowledge acquisition by [Grosso et al. 1999], the uses for a design rationale by [Burge & Brown. 1998], the research on exception handling operations in the design processes by [Tomiyama. 1985], the contextualization of data through the reasoning framework "Inference to the best explanation" identified by [Harman. 1965] and the studies on the traits of successful explanations by [Fogelin. 2007], due credit is given to them as the main source of reference for the method presented in this stage which aims to be properly suited and contextualized to the teaching of reverse engineering in the area of engineering design education at academic institutions all over with undergraduate programs and higher.

To the potential surprise of the reader might be the fact that conjectures do have their rightful place in a reverse engineering analysis. Knowledge about a subject system is traditionally acquired through the inspection, experimentation and research about it, however, when reaching a wall and not knowing where to go anymore in the analysis of a product; no additional information about it can be obtained, and problem solving heuristics have already been used, it is ok to conjecture about it. Indeed, because of the very nature of reverse engineering there will always be knowledge gaps in the analysis of a subject system; in cases of conflicting information in the analysis of it then, changes to the information taken for granted or a return to a coarser level of detail in the analysis of a subject system should help carry on with the reverse engineering analysis even if inconsistencies show up; every step accomplished in a reverse engineering analysis though, should be validated to the best of students' understanding based on the available information at that moment. In the end, there should be a strategy at hand to handle the domain knowledge gaps likely to be found during a reverse engineering analysis and the methodology presented further below presents the students with some options.

5.4.10.4 Relationship to Other Stages of the Methodology:

Up to this point, stages of a 'technical' and 'hands-on' nature have helped gather as much data as possible about the subject system in preparation for the conduction at a later time of a proper analysis and contextualization of it (e.g. By connecting all pieces of information and extracting some actual knowledge from it); it is true though that at this point in the methodology the dissection of a product, its analysis and the knowledge synthesis from it could occur simultaneously in real life, specially so in the case of experienced students; still and in order to guide a proper didactic experience each process has been given its individual stage in the methodology proposed here so a separate conscious effort for each individual stage is made by students thus targeting all their levels of experience and depths of planned analyses. In regard to Kolb's learning cycle [Kolb. 1984] and continuing with the closing sequence started at the past stage, this one is of an 'Abstract conceptualization' nature too and provides a culmination point to the cycle effectively providing students with the support to come up with feasible improvement suggestions to their subject system throughout the following stages

5.4.10.5 Difference to Other Stages of the Methodology:

Although some testing and interviewing could still be done at this point, this stage is conceptually at least, of a purely mental nature, meaning that the development and exercise of the students' cognitive processes of synthesis and contextualization is of paramount importance in the search of the knowledge (both technical and non technical) about the subject system that will actually help understand its design history and rationale

5.4.10.6 Stage Tasks, Questions and Analyses:

The following tasks, questions and analyses intend to guide you throughout this stage in a way that allows you to synthesise and contextualise all available data about your subject system in a natural manner; the algorithmic approach and sequential nature of the tasks themselves can be considered a very practical shortcut to a thorough more complex synthesis process and it was derived as a specific application for the teaching of reverse engineering in the area of engineering design from research previously done on the field of knowledge engineering, the items suggested below then have been fitted to meet the goals of an EREA and represent the kind of knowledge expected to get from it

1. Consolidate all previous work assessing the different aspects of the subject system:

The following areas for example are relevant to mention (but you should not limit yourself to them only) and have all been investigated throughout the past stages of the methodology already, however it is worth revisiting them at this point in order to add any newly available information that helps continue with the reverse engineering analysis of the subject system, namely: advantages, aesthetics, assembly, competition, competitive intelligence, constraints, design and development process, diagnosing, disadvantages, environmental design, electromagnetic, ethical issues, evolution, functional analysis, functionality, history, industrial design/ergonomics, life cycle, logistics, maintenance, manufacturing, marketing, materials, mechanics, modelling, operation requirements, performance, PDS (Product Data Specifications), production, quality management, realization, safety and liability, socio-economical issues, standards and legislations, market success/failure, suppliers, systems, technology, usability, etc.

2. Integrate and organize all available information:

2.1 Gather all available data, information and knowledge about the subject system (e.g. Patents; domain models, domain theories, residual evidence; performance tests, design, manufacturing process, patents, manufacturing marks, domain specific representations to describe behaviour, etc.)

2.2 Organise all available information so far to facilitate the analysis-synthesis process of this step

2.2.1 Organise all data collected in Product Data Specification (PDS) categories to further expand those categories for investigation and subdivision of tasks

2.2.1.1 Position the product's information obtained from the analysis, according to the design stage where it generated (e.g. By following authors' [Buura & Myrup. 1989] examples)

2.3 Integrate all available information to facilitate the upcoming synthesis-contextualization process of this step

2.3.1 Integrate from several sources and disciplines all relevant data, information and knowledge about the product under analysis in semi formal data structures or major domain categories initially, but later in more formal structures (e.g. In a "knowledge worksheet")

3. Synthesize all available data, information and knowledge:

3.1 Devise a strategy to get a reasonably accurate and realistic reconstruction of how the design of the subject system went and why (e.g. By following authors' [Blessing & Chakrabarti. 2009] advice on how to interpret all available information, or by following the steps listed below)

3.1.1 Become familiar with the problem domain (e.g. How to turn all available data into usable knowledge)

3.1.1.1 Identify the major domain concepts

3.1.2 Characterise the reasoning tasks necessary to solve the problem

3.1.2.1 Identify the reasoning strategies used by experts

3.1.3 Categorise the type of knowledge necessary to solve the problem

3.1.4 Define an inference structure for the resulting application that solves the detected problem

3.1.5 Acknowledge how much available knowledge about the subject system exists up to this point and assimilate it

3.1.5.1 Take new information from diverse sources and effectively integrate it with previous knowledge

3.1.5.2 Assimilate the operation of the subject system in the overall scheme of things

3.1.6 Identify and understand the structural and functional relationships among the Data/Information/Knowledge triad (e.g. Resulting from the analytic tools, cognitive processes and measurements obtained from your subject system)

3.1.7 Identify and determine what kind of scientific study method can be appropriately used to support the synthesis – contextualization process of this stage

3.1.8 Extract ideas from differences found from a wide range of viewpoints and various types of analysis and evaluation

3.1.9 Derive information about the product under analysis by triangulating data; conjectures and knowledge of the theory behind it and its real life implementation

3.1.9.1 Supplement disperse information and product production evidence with conjectural reconstruction of your own

3.1.9.2 Discern or deduce design details through educated assumptions and results from engineering analyses done on your subject system

3.1.9.3 Put forth educated assumptions regarding the subject system

3.1.10 Retrieve design information by comparing the subject system's proposed PDS (Product Data Specifications) against their actual implementation (e.g. By following author's [Tomiyama. 1985] findings)

3.1.11 Make use of simple enumeration or descriptive statistics to help interpret existing information about the subject system

3.1.12 Select and refine probable design ideas and concepts using appropriate qualitative and quantitative techniques (e.g. brainstorming, decision matrix, and economic analysis)

3.1.13 Prepare to perform estimations, qualitative analyses and start the synthesis-contextualisation process of this stage

3.1.14 Whenever possible meet with qualified people who can help contribute to specific problem resolutions and discuss the results of your synthesis-contextualization process

3.1.15 Link all findings regarding the subject system

3.1.15.1 Identify from existing information about the subject system correlations and possible causal relationships

3.1.15.2 Find explanations and draw inferences from existing information about your subject system

3.1.15.3 Put forth Inferences about causality (but look for evidence of time order between concepts; covariance between concepts; and exclusion of rival factors (spurious relationships))

3.1.16 Reduce at the earliest possible moment the huge theoretically admissible, but practically unattainable, number of solutions and design actions leading to the final materialization of the subject system

3.1.17 Formalise the resulting strategy from this step in a generic and reusable way

3.2 Synthesize all available data and information about the subject system (e.g. From its mathematical modelling; metrics of DFX tests performed, etc.) in order to acquire knowledge from it and uncover the history of the subject system (e.g. Its manufacturing, distribution, etc.) and its design rationale (e.g. The design process and why it came to be the way it is)

3.2.1 Question and interpret every aspect of the design of the subject system given the available information

3.2.2 Assume that everything in the subject system is there or was done the way it was for a reason

3.2.3 Assume (for later verification or refutal) that the final design of the subject system is optimal and carefully thought

3.2.4 Make educated generalizations about products of its kind and adapt them to your own subject system

3.2.5 Apply techniques for knowledge acquisition from the discipline of knowledge engineering such as those suggested by [Grosso et al. 1999]

3.2.6 Apply systems thinking to synthesise all information about your subject system

3.2.7 Draw inferences from the particular representation of data obtained for your product under analysis

3.2.8 Make use of problem solving techniques (e.g. As in open ended problems) to synthesise all information about the product under analysis

3.2.9 Make effective use of brainstorming; mind-mapping, visual thinking, kinaesthetic thinking and other related techniques for the generation of ideas to make sense of it all and to aid in the synthesis process

3.2.10 Draw valid inferences about observed things (but as mentioned above, avoid spurious relationships)

3.2.11 Conjecture and derive partial explanations and design information about the design of your subject system based on available data (e.g. effects in functions, costs, etc.)

3.2.12 Come up with a plausible account and explanation of the subject system's design history (e.g. The actual design, engineering, manufacturing and distribution actions, a.k.a design plan/design process) by leveraging from author's [Jounghyun. 1994] research on the reconstruction of default design plans for product analysis by using default knowledge or alternatively by following the steps listed below

3.2.12.1 Make use of all collected resources about it (e.g. Empirical tests; your own reverse engineered data, design for assembly techniques, etc.)

3.2.12.2 Speculate on plausible project planning actions in the design of your subject system (e.g. Use of critical path methods; scheduling, methods of work organisation, design reviews and project management techniques)

3.2.12.3 Suggest an initial representation of the design plan of the product under analysis

3.2.12.4 Propose a possible design plan for your subject system

3.2.12.5 Suggest a sequence of probable design actions that could have happened during the actual design process of the subject system

3.2.12.6 Identify design events in your subject system and understand how they interrelated with each other

3.2.12.7 Associate available pieces of knowledge and reasoning processes to each listed design action

3.2.12.8 Track back specific design problems / particularities / features of your subject system and map them to the corresponding stages of its engineering design process

3.2.12.9 Find possible design patch-ups in you subject system

3.2.12.10 Determine if optimization strategies (such as DfA) are applied to the portions of design of your product which exhibit minimal kinetic behaviour (as suggested by author [Jounghyun. 1994])

3.2.12.11 Relate to the best of your understanding all available information into a coherent, realistic, preliminary design plan

3.2.12.12 Try to reconstruct your subject system's manufacturing and distribution history

3.2.12.13 Refine your design plan by soliciting and aggregating further design information from specific sources or by going through problem solving heuristics (if not done already)

3.2.12.14 Try to come up with the decision history of your subject system (e.g. By remembering that the pattern created by the previous decisions create a unique scenario for the specific decision)

3.2.12.15 Present a final version of your design plan in a format previously agreed with your professor in charge.

3.2.12.16 Try to determine how the original designer's design plan of the subject system was, (e.g. Of the “Record and Replay”, “Acquire and Generate”, “Create and Debug” or any other type)

3.2.13 Acquire to the best of your understanding a plausible design rationale (e.g. The designers' tradeoffs) for the product under analysis based on the available information

3.2.13.1 Write a design rationale statement about your subject system that justifies the design process and resulting insight from the original designers and that led to the specific device structure of the product under analysis so that it helps your teammates see what engineering practices worked for others and why, there are indeed alternate paths for this goal, for example by following the suggestions of authors [Garcia & Howard. 1992] or by following authors' [Gruber & Rusell. 1992] method which considers the following categories of interest: Requirements; structure/form, behaviour/operation, functions, hypotheticals, dependencies, constraint checking, decisions, justification and evaluations of alternatives, justification and explanations of functions, validation/explanations, computations on existing model, definitions, and other design moves, or alternatively by completing the steps listed next.

3.2.13.2 Speculate about what was done in the design process of the subject system (e.g. Values, scenarios, etc)

3.2.13.2.1 Debate (e.g. With your classmates; experts, consultants, etc.) about different views on the potential actions that made up the design of the product under analysis

3.2.13.3 Brainstorm in team about the rationale behind the design and manufacturing of the subject system and all relevant PDS items that provide a comprehensive view on it

3.2.13.3.1 Develop, organize and process ideas

3.2.13.4 List all your hypotheses proposed for coming up with a potential design rationale for your subject system

3.2.13.5 List all the assumptions made for coming up with a potential design rationale for your subject system

3.2.13.6 Come up with design cues and bearings about where the design decisions about the subject system might come from and why

3.2.13.7 Use a basic knowledge of social sciences and humanities in the uncovery of the design rationale of the subject system

3.2.13.8 Try to backtrack (retrace) the design path of the subject system

3.2.13.9 Identify design decision taken in the design of the subject system

3.2.13.9.1 Speculate why given decisions in the design process of your subject system were made (e.g. The context in which decisions were made; issues considered, stages of the design process were decisions were made, etc.)

3.2.13.9.2 Generate and evaluate explanations for the design decisions taken in the design of the product under analysis.

3.2.13.9.3 List the possible solutions tested in the process

3.2.13.10 Speculate about the alternatives the original designers considered

3.2.13.11 Speculate about possible designer's preferences, represented either as constraints or as evaluation functions (frequently derived from experience) in the design of your subject system

3.2.13.11.1 Determine which constraint(s) was / were the designer trying to satisfy or violate in making given design decisions detected from your product under analysis

3.2.13.12 Try to identify addition of specifications (addition of overlooked or misunderstood requirements) in the design of the subject system

3.2.13.13 Try to identify relaxation of specifications (giving up on unattainable goals) in the design of the subject system

3.2.13.14 Try to find signs of conflict resolution (understood as the deviations from the actual to the planed design path) in the design of the subject system

3.2.13.14.1 Speculate about potential creative measures taken by the original designers

3.2.13.15 Identify if design choices in your product were made which weren't optimal but likely a trade off against a number of different situations (keep in mind that in real design experience, design choices and decisions can be iterated only within limited resources and timeframes)

3.2.13.15.1 Try to find the original designer's source of design constraints (e.g. Specifications, preferences, etc.)

3.2.13.15.2 Try to find potential changes in parameter values in the design of your subject system

3.2.13.15.3 Speculate about possible, intermediate refinements to the design

3.2.13.15.4 Speculate about potential experiences acquired by the original designers along the process

3.2.13.15.5 List potential decisions taken by the original designers to come up with the final version of the subject system's design

3.2.13.16 List from the information collected so far, potential situations during the design of the product where specifications might have been augmented; corrected, relaxed, refined or compromised

3.2.13.16.1 Try to find out what constraints designers had to relax in order to make a valid design decision

3.2.13.17 Speculate why not certain actions were taken or decisions were not made (e.g. The designer's conjectures on what should have been done or what would be the impact on the design if instead of "X", they would have chosen "Y", etc.)

3.2.13.18 Speculate if the original designers considered a given issue you can think of

3.2.13.19 Speculate if the original designers considered a given alternative you can think of

3.2.13.19.1 Speculate why the designers didn't consider a given alternative you can think of

3.2.13.20 Present a final version of your understanding of the original designers' design rational for your subject system in a format previously agreed with your professor in charge.

3.2.14 Speculate and explain what kinds of tradeoffs you think the designers (or even the engineers) had to make to attain the final version of the subject system

3.2.14.1 Explain how design tradeoffs can be seen throughout the life cycle of the product

3.2.14.2 Reflect on the potential solutions implemented along the process

3.2.14.3 Understand and explain to the best of your understanding why the product's final design configuration is the way it is

3.2.14.4 Document some of the requirements, specifications and constraints that influenced the design; engineering, material selection and manufacturing of the subject system

3.2.14.5 Make educated guesses as to why certain design decisions might have been taken in designing and producing the subject system

3.2.14.6 Explain why the final design of the product is not manifested in some other form

3.2.14.7 Speculate how the final design configuration of your subject system was reached

3.2.15 Speculate about what kinds of specialists you think were involved in the design of the subject system

3.2.15.1 Speculate about potential exchange of knowledge among designers

3.2.16 Reconstruct design knowledge embedded in the product under analysis based on the findings so far

3.2.16.1 Reconstruct missing design data (e.g. From the one originally acquired)

3.2.17 Try to evaluate the functions applied in the final version of the design of your subject system

3.2.18 Alternatively to the abovementioned tasks, leverage from the research on the components of a design solution by [Khandani. 2005] to use it as a guide and checklist for the synthesis of all data and information available about your subject system

3.3 Develop new hypothesis about the understood aspects of your subject system (e.g. Its workings), based on all available resources and that you think might help you expand your knowledge about it and its associated knowledge domains or at least reach a satisfactory level of knowledge about your subject system

3.3.1 Test and defend (as much as existing resources allow it) to validate new hypotheses and to uncover new information about your subject system

3.4 Stop the analysis-synthesis cycle of this stage whenever one or more of the following conditions are met

3.4.1 You have achieved a clear empirical knowledge not only about the product's performance but also about the principles and natural laws relevant to that performance

3.4.2 The product can be considered a white box (as opposed to a black box) and all needed information about the system is available

3.4.3 A desired level of knowledge is achieved or settled for in order to come up with conclusions and insight about a product and its history

3.4.4 You can explain not only the product's design goal (e.g. The primary function) along with the structures supporting the functions and subfunctions but also the reason "why" these functional and structural compositions of the object were selected from among other alternative choices

3.4.5 You have achieved a full understanding of the fundamentals of the product under study

3.4.6 You have gained an understanding of engineering tradeoffs and increased your awareness of the design process overall

3.4.7 You are able to understand the workings of the subject system and suggest improvement ideas about it and its manufacturing process.

3.4.8 You can track back product features to the corresponding stages of its engineering design process

3.5 Document (derived from your findings) what you think was the most likely design sequence and rationale of you subject system

3.5.1 Sketch a plausible description of the lifecycle of your product form its manufacturing to its disposal

3.5.2 Report your preliminary findings and conclusions

4. Contextualise all resulting knowledge:

4.1 Affirm your level of understanding of the technical aspects of your subject system (e.g. Its inner workings) by answering and reporting about the following items taken from the research by [Menchu. 2007]

4.1.1 The players: the key components that make up the system.

4.1.2 The functions: the main building blocks of the system.

4.1.3 The relationships: the threads that tie the functions together.

4.1.4 The flow of information: the energy and the information used to carry out the system strategy.

4.1.5 The strategies: which define what the system is supposed to do and how it will do it.

4.1.6 The Stimulus, process, and outcome: from user input to all the steps that take place and lead to the system output

4.2 Affirm your level of understanding about your subject system in all relevant non technical aspects of it (e.g. Socio-economical issues) by performing a design critique that also helps contextualize all your knowledge about it and state your level of understanding of it (e.g. By completing the set of tasks and questions suggested below as a guideline)

4.2.1 Explain what are the elements that give the product its main characteristics

4.2.2 List what you think were the major business concerns related to the design of the subject system

4.2.2.1 Document the subject system's business model

4.2.3 Discuss the various fields of engineering that helped materialize your subject system

4.2.4 Document cases in the design of your subject system where various engineering disciplines complement each other (e.g. Software engineering providing interfaces for touchscreens in your product)

4.2.5 Explain your subject system's design constraints; design specifications, design history, assumptions and list them appropriately

4.2.5.1 Describe the criteria and constraints that were met by the product's design

4.2.5.2 Analyse and list examples of how constraints vs. criteria were satisfied in the design of your subject system

4.2.6 Explain why the main problem the subject system must solve has nothing to do with its construction per se (or if you challenge this statement and why)

4.2.7 Report the situational characteristics of the product under analysis (e.g. Why was the product produced, and at what historical timing, its use of transitional technologies, materials, etc.)

4.2.8 Report where the subject system stands in the general history of technology and why

4.2.9 Explain the technological level of your subject system and its implications

4.2.9.1 Explain your product's lifecycle in terms of technological impacts

4.2.9.2 Explain how the subject system influences future technology or how you think it will

4.2.9.3 Explain how newer technology has influenced/changed the subject system

4.2.9.4 Relate the subject system to the overall history of technology (e.g. By considering external and internal components of it)

4.2.10 Identify the societal impact of your product's engineering solution

4.2.10.1 Report the subject system's impact on society

4.2.11 Understand and document the subject system's impact on the market

4.2.12 Correlate and discuss the suitability of materials against manufacturing processes in your subject system

4.2.13 Explain the ethical and societal constraints on your product's design and how they influenced its design process

4.2.13.1 List any ethical concerns regarding the design of your subject system

4.2.14 Evaluate the design of the engineering systems of the product under analysis (and of its overall engineering) in comparison with the recovered goals and constraints of it

4.2.15 Evaluate if the design of the subject system is any better than other similar products (e.g. By taking some time to think about it and to look at it from different points of view)

4.2.16 List the benefits of the subject system for its consumers

4.2.17 List major design features or undesirable design aspects of the product

4.2.18 Write an initial, possible, original designer's Product Data Specification based on all information available so far (but the final version of it will be reported at the later stages of the methodology)

4.2.18.1 Keep refining the potential, engineering specifications about the subject system

4.3 Acknowledge and reflect on the still ununderstood aspects of your subject system

4.3.1 Write hypotheses; assume, speculate, and put forth educated guesses about the ununderstood and most relevant aspects of your subject system’s design

4.3.2 Test (as much as existing resources allow it) new hypotheses about the ununderstood aspects of your subject system and research to arrive to the full understanding of it

4.3.3 Provide possible explanations to the ununderstood aspects of the subject system

4.4 Infer to the best explanation in order to finish the synthesis-contextualisation process of this stage as suggested by the research by [Harman. 1965] on reasoning frameworks and the studies on the traits of successful explanations by [Fogelin. 2007]

4.4.1 Consolidate your work putting forth hypotheses that explain (depending on the available knowledge) the overall design process of the product under analysis and specific aspects of it

4.4.2 Choose the hypotheses that best account for your subject system’s operation and construction

4.4.3 Assess if the hypotheses chosen provide simple, coherent, and causally adequate explanations of the evidence or phenomena in question

4.4.4 Confirm the hypotheses selected, to the best of your understanding

4.4.5 Contextualize all resulting knowledge from the reverse engineering analysis of the subject system in order to make sense of it (e.g. By using brainstorming techniques; accessing design databases, using analogies, etc.)

5. Develop preliminary conclusions:

5.1 Communicate your team members your personal assumptions, beliefs and/or biases regarding the subject system and its associated design history and design rationale

5.1.1 Find a compromise for a shared view of all your team members about the subject system

5.2 Get in touch with designers or reverse engineering practitioners to get further information and insight about the product under analysis

5.3 Consolidate your previous work in coming up with a definite specification of the subject system

5.4 Report any design issues you might have found in analysing your subject system (e.g. As suggested by authors [Otto & Wood.2001])

5.5 Determine what further information about the subject system could still be sought

5.6 Draw preliminary conclusions about the subject system that help arrive at the full understanding of it (e.g. By deliberating about how the product works, about its engineering work, market impact, how it came to be and why and so on) but report your final conclusions at the upcoming “Conclusions” stage of the reverse engineering methodology

5.7 Formulate a hypothesis (or hypotheses) that satisfactorily accounts for the product under analysis

5.8 Consolidate your work creating a troubleshooting document intended for a general audience about your subject system

5.9 Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution ,decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.9.1 Write a document for future readers of your analysis that explains ways to avoid repeating past design mistakes and issues in your subject system

5.4.11 Stage 11: Redesign Suggestions:

5.4.11.1 Introduction:

At this stage students get a chance to put all experience gained in analysing the subject system into practical use, in here all knowledge gained about it can be used to come up with improvement concepts which (depending on the educational needs and goals of the professors in charge) can be further developed to a level where either a functional, theoretical model or a full mechanical prototype is created, This stage also, goes further from the simple proposal of redesign improvements for the product under analysis since it also serves as a starting point for the suggestion of changes to all aspects of its surrounding technologies and the processes needed for its actual materialization

5.4.11.2 Stage Purpose:

To close the analysis-synthesis-contextualisation process inherent to an educational reverse engineering analysis by actually leveraging from all the experience gained with the subject system and providing improvement ideas for its redesign (be it actual or theoretical)

5.4.11.3 Background:

This stage is comprised of five different steps which naturally transition from putting forth suggestions for the improvement of the subject system to actually materialising them, namely:

1. Identify weaknesses and improvement opportunities for your subject system
2. Suggest competitive, value adding changes to your subject system's design
3. Develop and explain suitable improvement concepts for your subject system
4. Prototype or generate a working model of your improvement concepts
5. Document and present the stage finding

Major attention must be given by the professor in charge to step four of this stage and whether in it students will be required to actually prototype an improved redesign of the subject system or just come up with a theoretical model of it (e.g. A CAD file, animation or simulation); the author of this collection of resources argues that the mechanical prototyping and testing of a design concept is already a typical task of any (forward) engineering exercise for which published theory and examples already exist, thus failing outside the scope of this collection of resources and of the doctoral dissertation from which it originates. As mentioned already reverse engineering as envisioned in this collection of resources is used as an opportunity for students to acquire and exercise abilities relevant to the practice of engineering design; if students go into a prototyping stage they effectively link a reverse engineering analysis with a typical (forward) engineering activity in a way that is similarly done in industry, and although it is the more known use of it, educational reverse engineering analysis is much more than that at as will be seen in Section 8.3 where future lines of research for it are shown; still , the opportunity for students to actually materialize their improvement ideas and get even more practical experience from this educational exercise undoubtedly adds to their education (although EREA entail a heavy workload already as they are), so the final decision to actually go into a prototype building step is better left to the professors in turn and their educational goals

5.4.11.4 Link to Subsequent Stages of the Methodology:

This is indeed the last stage covering the analysis-synthesis-contextualisation cycle inherent to a educational reverse engineering analysis, where an opportunity to show everything learnt about the subject system and its design process is given; thus from now on, only stages dealing with the drawing of conclusions and dissemination actions for the results of the EREA will follow in the methodology

5.4.11.5 Stage Tasks, Questions and Analyses:

1. Identify weaknesses and improvement opportunities for your subject system

1.1 Research internally on the product itself (e.g. By leveraging from your own findings dissecting it)

1.1.1 Consolidate your work identifying and understand customer needs

1.2 Acknowledge current constraints in your subject system's design

1.3 Discover competing products' weaknesses and potentially exploit them to your advantage

1.4 Consolidate your work investigating, predicting and hypothesizing about the subject system as suggested by [Otto & Wood. 2001] in preparation for a potential, future redesign in mind (e.g. Higher performance, lower failure possibility, etc.)

1.5 Determine if a new product is needed or only a modification to the current one (e.g. In terms of technological projections)

2. Suggest competitive, value adding changes to your subject system's design

2.1 Look for improvement opportunities for your subject system (e.g. By examining the results from past analyses)

2.1.1 Research externally on similar products and companies (e.g. Patents)

2.1.2 Think of ways to unlock features or boost performance of the subject system (but keep in mind that it will likely result in the loss of the product warranty)

2.1.3 Think of possible improvement ideas to the subject system's design from varied perspectives (e.g. Through an integrated product development approach but not necessarily employing a formal design for X method or tool, or by determining possible improvements for the product's life cycle stage with the largest environmental impact)

2.2 Assess if a change of the subject system's working principle would lead to a better product (Given that the subject system was actually based on a specific working principle)

2.3 Propose preliminary, potential improvement ideas and concepts for the subject system (e.g. By considering different options such as going for minor/major changes; new designs, immediate, future improvements, short/medium/long term improvements, fulfilling the same original needs, etc.)

2.3.1 Demonstrate your mastery of the subject system by summarizing the major features of your subject system and explaining how it would affect a change in its key parameters

2.3.2 Come up with at least one alternate design concept based on variant design by varying the parameters (e.g. Features, components) of certain aspects of the subject system to achieve new functionality or to develop a new and more robust design

2.3.3 Come up with at least one improvement idea for your subject system based on parametric redesign

2.3.4 Suggest at least one idea for an improved subject system bases on adaptive design

2.3.5 Think of at least one improved, derivative product that could be created using the subject system as a baseline (e.g. By generating and evaluating several ideas of conceptual design for the whole subject system or whole assemblies)

2.3.6 Suggest at least one original redesign that fulfils the same goals and improves on the existing subject system

2.3.7 Suggest at least one follow-on innovation from your subject system

2.3.8 Suggest at least one compatible product (e.g. Accessories) with the existing subject system

2.4 Analyse if your subject system is now obsolete or when and how it could happen, if so suggest redesign actions against it

2.5 Think of possible actions to strengthen product features such as modularity, reliability or ergonomics (e.g. According to feedback from long term user experiences)

2.6 Assess, based on your findings, if the risk of new product launches is lowered by avoiding design errors that competitors might have made already

2.7 Think of a platform/hardware independent alternative to your subject system

2.8 Explore ways and tools that would allow you to determine beforehand the impact of any proposed design changes to the subject system

2.9 Come up with definitive, improvement suggestions for the redesign of your subject system by evaluating options and choosing the best overall one and suitable candidate for further refinement

3. Develop and explain suitable improvement concepts for your subject system

3.1 Scope the reach of your redesign developments with agreement from your professor

3.2 Evaluate suitable design improvement concepts

3.3 Select the improvement concepts for further refinement that are the most efficient and suitable for your target market and available resources (e.g. Considering among others; product's cost, safety, feasibility and so on)

3.4 Detail the improved redesign and write initial specifications for it

3.5 Develop the selected concepts for improvement of your subject system to a satisfactory level of detail agreed with your professor

4. Prototype or generate a working model of your improvement concepts

4.1 Assess your understanding of time and cost issues related to prototyping and knowledge of rapid prototyping skills

4.2 Plan a realistic implementation for your improved product design (e.g. Creation of a working model of it, a working physical prototype, etc.)

4.3 Implement your design improvement concept for prospective clientele to a state of usefulness agreed with your professor (e.g. Physical or theoretical implementation)

4.3.1 Build up, test and evaluate real hardware and working prototypes featuring your chosen improvement concepts by making use of your first-hand design skills (e.g. Model making, fitting and testing) but only if requested by your professor since this would be considered already a traditional (forward) engineering exercise

4.3.2 Alternatively (instead of prototyping) and if requested by your professor, create a working theoretical model of your redesigned product

4.3.2.1 Suggest the steps needed for the creation of derivative products (at least theoretically) in case no actual building or prototyping is made before this point

5. Document and present the stage findings

5.1 Document your stage findings and explain how you performed the required steps

5.2 Present a case for your chosen, improved design, neatly and persuasively

5.3 Report on how your improvement suggestions would relate to the area of product/ new product development (e.g. The product and process development (IPPD) paradigm)

5.4 Explain other ways the design of your subject system could have been achieved

5.5 Report on how else the subject system itself could be improved based on your findings

5.6 Explain how you would sell the redesigned product

5.7 Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution ,decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.12 Stage 12: Conclusions:

5.4.12.1 Stage Introduction:

At this point students sum up all their findings from past stages and come to a conclusion with the EREA and its associated learning experiences; they record everything relevant to the study of the product under analysis and of the events surrounding the whole activity (e.g. The rationale behind the product analysed, the knowledge acquired from the EREA and the conclusions of a personal; technical, and methodological nature about it). Examples of the minimum items to record in a final report include but are not limited to:

- An affirmation of the understanding of how the product under analysis works
- An evaluation of predictions about the subject system (e.g. Parts, inner workings, manufacturing processes, etc) against actual findings
- The state of the device after reassembly (It still works/doesn't work anymore, warped parts, destroyed parts, etc)
- Further analyses that could still be performed to the product under analysis by the students (e.g. Durability tests to discover how it holds up, etc.)

Additional to the abovementioned, this stage also includes a section regarding the evaluation of the personal and academic goals set initially for the EREA as well as a section dealing with the formatting of the final report in preparation for the next stage of the methodology. It will be worth remembering then, that all relevant conclusions reached and documented at this stage will be eventually disseminated with a general audience in mind later on in the methodology and so the final report from the EREA is expected to benefit current and future readers of the work

5.4.12.2 Stage Purpose:

To evaluate the attainment of the goals -both personal and academic- initially set for the EREA and to reach the definite findings and conclusions relevant to the whole EREA in order to write them down for the dissemination of them at the next stage of the methodology

5.4.12.3 Background:

By following Kolb's model of learning [Kolb. 1984] one can see how this stage is of an abstract conceptualisation nature and so it helps close the cycle suggested by him; at the end of this stage then, the student will have gone through an analysis-synthesis-contextualisation sequence and is ready to conclude the major part of the EREA where the most relevant findings and impressions from the past Knowledge Synthesis stage are now made explicit and written down next to everything else deemed important for a general audience eager to know about educational reverse engineering

5.4.12.4 Link to Subsequent Stages of the Methodology:

As a conclusion for the major part of an EREA this stage is different to the rest of them in the sense that an introspection and critical self evaluations is done here about everything that happened during the EREA whereas the previous stages have mostly followed a methodological approach to reach a fixed goal which ultimately lead to the reverse engineering of a given consumer product; Still, this stage manages to show how all of them in the methodology are actually closely dependant on each other since whatever new, available information generated at the rest of the stages has to be integrated incrementally in a continuous cycle which ultimately leads to an updated conclusions report which after a proper refining and formatting effectively becomes the final deliverable from this stage and a document that will be eventually presented to the pertinent academic evaluators and audiences

5.4.12.5 Stage Tasks, Questions and Analyses:

1. Evaluate the achievement of the educational goals set for the EREA

1.1 Self evaluate your attainment of the personal goals originally set for the EREA

1.2 Be evaluated externally to determine the attainment of the academic goals set for the EREA

2. Prepare a final, written report encompassing all relevant data, findings and conclusions about the whole EREA and submit it to your academic evaluators (The format and level of comprehensiveness of the report is left to the instructor in turn)

2.1 Hold a wrap-up session to consolidate all findings and conclusions and to discuss how to record them appropriately (e.g. By elaborating on the findings from previous stages)

2.1.1 Describe the processes used to come by the assertions in your final report

2.2 Record your conclusions regarding the unfolding of the EREA itself (e.g. Methodological, team-related, tasks performed, etc.)

2.3 Record your conclusions regarding the design (rationale and history) behind the product under analysis itself (e.g. Technical design of it, associated engineering, manufacturing and production processes, protocols, results' documentation, etc.), support and explain your findings

2.3.1 List, in chronological order what your team did during the stages of the EREA, explain how tasks were distributed and how decisions were made.

2.3.2 Illustrate the reverse engineering process as conducted in your team

2.3.3 Describe the methods of analysis (e.g. Procedures followed, devised or avoided)

2.4 Record your personal impressions and conclusions regarding your performance and interactions in an EREA in particular and in engineering design in general (e.g. Learned bits; knowledge generation, findings, remarks, etc.)

2.4.1 Think of potential scenarios where the knowledge and skills learned during the EREA can be appropriately transferred to future situations (e.g. In industry).

3. Submit your student's journal and a final, formal report to your evaluators

3.1 Submit your student's journal with all entries from previous stages for evaluation (e.g. Answers to all questions, sketches of product elements, etc.)

3.2 Assemble with other class teams and give and receive constructive criticism and suggestions on how you reverse engineered your product, and discuss findings and impressions of the whole activity to help write down your final report

3.3 Consolidate your discussion on what you learned about engineering design itself and write down your conclusions

3.4 Consolidate your discussion on what you learned about the subject system itself and write down your conclusions

3.5 Document in chronological order stage findings; group activities, achievements, ideas, data, tasks distribution ,decision making, overall progress and other information in personal design journals and explain how you performed the required stage steps

5.4.13 Stage 13: Results Dissemination:

5.4.13.1 Stage Introduction:

Although at this point a final, written report has been submitted already to the evaluators of the EREA; it is only at this stage where classmates and people in general get to know about the conclusions and work done throughout all the stages of it, to achieve this, appropriate documentation and dissemination formats such as written reports, oral presentations and graphical illustrations are presented and communicated at the appropriate level of detail, for example, internally to classmates, teaching assistants (and professors to a lesser extent), or externally to a general audience (e.g. Sponsors; students of different fields, etc.)

5.4.13.2 Stage Purpose:

To present internally and externally the results and conclusions from the EREA and lay the basis for the potential expansion of the activities or the publication of its results in the future

5.4.13.3 Background:

Because of their educational nature EREA require a explicit stage and a conscious effort to make all results obtained from it publicly available, not only for the benefit of general audiences but for students and evaluators alike to find themselves motivated to come up with quality results knowing that they will be eventually communicated and inspected

5.4.13.4 Link to Subsequent Stages of the Methodology:

This stage is the natural continuation of the past one “Conclusions” in the sense that at the previous one the results and conclusions were recorded and written down but at this one specifically, they are presented publicly to classmates, evaluators and external audiences

5.4.13.5 Stage Tasks, Questions and Analyses:

1. Communicate your results, findings and conclusions internally (e.g. Professors and classmates)

1.1 Brief both your professors and your classmates about everything relevant to the EREA

1.2 Critique each other's work in class (e.g. In teams)

1.3 Acknowledge donors or supporters of the EREA if applicable

1.4 Lay the basis to produce a technical paper out of your work in an acceptable style and format (e.g. For submission to a congress/journal opportunity)

2. Communicate your results, findings and conclusions externally (e.g. General audiences)

2.1 Prepare a Poster / Display board / Multimedia / Oral presentation / Webpage to show a general audience the most relevant aspect of your work

2.2 Give a demonstration in public of how your subject system works (i.e. In a non-technical approach to it)

2.3 Display prominently the results of successful reverse engineering projects (even long after the activity ended) at relevant venues

2.4 Organize an "open house" event where other students of your university can know about your work

2.5 Write a short document directed to future designers/redesigners of your subject system, summarizing your major advices to them

2.6 Collect ideas from visitors to your exhibition and screen them for future EREA

2.7 Acknowledge donors or supporters of the EREA if applicable

3. Submit the final edition, binding and presentation of your written work to classmates and evaluators (if you haven't done so already or if any significant change had to be made after presenting the results publicly)

3.1 Submit a dissemination activities' report to your evaluators (if they're still around), and wait for feedback

3.2 Consolidate your work documenting in chronological order findings from all stages; group activities, achievements, ideas, data, tasks distribution, decision making, overall progress and other information and explain how you performed the required steps of all the stages

5.4.14 Stage 14: Project Closure/Follow Up:

5.4.14.1 Stage Introduction:

This stage marks the formal ending of the EREA and the start of the planning of the actions that will ensure that every benefit obtained from it remains available over time. This point too is ideal for students to finally reflect on two things; how their findings can be transferable to benefit other people too, and the potential opportunities arisen as a result from the work on the reverse engineering project (e.g. Related paid internships or job offerings)

5.4.14.2 Stage Purpose:

To give a proper ending to the educational activity that sets up the mechanisms that allow all knowledge gained from it to be kept and reachable in case it still proves valuable in the future

5.4.14.3 Background:

This is a stage of a purely abstract conceptualisation nature and marks indeed the final point in the learning cycle suggested by Kolb [Kolb. 1984]. From the experiences gained up to this point then, students are ready to take actions not to lose any benefits gained from the activity and can now anticipate what kind of resources are needed and what experiences are expect for future, similar projects.

5.4.14.4 Stage Tasks, Questions and Analyses:

1. Set up any follow up tasks for the EREA

1.1 Plan actions for the tracking and following up of the results from the EREA (e.g. Further investigations and analyses in case new analytical tools become available or if new insider's knowledge comes up)

1.2 Evaluate the possibility to set up a collaborative Google Doc or a Wiki, updated by a group of enthusiasts (e.g. Your classmates)

2. Foster individual or institutional connections between local companies, sponsors and the academic scene that help promote your new abilities in the search for a future internship / job opportunity

2.1 Help your university get company donations of both physical equipment and experts visits for the benefit of future students

3. Wrap-up the EREA

3.1 Reflect on all experiences gained that could help plan ahead future reverse engineering projects either in academia or in industry (e.g. What experiences are expected and what resources will be needed)

3.2 Think of future themes for reverse engineering projects

3.3 Reflect on your findings that could be potentially transferable to other students/professors/academic institutions, etc.

4. End the EREA

4.1 End the activity whenever you consider you know the product under analysis in detail, the methodology to analyse it and your professors agree to this based on their knowledge and evaluations of you and your teammates

5. 5 Resource Conclusions

The methodology for educational reverse engineering analysis presented in this resource has been devised so that it can serve as a template that provides a contextual anchor where professors can customize their own EREA based upon the course level, course goal or available product for analysis thus, aiming to make a methodology that is suitable for different educational settings and that can fit varied teaching practices. The methodology also strives to be self descriptive so experienced students and professors alike have no problems in following it; it has been written here as short as possible to allow for readability and space constraints in this document but in turn, it is further complemented with the examples and accompanying pedagogy suggested in Resources 7 and 6 respectively, as well as Resource 9 “Miscellaneous Resources” of this same document which contains additional information for the successful development of EREA.

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RESOURCE 6: A SUGGESTED PEDAGOGY FOR THE TEACHING OF EDUCATIONAL REVERSE ENGINEERING ACTIVITIES

6.1 Resource Introduction

In the previous resource a methodology for the educational reverse engineering analysis of consumer products was introduced, in this resource, a pedagogy for the teaching of such methodology which considers students, professors and the existing administrative structures that support a student's instruction is presented to professors of engineering design in an effort to assist an eventual integration of EREA that is as smoothly and beneficial as possible into their existing teaching curricula

A pedagogy for the teaching of EREA as presented in this collection of resources then, consists of a collection of tips and advices (as opposed to teaching and learning theories) regarding the analyses, tasks and questions that have proved successful in the past in guiding and supporting each of the individual stages of the abovementioned methodology, whenever required though, extra content, specific to the guided example in Resource 7 will be included in the sections below to support the eventual teaching of it

Still, the contents of this resource, as comprehensive as they could be, are meant to be read in tandem with the rest of the resources in this collection of resources for a better contextualization and clarity of the information presented.

6.2 The Rationale behind a Pedagogy for the Teaching of EREA

The pedagogy presented here intends to provide researchers and professors of engineering design with the elements that will allow them to guide their students through a methodological, educational experience that facilitates self-discovery learning, and where students are allowed to plan their own disassembly, analysis, and reassembly steps thus helping them to ground fundamental concepts, and reinforce their theoretical knowledge through activities that are closely connected to the design process, and that require the application of "core" engineering knowledge to reverse engineer a consumer product

The advice for the teaching of EREA presented in this resource is supported not only by a thorough bibliographical analysis of existing approaches, or the author's own experience in reverse engineering, but also by the input from advisors at the Design Society's 2009

Summer School on Engineering Design; the staff of the Engineering Design Department at the Technical University of Ilmenau in Germany during an author's stay in 2010, the advice from participants of the E&PDE 2008/2009/2010 congresses, the Design 2010 congress, and the IPMA's 2010 congress where the fundamentals of this research were presented.

The major challenge in coming up with the methodology and pedagogy presented in this document then, stemmed from balancing the socio-technical issues covered by the methodology with the didactic and experiential activities suggested by the pedagogy in a way that still fitted within well established learning theories and strategies.

6.3 The Different Phases in the Teaching of EREA

Four clear phases can be distinguished in a pedagogy for the teaching of EREA and whose completion can help attain the educational goals set for them, namely: Preparation; Execution, Evaluation, and Follow up, each of the phases will be explained and discussed in this resource which comprises several major section covering them, and the flows of information among phases in a fully fledged EREA and as seen from an instructor's perspective. For each of the phases then a compendium of ordered steps with a detailed set of actions, tips and advices that ensure the accomplishment of the educational goals set is presented

As mentioned already, and as seen in Figure 6.1 below the pedagogy and its comprising phases have been structured in such a way that each phase of the pedagogy supports a corresponding stage of the methodology for the reverse engineering analysis of consumer products previously shown in Resource 5; the sequential nature of the pedagogy then, will allow professors to locate their actions within an overall framework and plan from that point the steps that will help them either reinforce their current state, or move forward into a satisfactory one that ends up with the achievement of the goals of the EREA

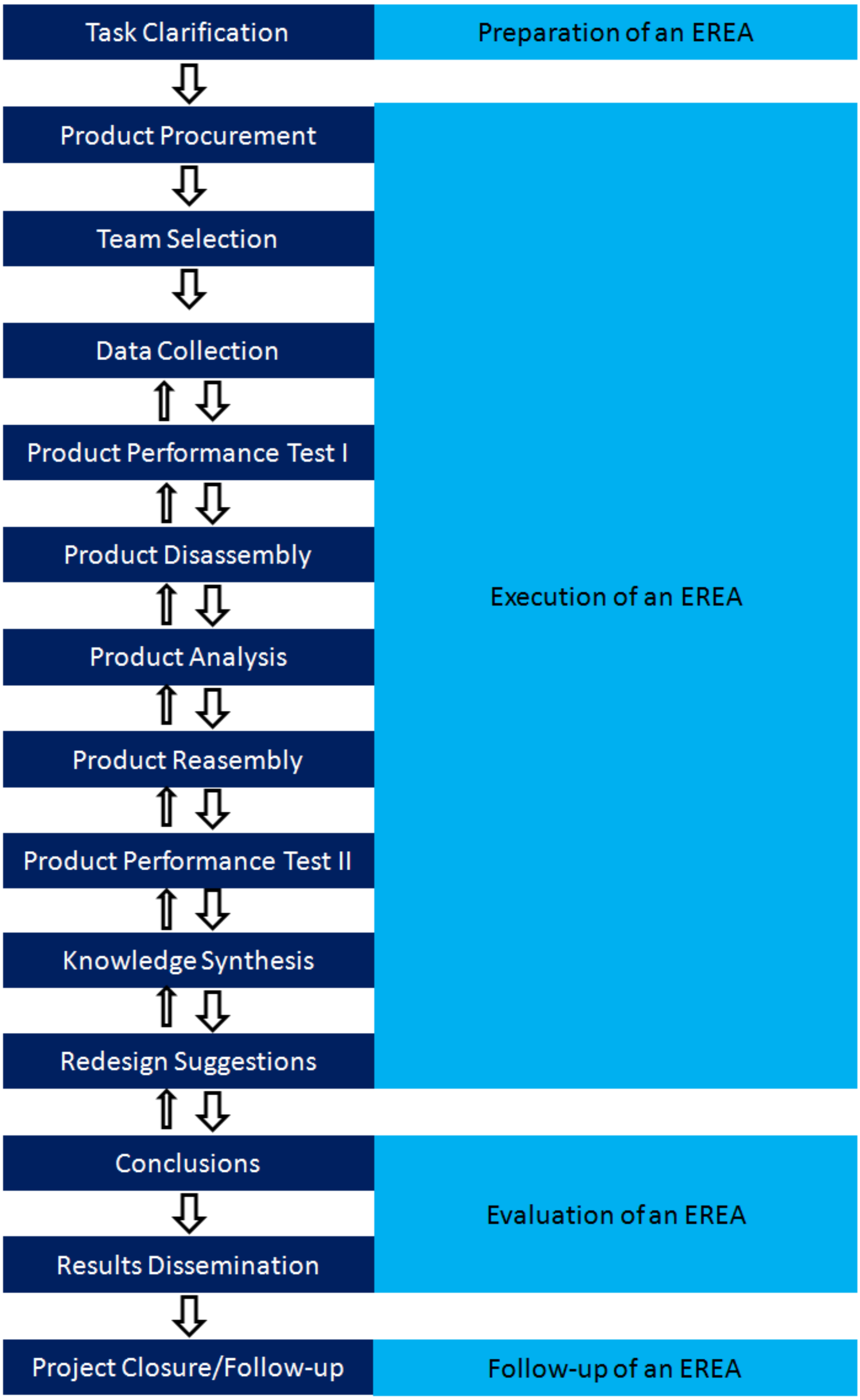

Figure 6.1 Phases of the pedagogy for the teaching of an EREA and their match to the stages of the methodology for educational reverse engineering analysis

From the perspective of professors, the following checklist summarises the major aspects to consider in fully fledged EREA and serves as a quick overview of what will be covered in this resource

1) Preparation of the EREA

a. Setting of educational goals and means to achieve it (e.g. Learning outcomes in line with the university curriculum)

    a) Setting of specific learning objectives

b. Setting of steps to carry out the EREA

c. Setting up of activity logistics

d. Planning of evaluation mechanisms

e. Selection/Acquisition of the product for analysis

f. Putting in place of feedback mechanisms for students

g. Budgeting

h. Setting the teaching strategy for the EREA (e.g. Presentation of introductory lectures followed by lab work and concluding dissemination activities)

i. Determining the total duration of the exercise

j. Setting of the teaching method: (e.g. An activity taken over eight session of 1h each where students will be evaluated on the application of the reverse engineering methodology presented here)

2) Briefing to the Students

a. Setting of tasks, expectations and procedures to follow

3) Execution of the EREA

a. Execution of all stages of the methodology

b. Guidance during the stages of the methodology

c. Guidance during the students' deliberation processes to help them learn and arrive at their own conclusions

4) Evaluation of the EREA

a. Evaluation of the achievement of the overall goals of the activity

    b. Evaluation of attainment of learning objectives

    c. Grading of students and teams

5) Documenting and Dissemination

    a. Documenting of knowledge obtained from the EREA

    b. Dissemination of findings from the EREA

    c. Opinions on knowledge generation and application

6) Follow up

    a. Collection of students feedback

    b. Archiving of student’s project

    c. Preparation of new EREA for upcoming semesters

From the abovementioned checklist, note that every phase and individual item in it will be further expanded in the subsequent sections of this resource.

6.4 Fundamentals of the Teaching of EREA

The information in this section applies to all cases of EREA irrespective of the depth pursued or the product analysed, and relates to the specific educational needs of professors, students and academic institutions involved, as such, it is presented in this separate section to highlight its foundational nature, and after having dealt with the information presented here, the reader can naturally move onto the next phases and stages of the teaching of EREA (e.g. The Task Clarification stage). In this section then, several pieces of information more akin to the areas of the teaching and pedagogy of engineering are presented which will help contextualise the information for the specific phases and stages shown further below

6.4.1 Setting the Goal and Learning Outcomes of an EREA

The general goal of an EREA is always dependant on the professor in charge but it is usually in line with those already standardized in the teaching of engineering design such as the ones from the Accreditation Board for Engineering and Technology (ABET) in the USA (e.g. Appreciate wider design issues such as ethics, liability, safety, and product disposal, be familiar with the product realization process and its documentation [ABET. 2010] etc.), or those similar ones from CDIO in Europe [CDIO Council. 2010], in this sense, and as envisioned in this collection of resources the general goal should be one that contributes to the students' education and to their future professional performance via a practical (rather than theoretical) educational experience, so the following one is suggested as an example "To provide students with an opportunity to familiarize with a variety of engineering design-related topics through the reverse engineering analysis of a consumer product." For specific implementations of EREA though, the goal is still defined by the professor in charge but it usually describes the final point the class should achieve after taking the EREA (e.g. To introduce students to modern product design by the analysis and redesign of existing consumer products) and it may or may not coincide with the general goal for all EREAs.

The general learning outcomes after the completion of an EREA on the other hand describe what students will be able to do at the end of instruction and provide clear reasons for teaching. A number of authors have already provided examples of achievable examples well within the reach of academic institutions and students with minimum resources at hand for the conduction of an EREA, the examples of learning outcomes listed below then, have been suggested by authors such as [Sheppard. 1992b], [Sathianathan. 1997] and others, and are presented here as an aid in setting your own ones at the upcoming Task clarification stage, that are specific to your own case of an EREA and dependant on the details of the curriculum of your engineering design programme, namely:

- To develop an awareness of the design process (e.g. Through hands-on design assignments that highlight the importance of functional specifications in design and how they map into specific functions)
- To develop an understanding of the knowledge and skills required in contributing effectively to product development as a design engineer.
- To introduce students to modern product design by analysing and redesigning existing consumer products
- To introduce students to the science and art of design by evaluating the work of practicing designers
- To empower students to determine how scientific principles; material properties, manufacturing techniques, cost, safety requirements, environmental considerations, intellectual property rights, and other considerations of engineering impact the design of a product
- To incorporate the skill oriented tasks, such as analysis and interpretation of experimental data, into team oriented design projects

- To understand the underlying design concepts behind the product under analysis and its technological history
- To be able to explain materials characteristics and properties, and relate them to performance, manufacturing process, and the environment
- To make students aware of the power of clear, concise communications (oral, written and graphical) by having them present descriptions of mechanical artifacts and critique each other's work.
- To be proficient in the disassembly, inspection, performance measurement, rebuilding, and assembly of consumer products'
- To connect the engineering knowledge to the physical realities of the subject system

From all the above mentioned outcomes you should pick those that are more relevant to your target students

6.4.2. Suitable Format of EREA to fit an Engineering Design Syllabus

Educational reverse engineering activities can take any of the following forms:

- A capstone project administered at the senior semester culminating what was learned throughout all courses of the career curriculum
- A year/semester project culminating what was learned across all the courses of a given career year/semester (e.g. Freshman, senior, etc.)
- A unit project culminating everything learned during one of the courses of the engineering design curriculum (usually Introduction to Engineering Design 101)
- A self-contained educational experience; of limited duration and depth; running in parallel to any of the courses comprising the whole engineering design curriculum, intended to achieve a specific educational outcome and support the teaching of topics in the host course (e.g. An example done at The University of Washington, [UOW. 2010] across seven 1hr sessions).

The most popular choices from the above mentioned cases can be considered the year / semester project and the self-contained activity. The methodology of Resource 5 and the pedagogy of Resource 6 presented here then, both support any of the abovementioned cases where due provisions are taken to ensure the flexibility necessary to shorten or stretch the span of the selected case and match the specific needs of a class and its available resources

The guided example of an EREA of Resource 7 thus, has been designed as a self-contained activity of limited duration (eight sessions) in the form of a side project, running parallel to the regular schedule of any of the courses of the first year curriculum of engineering design (e.g. Introduction to engineering design, or introduction to systems engineering)

It was designed that way because the integration of EREA into existing teaching practices might be a new activity for the readers of this document and so an initial example of limited resources and expectations has been favoured in this collection of resources to serve as first step into reverse engineering, experienced professors though can easily expand the example presented in Resource 7 into a fully fledged activity according to the needs of their own students

In short, the exact moment of inclusion and to what depth the results from the EREA are asked, is a decision left entirely to the professors in charge since the methodology and resources presented here will allow for such flexibility.

6.4.3 Setting the Depth of an EREA

The thoroughness and level of detail to go into the analysis of a consumer product will be mostly dependant on the semester students are, and on how much they have covered about their career’s syllabus; this means that not all potential stage questions, tests and tasks tests are to be assigned to the same students and that there should be a clear difference about what to expect in terms of technical proficiency from freshmen to senior years (e.g. A fully fledged reverse engineering analysis against a superficial one). Authors [Malmqvist et al. 2004] state when referring to the right level of difficulty in an activity that a too difficult task may result in an impressive analysis that is teacher-created, with student as implementers (whereas) a too simple analysis may not promote motivation nor build confidence from having met a challenge , in this sense the knowledge and experience of the professor in charge should help both, the student to know what to look for when reverse engineering a product, and the professor to know what to ask and what to expect from students,

6.4.3.1 Setting the level of disassembly for the subject system

Every product is different and has different properties which affect the type and breadth of empirical knowledge available to the analyst, this mean that just as the depth of analysis in an EREA has to be tailored to the knowledge and capabilities of students, the actual disassembly of the product under analysis has an optimal level depending on the complexity of it; a general level of detail is set for the overall product then, but in practice another one is achieved for the individual parts of it , the following criteria should be taken into account in descending order in order to suit the level of disassembly to the needs of the professor in turn, namely:

- Try for a full disassembly down to the last individual part even if it requires the destruction of components (e.g. Suitable when analysing out of order products of no significant value)
- Try for a full disassembly down to the last individual part that still allows for a satisfactory reassembly to original working conditions
- Dismantle only to the level of major subsystems, if a full understanding of a product is already attainable (e.g. For a disposable camera: Power/battery, film advance mechanism, lens, and flash)
- Disassemble down to the level where a classification of the major components allows for the recognition of its materials (e.g. Metal, plastic, etc) or its plausible manufacturing process (e.g. Machining, stamping, etc.)
- Disassemble down to the level of major subsystems even if some areas of the product remain a black box for which further speculation about its operation will be needed

Given that the subject system must be analysed down to the appropriate level that allows the verification of the hypotheses about it these criteria will help professors set the disassembly of the subject system down to a level that still allows for an educational, fluid experience with the available resources

6.4.3.2 Advice Specific to the Guided Example in Resource 7

When analysing your subject system, do not try to reverse engineer beyond irreversible reactions (e.g. The actual film and how it works (in terms of chemical reactions)), but bear in mind that the purpose of the dissection and the desired level of detail will dictate the specificity of the data collected.

6.4.4 Time of Inclusion of an EREA in an Engineering Design Curriculum

Although EREA can be administered to students at any point throughout the duration of their career studies, two major timeframes have been favoured already in past published research and for different reasons, namely:

- Inclusion at the beginning of career studies (e.g. 1st Year): Because the integrative nature of EREA makes students quickly familiarise with the field of engineering design and the topics that will be covered more comprehensively later in their studies, and because an EREA at this point can be done with less resources and contained expectations
- Inclusion at the end of career studies (e.g. 4th Year): Because at this point students can better tackle the tasks, questions and analyses of a fully fledged EREA which can also serve as opportunity to consolidate and make use of all previously acquired knowledge during their studies (e.g. A “capstone project)

A notable exception from the cases presented above comes from the Stevens Institute of Technology in the US where reverse engineering courses support the teaching of engineering though seven continuous terms [SIT. 2012]. For the specific example in this collection of resources, the inclusion at the first year of studies has been favoured because the EREA itself, has been planned as a short, exploratory activity and limited resources for its development are anticipated

6.4.5 Introductory Talks

Irrespective of the type of implementation of an EREA (e.g. Time of inclusions, length, target students, product chosen, etc.) students must have a kick off meeting; this is indeed common to any hands-on activity or laboratory work in educational environments and the only difference would lie on what topics are covered in said meeting. Under a reverse engineering approach for example it is here when students can be explained that they’ll perform a reverse engineering analysis of a consumer product and that they’ll be required to document and execute a variety of tasks an analyses associated to it (e.g. Disassembling; analysis, assembling, etc). The following list of tasks and items then, intends to exemplify the aspects that should be reviewed with target students before the beginning of the activity, namely:

- Ask your students think about what reverse engineering is and why are products reverse engineered, so they can better contextualize their educational experience
- Familiarise your students with shop practices, safety measures and use of tools and equipment
- Ask students to brush up on all related theory and published resources about reverse engineering, to level all students’ understanding about it and set the expectations from the activity

- Assess your students' knowledge of common engineering design topics, if needed, familiarize them with the concepts of systems engineering, engineering design and other you'd consider essential for the success of this activity
- Explain your students what disassembly, analysis and assembly activities are like
- Explain your students why the exercise exists and how it fits with the rest of the syllabus
- Introduce your students to the methodology for educational reverse engineering analysis suggested in this collection of resources
- Assess your student's previous knowledge or experiences needed to go through the EREA without major knowledge gaps and provide remedial actions if needed
- Explain the assignment and expectations for the EREA
- Suggest appropriate ways to proceed safely and efficiently during work sessions
- Talk with students about possible product to dissects
- Ask students to reflect on what they will find on the inside of consumer products and how they will work
- Ask your students to reflect on what the ethical and societal impact considerations in product design are
- Refresh your students understanding on varied topics such as use of design catalogues, basic engineering materials properties and their selections for various applications
- Refresh your students' skills on technical writing
- Ask your students to keep a design journal throughout the duration of the EREA where they'll document all their impressions about it
- Determine if a field trip to industry would be needed
- As mentioned already EREA stem from the more common hands-on type of activities which can be seen here through the similarity in the preparatory activities common to all of them

6.4.6 Familiarising Students with Vocabulary and Terminology

EREA are a suitable way to familiarize students with the vernacular of engineering design practice, as a professor it is easy to anticipate the kind of terms students will acquire throughout the duration of their studies and Table 6.1 below for example summarises those words mentioned in typical EREA, and the list can be expanded/contracted as per the professor's requirements

Aesthetics	Analysis	Assembly	Black Box Model	Component
Computer-Aided Drafting (CAD)	Constraint	Criteria	Critique	Design Process
Documentation	Ergonomics	Exploded view	Innovation	Mock-Up
Parameters	Process	Product Lifecycle	Reverse Engineering	Trade-Off

Table 6.1 Sample Vocabulary of an EREA

The information presented in this section can be considered foundational for all cases of EREA and is of special importance to first time participants of reverse engineering activities, the information presented at the "task clarification" stage though is one that has to be tailored to the subject system chosen, the specific needs of the professor in charge and the characteristics of the target students, thus experienced professors could skip this and go directly to that section.

6.5 A Suggested Pedagogy for Educational Reverse Engineering Activities

The pedagogy for the teaching of EREA suggested here is comprehensive in nature in the sense that it's been written to support a maximum case scenario for a fully fledged EREA and so it is filled with details and alternative paths to arrive at a same goal thus supporting any kind of experience the professor in charge decides students should get from it. A pedagogy written at such level of comprehensiveness then, provides a sense of flexibility that allows for the teaching of any case of EREA and the analysis of a variety of products at different depths of detail while still allowing for a coherent continuum that helps reach the goals set for the activity

In the following sections it will be seen how each of the major phases of the pedagogy can in turn be subdivided into a number of actions, considerations and decisions; however, experienced educators will notice that not all items listed here will need to be fully developed and in fact only a few of them will matter depending on the particularities of the EREA in turn (e.g. Educational goals set; resources available, target students, etc.), the professor in charge then should from the elements listed in this resource choose only those truly relevant and decide to what depth to attempt them. A practical implementation to support the teaching of the guided example in Resource 7 is also given here in order to clarify what is expected from this stage

It is important to keep in mind though that the pedagogy is presented in a linear, sequential and accumulative manner, and so at any point of the methodology, you should feel free to safely repeat any step of it to provide your students reinforcement and repetition of key information until the desired goal is attained.

6.5.1 Phase 1 Preparation of an EREA:

This is the phase were all the planning for the development of a safe, educational activity for the students is done, the resources listed here for that purpose cover the most relevant aspects for the proper attainment of this stage and in that sense the information presented here can be considered comprehensive, it is expected that first time instructors of reverse engineering will find in this resource everything they need from the battery if items to check before starting an EREA, experienced professors however, and as stated before, will only pick and attempt those needed for them.

It is advised that two main aspects lead all the work in this phase for the benefit of both professors and students and by sticking to those two points the resulting work from this phase should contribute for the attainment of the overall goal of the EREA, one is that all work should converge toward meeting all project milestones & deadlines (e.g. By using time efficiently) , and the other is that all work done should stay focused on the task being asked, by following these two directives then , this stage should be attained without any unexpected complications

The methodology for educational reverse engineering analysis suggested in Resource 5 already contains a sequence of stages that consider all aspects of the actual analysis of a subject system, the pedagogy of this resource though, is divided by phases and each of them correspond to one or more of the stages of such methodology, for the “Preparation” phase then, the corresponding match is the “Task Clarification” stage and for all intents and purposes they pursue the same goals but they are seen from the different perspectives of the analyst (cf. Undergraduate student of engineering design) and of the professor in charge.

6.5.1.1 Task Clarification:

At this stage most of the work to understand the actual situation, its goals and how they will be achieved is done, the preparation of an Educational Reverse Engineering Activity (EREA) then, is not that different from any other laboratory activity used in the teaching of engineering design, and as such the writing of a lesson plan that can effectively work as a checklist for the items to consider in the process is necessary, The information listed below for example, represent a possible lesson plan for the preparation of an EREA which includes all relevant points to keep in mind; because of reasons of space though not all items listed in it will be developed here, only those specific to the reverse engineering nature of the activity whereas for the rest of them, just a self descriptive explanation will be mentioned for the readers to expand at a later time

A. A General Lesson Plan for EREA in an Engineering Design Curriculum

In support of the eventual implementation (or expansion) of EREA into existing teaching curricula, the following list inspired by researchers such as [Hannaford. 1995] and [Eggert.1996] comprises the suggested elements to include in a lesson plan for an EREA; the elements included therein are of a self explanatory nature and support the planning of all cases of EREA, they can be considered standard elements from existing engineering design courses and intend to improve the cognitive abilities of students learning under the pedagogy suggested in this resource. For specific advice on a given application of an EREA though, the rest of the subsections of this resource will provide further explanation to the elements that could change depending on the nature of the EREA being done. Earlier version of this resource included fully developed lesson plans, supporting documents and a syllabus. Because of space constraints and readability, now only the most relevant items are developed as a sample while the rest is given self descriptive leads for reference, so the readers of this document can eventually develop their own lesson plan according to their own needs, criteria and regulations of the host academic institution. From the items listed below then, select those to assign your students and tailor or complement them accordingly to fit your teaching needs and those of your target students , namely:

A.1 Aspects Related to the Identification and Control of the EREA

• Activity credits: It describes the points obtained after approving the activity and how they are distributed depending on the professor in charge and the host university

• Activity description: An account of the major elements of it, e.g. “This activity will further develop the student’s knowledge of the engineering design process and emphasis will be placed on accepted practices in disassembly; assembly, inspection and performance measurement of the subject system’s parts. In their final reports, students will critically appraise the design of it and suggest improvement alternatives for it.”

• Activity Format: How the course will be structured, this item is further discussed in Section 6.4.2 and 6.4.3

• Activity title and code: A name to portray the basic idea and key features of the activity and its control number according to the host university

• Additional notes: An optional section to emphasize any aspect of the activity that needed to be made clear or could be useful for prospective students (e.g. The following activity is directed to engineering students with an interest in discovering the links among markets, materials, and manufacturing processes by analysing the design of everyday products).

• Allocation of Resources: Assess available resources for the EREA (e.g. Workspace, storage space, tools, potential extra help from teaching assistants, running costs, maintenance and support, etc.) and allocate them

• Allocation of students' resources: It refers to the expected workload students will do over the length of the activity (e.g. On average students need to spend two hours of study and preparation for each 50-minute session)

• Arrangement of field trips to industry: In case donors or supporters offer it or if the study of product under analysis dictates it

• Assumptions: To communicate the professor's assumptions; biases, principles and beliefs regarding the activity content to set it off from other similar courses

• Class meeting times: The time allocation where the activity will be done and discussed, as well as the suggested hours outside class dedicated to it

• Course communication: It refers to e-mail addresses, drop boxes, etc.

• Course goal: The general outcomes the course is designed to achieve and how they contribute to the education of students, this item is discussed in Section 6.4.1

• Course prerequisites: Depending on the host university or professors' criteria but related to the previous knowledge or experiences needed to go through the activity without major knowledge gaps

• Course Rationale: Why the activity exists and how it fits with the rest of the curriculum, (e.g. In this activity students can get in one single activity the condensed experience in the design process and associated manufacturing actions that the analysis of an existing product can provide)

• Course reading: Required text and background readings (if any)

• Course Schedule and due dates: it refers to the allocation of time and distribution of assignments and milestones throughout the duration of the EREA (e.g. Lectures, consultation, trips, class demonstrations, students' journal entries, etc.) according to the length and depth required by students to acquire or exercise a given capability in concordance with a realistic use of available resources, major activities to include in it include but are not limited to: Assigning project dates and milestones; - structuring, planning and managing group and individual activities to meet deadlines, determining the time frame of the full project as well as the time allocation for the individual stages and substeps of them, introductory talks to the activity, the operation, disassembly and reassembly activities needed therein , and the writing and presentation of a final report; the schedule for the EREA should be created and handed to the students so they know what to expect from the activity, Table 6.2 for example shows a suggested template to be filled out by professors as needed.

Week	**Class Session Numbering**	**Programmed Date**	**Class Session Title**	**Topics Covered**	**Class Contents**	**Assignment**	**Reading Sugges-tion**
1	1	TBD by educators	e.g. Overvie w and Course Syllabus	e.g. Class overvie w	Case study, Team debate projects, Team reports, Labs, etc.	e.g. Write, review, read, report, present, etc.	Chapter; Section, or book
1	2	-.-	-.-	-.-	-.-	-.-	-.-
…	…	-.-	-.-	-.-	-.-	-.-	-.-
n	n	-.-	-.-	-.-	-.-	-.-	-.-

Table 6.2 Class Schedule Example

• Homework format: No actual homework are expected from an EREA however and according to the professor's requirements they can be asked to students.

• Instructional approaches: The specific use of lectures, discussions, laboratory work, guest speakers and so on; e.g. "The EREA will be presented through a combination of lectures, class discussion, student presentations, guest lectures, and laboratory experiences and is based on studying the intent and function of a consumer product by disassembling it in order to see how its intent is realized, then reassembling it and suggesting improvements for it

• Lab time Scheduling: For the actual analysis of the subject system students will meet several times at the laboratory and won't assemble the subject system again until they have fully analysed it (If no further lab sessions were are available they can work at the classroom or at their homes and present later their findings to the class). It can also be understood as the number of sessions needed to cover all stages included in the methodology, (but flexibility on different configurations and number of sessions should be considered)

• Medium of instruction: It refers to the language used in the activity

• Name / Office location / e-mail / Phone: The main contact information for the professor in charge and / or, teaching assistants, guest speakers and industrial partners if needed

• Office hours: The time available for counselling to the students

• Overall teaching pattern: The main parts that constitute the full activity content and how they intend to be approached (e.g. Duration of the activity, mix of hours of lecture / tutorial / laboratory / other, use of class time, etc.)

• Participants' identification: the general data about students undergoing an EREA (e.g. Team name; team members, product under analysis, date, etc.)

• Preparer: The name of the creator of the lesson plan in case it is different from the one teaching it

• Provisions for teaching assistants: Determine if extra support personnel will be needed (e.g. Depending on class size)

• Request for additional equipment: It concerns the mechanisms that will allow to look for additional equipment for the attainment of the goals of the EREA in case it becomes necessary, e.g. tools, videocameras, etc.

• Required Activity materials and infrastructure: The resources needed (e.g. Equipment, facilities, etc.) for undergoing an EREA, this item is further discussed in Task Clarification at Section 6.5.2.1

• Semester/Year: The time frame where the EREA will be delivered

• Statement of Purpose: The focus of the activity, what the students will learn, the abilities to exercise, etc.

• Suggested bibliography: Course text and supplemental readings suggested by the instructor to support the teaching of the subject, e.g. Course Text: “Product Design: Techniques in Reverse Engineering and New Product Development” by [Otto & Wood. 2001]. Reference Text (Not compulsory): “Hacking the Xbox: An Introduction to Reverse Engineering” by [Huang. 2003]. See also Resource 9 “Miscellaneous Resources” for support on this item

• Target student group: The details about the students undergoing an EREA

• Teaching / Learning styles: It refers to the pedagogies (e.g. Teaching styles, learning styles, educational environment) the target students and the professors in charge may be more acquainted with

• Venue: The physical space (e.g. Classroom and engineering laboratory) where the activities will be conducted and the students’ safety can be guaranteed

• Version: It shows the latest valid version of the activity and when it was revised

A.2 Aspects Related to the Management of the EREA

• Abilities to be developed: It the refers to the set of abilities and skills to be acquired and developed in this activity, this item is further discussed in Section 4.3

• Acknowledgement of advantages: State your class strengths and potential contributions for the success of this activity

• Activity instructions: The directions on what to do for the EREA , e.g. “By following the methodology for the reverse engineering analysis of consumer products given by your professor attempt all questions, tasks and analyses that apply to your product” or “In this project you will reverse engineer a typical consumer product that contains both electrical and mechanical components, you’ll be asked to create engineering drawings for the device analysed as well as disassembly and assembly instructions for others to follow; you will work in teams and document everything you see and will have to do research on how the subject system is manufactured to finally report on how to make the process more cost effective, environmentally friendlier and how the product itself could be improved based on your findings”

• Activity requirements: The tasks and assignments included in the activity and aligned to the learning outcomes that will help students to achieve the final abilities to leave the course with, Resource 6 with the pedagogy itself discusses this item

• Activity topics: The list of themes about what is covered each class session or throughout the activity, Resource 5 for example, supports this item however, an introductory lecture mentioning the topics of manufacturing principles; product cost analysis, product architecture, concept embodiment, DfX topics (e.g. DFMA, DfE, DfRobustness), and prototyping is suggested

•Arrangement of facilities: It refers to the selection of the workplace for the EREA; the planning for the straightening out of the workplace after finishing the activities, the laboratory equipment and in general an assessment of the infrastructure requirements for the safe and smooth development of the activity

• Assessment of challenges: To anticipate potential shortcomings or challenges a professor might face in the development of an EREA (e.g. Unplanned student needs) and thus develop contingency plans (e.g. Corrective action based on feedback from students) for any unexpected circumstances where common sense should prevail

• Grading Procedures: It refers to the assessment criteria, tools and techniques for the evaluation of students again learning objectives; this item is further discussed in Section 6.5.3

• Ideal number of students / Class size: This item is further discussed in Section 6.5.2.2 and considers the number of students enrolled to the activity

• Learning outcomes: It refers to the learning objectives the EREA is intended to produce at the end of it, they are usually worded starting with "by the end of this activity, students will…" and they should be listed as specifically as possible based on the kind of evidence you will need to assess the student's learning, this item in discussed in Section 6.4.1

• Preparation of tooling: it refers to the expected equipment necessary for the attainment of the goals of the EREA

• Provisions against disliked aspects of product dissection activities: According to authors Sidler-Kellog and Jenison regarding the things students less like in a product dissection activity, their answers typically reflected they dislike tasks that are detailed oriented like counting and measuring pieces, creating drawings, and most of all writing the formal report, [Sidler-Kellog & Jenison. 1997] and thus care should be taken to consider these tasks as an integral part of all projects and enhance them (as reflected in the methodology presented in Section 5.4.12 so students can perceive them as important and meaningful.

• Students' tracking and management mechanism: Students can be advised to document team actions in a dissection journal (A detailed record kept by each student of their dissection activities; sketches, reflections, calculations, photographs, etc) that can be periodically collected and graded for completeness and accuracy

A.3 Codes in Practice during an EREA

• Academic integrity: The codes in place in every institution to ensure a fair learning experience for all students and how they'll be applied to this activity

• Affidavit: A section included in the lesson plan linking the university, the professor and students to a common set of rules, (e.g. Through signatures of all relevant parts)

• Attendance policy: It refers to the demonstration by students of class attendance, assignments, attitude, participation, respect for others, use of class time, inclement weather and enthusiasm in both lecture and laboratory activities

• Provisions for students with disabilities: The consideration of appropriate academic accommodations for students with disabilities in accordance with the specific university policies and equal access laws in place. Examples of disability categories are AD/HD (Attention-deficit hyperactivity disorder); specific learning disabilities, hearing, vision, health impairment, psychological, orthopaedic, traumatic brain injury and so on

• Rules of conduct and academic policies in general: Depending on the host university and professor in charge but usually considering points such as students' participation, ethical behaviour and safety, e.g. . "Students are required to maintain a professional attitude while in classes and at the laboratory. Students must adhere to standard safety practices at all times and will not operate any piece of equipment they have not been given instruction on. Students may and will be removed from the premises for behaviour that is considered "unprofessional" by the professor in charge, including but not limited to: Constant tardiness; excessive loud talking, sleeping, not being prepared, inappropriate attire (e.g. Safety goggles, hats, boots), bullying, inappropriate language and so on, throughout all stages of the EREA

• Safety and emergency provisions: It refers to the practices to maintain the well being of students at all times, e.g.: Keep telephone numbers at hand; work at least in pairs, set class order and rules (e.g. No horseplay during handling of tools and testing devices, require students to wear safety glasses every time the product or tools are being handled, in order to prevent electrical shocks basic electrical safety measures should be followed, always read device labels carefully before taking items apart, perform training and enforcement of safety procedures for both students and faculty, take care when dealing with hazardous materials; handling risky loads or pointy part profiles, if your product uses magnets, (e.g. Single cylinder 4-cycle engines) remove and store watches since strong magnetic fields (e.g. Around the armature of a motor) can damage watch mechanisms

• Statement of expectations: Professor's expectations in terms of student responsibilities.

Just as in any other educational activity, an EREA requires a document to organize the main ideas in it, its creation then, is no different to any other lesson plan previously done by the professors in charge, and because of this, their own experiences and requirements can be easily integrated to the sample structure shown above to come up with a lesson plan that covers the needs and aspirations of the students in mind and in accordance with regulations at the host academic institution. If the professor in charge deems it important then, a copy of this could be given to the students

Finally and as mentioned already the contents presented here are of a comprehensive nature but experienced educators will know what items to attempt, to skip, or even decide to go straight to the task clarification stage altogether, this is specially true since only a few of all the abovementioned items are usually developed, depending mostly on the particularities of the EREA in turn.

6.5.1.2 Specific Phase and Stage Advise for the Guided Example in Resource 7

Setting the Depth of the Reverse Engineering Analysis: for the specific example shown here; the film canister for example isn't fully reversed engineered because of the non reversible chemical reactions embedded in it, the instructor then, decides to what depth of analysis students should go according to the educational goals previously established

6.5.1.3 Creation of Supporting Documents for Students

Additional to the information presented above, professors can come up with their own supporting documents to give students and to help them go through the development of an EREA, the example listed below provides support for every stage of an EREA and is presented here so the readers can use it as baseline for the creation of their own examples.

6.5.1.3.1 Activity Handout for Students ndergoing an EREA

This section intends to portray what the contents of a supporting document (e.g. An activity handout) for students undergoing an EREA would be, it lists tips and suggestion on what to do at every step of the methodology for EREA suggested in Resource 5. It is directed to students of engineering design newcomers to reverse engineering activities and its intention is to help ensure a safe, successful educational experience. The handout itself is written in a general way so it fits any format of EREA and the selection of any consumer product for analysis. The professors in charge then, could either withhold or present this information to their students according to their proficiency in analyzing systems, but its distribution is actually recommended to help equalize the knowledge of all students about what to do and how, given that this handout would effectively be a pedagogy for the conduction of an EREA as seen from a student's perspective, the readers of this document could create their own example based on their own needs using the example provided below as a baseline

• **Stage 1: Task Clarification**

• Goal:

To understand the nature of the tasks you are being asked / wanting to perform

• Student Tasks:

1. If not mentioned by your professor already, state your what you would like to learn from this first stage and your goals and expectations in participating in this whole activity, share them with your teammates too

2. Familiarise with the concept of Educational Reverse Engineering (e.g. Read a paper about it or consult the 'Miscellaneous Resources' section of the collection of resources of your professor)

2.1 Familiarise with a methodology for the educational analysis of consumer products (consult with your professor or look at the 'Miscellaneous Resources' section of your professor's collection of resources)

2.1.1 Familiarize with the concepts of product testing; disassembly, analysis and reassembly

3. Present a project proposal to your professor with action plans, diagrams, charts and timetables that track and show your progress towards the completion of the activity

3.1 Allocate resources and assign the tasks to perform

4. Prepare both an individual and team's journal to record your stage findings; observations relevant to the EREA how you performed the required steps and assign how the team journal will be kept by who and when.

• **Stage 2: Product Procurement**

• Goal:

To select and procure a suitable product for educational reverse engineering analysis

• Student Tasks:

1. If your Professor / Institution hasn't already provided one, choose a suitable product for reverse engineering analysis

2. Get the selected sample (but also look for potential sponsors/donators)

    2.1 If indicated by your professor also collect competing products or specific product parts for areas of subsequent, detailed comparison and analysis.

3. Document in an individual and team's journal your stage findings; observations relevant to the EREA and how you performed the required steps.

• Tips:

-For the selection of the product for analysis:

-- If the decision to choose a subject system for educational reverse engineering analysis rests in you, think about your school and community. Identify local examples of a natural system, an engineered system and a social system to learn about the various kinds of systems that there are and choose one that you find of interest for analysis

--Procure a working product that is preferably operation-safe and from which something valuable can be learned

-- Choose one that at a minimum contains both electrical and mechanical components, a familiar product such as any home appliance found at home, i.e. A coffee maker or a toaster are a good starting option

-- To choose old products is good since their technologies are more transparent and easy to see

--From this stage forth you will notice how every stage brings new intermediate results; information about the subject system and about how to achieve your goals, but it will be only at the 'Knowledge Synthesis' stage when one will be certain of what is actually known about the product under analysis and what isn't

• Suggestions:

- Comment individually to your professor if you were already familiar with the product chosen for analysis

• Stage 3: Team Selection

• Goal:

To understand team roles and responsibilities so you and your team members' efforts are organized to ensure a successful completion of an Educational Reverse Engineering Activity

• Student Tasks:

1. Set up a work team with people you feel okay working with or with those assigned to work with

2. Assign team roles if your professor hasn't done so already (e.g. Assign turns to disassemble; assemble a product, keeping of notes, documenting the process, etc.)

3. Set fair labour division rules (differences in gender and cultural backgrounds can be partially alleviated with fair labour division) so ensure an orderly distribution of workload, fair distribution of tasks and a similar learning experience were all team members can have the disassembling experience and take equal turns irrespective of the product chosen.

4. Prepare a document showing division of labour and ground rules to support an effective group communication teamwork experience after the teams have formed

5. Document your stage findings and explain how you performed the required steps

• Tips:

- Complexity and size of the product chosen for analysis can be one of the major criteria used to assign roles and tasks

• Stage 4: Data Collection

• Goal:

To pose and answer at this stage as many questions about your product as possible

• Student Tasks:

1. Collect and document all possible data about the subject system under analysis

2. Expand and develop your research skills (e.g. By familiarizing with tools that retrieve information; by using visual and oral techniques, by questioning and observing or by bringing in information from ``outside'' sources to help make decisions)

3. Document your stage findings and explain how you performed the required steps

• Tips:

Use computer-based and library resources effectively to acquire needed information; seek information on problem from multiple sources, understand importance of learning what has already been done to solve a given problem, use traditional sources of information to het key data (e.g. Operation; performance, target market, outstanding features, technological level, market analysis, intellectual property, manufacturing company information, patents, data from online databases, etc.))

- Understand all available information about the product under analysis and bring it to the classroom the day of the reverse engineering activity or whenever indicated by your professor

• Stage 5: Product Performance Test I

• Goal:

To operate the product and gain concrete experience with it in terms of functions and forms

• Student Tasks:

1. Familiarize with the tools, measuring devices and basic safety measures for the use of the testing equipment

2. Observe, use and experience your product to familiarize with it in a structured way in order to understand it

3. Document your stage findings and explain how you performed the required steps

• Tips:

- Follow all relevant laboratory guidelines concerning safety (e.g. Testing equipment, behaviour, etc)

- If testing the product implies the permanent change or destruction of its parts, consult with your professor before carrying on

- Stage 6: Product Disassembly

• Goal:

To disassemble the chosen product in preparation for a thorough analysis of it

• Student Tasks:

1. Prepare for the disassembly of the subject system

2. Disassemble the subject system

3. Perform an initial analysis of the inner workings of your product

4. Document you findings

• Suggestions and Tips:

The disassembly of a product calls for a careful and methodological procedure where all necessary resources are at hand in an environment that guarantees the safety of participants at all times, the following tips and suggestions are presented in order to achieve a successful educational experience, namely:

-For the Management of the Activity:

-- During the activity practice effective listening skills; exhibit appropriate non-verbal mannerisms and give and receive constructive feedback

-For the Recording and Tracking of the Activity:

-- In order to record the information generated during the disassembly stage of an EREA (e.g. Components; parts that make up the product, description of how the components function to make the product work, etc.) you can use tables or pictorial function-component maps

-- Photographs should be taken of the product before dissection begins and frequently during dissection to aid in product reassembly

-- Keep a dissection notebook for recording and sketching what you see and what you do (e.g. Disassembly steps of the product)

-For the Disassembly of the Product:

-- Follow ordered and methodical product disassembly practices, fishbone diagrams for example, are powerful tools in organizing the disassembly of the product under analysis, use them if needed

-- Be systematic in the disassembly, examining each part, its function, and documenting how it interfaces with other parts and as you disassemble document in detail what you learn about how the subject system works

-- When disassembling, remove one component at a time and put all parts in a bin / transparent bag to help keep track of the process but whenever you remove a bolt, instead of just throwing it in your parts bin, thread it back into the place where it came from (after the mating part has been removed)

-- When disassembling your product be firm, but gentle, the pieces should come apart without breaking

-- When disassembling be careful with pieces that drop out or stick to other parts (e.g. Magnetic or sticky ones) they are very easy to lose.

-- When disassembling be careful of flying pieces

-- Organize the component parts of your subject system on their work area according to their subsystem and continue until all major components of the system have been dismantled

-- Be careful when disassembling mechanisms that require specific adjustments (e.g. Timing marks on cam shafts in motors) check its repair manual to clarify any doubt or ask your instructor

-- Take all possible precautions to impede a destructive disassembly of your product, or a condition that doesn't' allow the return to its normal operation. If disassembling; testing or analysing the product implies the permanent change or destruction of its parts, assess the consequences in bringing the product back to working conditions before going ahead with it and if a part needs to be / becomes broken during disassembly inform /consult with your professor.

-- Be extremely careful when disassembling gaskets, they may be reused again (although not generally a very good idea)

-- Be careful when prying parts with a screwdriver or anything from their original positions, since prying can ruin the parts, oftentimes lifting parts out is enough when they are correctly disengaged , a knife could also be useful in separating pieces

-- Be careful when handling springs since they are stretched very tightly causing them to fly away easily

-- During disassembly populate a table with the following information that can be later refined from information from other stages of the methodology (Part name; function (what function does the part provide?), material (what is the part made of?), joining method (what is used to join the parts?), production method (what manufacturing process was used?))

-For the Sketching of the Product:

--Use computerized techniques such as CAD or CAM for you product parts' measurements, parameters and 3D models

-For the Initial Analysis of Your Product:

-- When disassembling your product, just by looking at the relation between mechanisms try to guess what purpose the might serve

-For Safety Practices:

-- Take care when dealing with hazardous materials; handling risky loads or pointy part profiles, during disassembly beware of sharp edges.

-For Compliant Disposal Regulations:

--If during the disassembly some parts were destructed or damaged, collect the component parts in large bins and explain to your professor that you will see to it that the items are disposed of properly and according to local laws.

• **Stage 7: Product Analysis**

• Goal:

To understand your subject system's inner workings, how it works as a whole in its intended context and how it came to be

• Student Tasks:

1. Analyze the subject system on all of the required categories of knowledge down to a depth agreed with your instructor that allows the testing of hypotheses or conjectures proposed about it and with the available resources

• Suggestions and Tips:

-For the interaction with you professor:

Most of the work previously done on the topic of educational reverse engineering falls in the area of the technical analysis of the product under study and as such a wealth of information about how to execute this stage exists, it is important then to follow your instructor's advice in order to complete this stage in an efficient way where the desired results from it can be realistically attained with the available resources

-For the overall execution of the technical analyses in this stage:

--When analysing your subject system, consider it a black box to avoid bias and psychological inertia

--Use all your deliverables from previous stages to guide your reverse engineering analysis

-- Use appropriate quality tools and methods to analyse your product

-- Try to achieve technical mastery in the use of analytic tools and measuring devices

-- Answer questions and tasks as satisfactorily as possible

-For the Mechanical Analysis of the Subject System:

-- Read simplified catalogues of components for reference and starting point for further research about it

-For the analysis of your product's architecture:

-- Decide what actually constitutes a "part" on your product. Although your product can be broken down completely into elemental parts, sometimes it makes sense to leave things as a subassembly (c.f. [Durfee. 2008])

-For completing a morphological and functional analysis of the product overall:

--Identifying possible means to accomplish the sub-functions of the product but don't limit your thinking to examples or implementations you might already know

-For determining the manufacturing process(es) of the product under analysis:

-- Use all available information in conjunction with other information sources in understanding product components and the processes they have undergone.

-For determining the materials of the product under analysis:

--Draw on your or others' expertise to collect all information about a product's materials and come up with a conclusion about them (e.g. by checking author Ashby's research on the topic, c.f. [Ashby. 2005] about the identification of materials and common processes used on them)

-- Carry on a traditional search of information in published media about the product under study or consult with an expert since they still remain a valid source of information for an approximate rather than exhaustive identification of a product's material

-- Be as specific as possible when determining the product parts' functions and materials

• Student Suggestions:

Think about global engineering, why has global engineering become so widely used and how it might have affected the design of your product

• Stage Closure:

Always Show you instructor / teaching assistant a copy of your work, document your stage findings and explain how you performed the required steps

• Stage 8 Product Reassembly

• Goal:

To bring the product back to its original state as much as possible in preparation for the subsequent stages of the reverse engineering analysis

• Student Tasks:

1. Before reassembling your product tell the your professor if you have any unusable or missing parts, if so plan for remediation actions (e.g. Jumping directly to Stage 10 "Knowledge Synthesis" altogether)

2. Once the stage is done and although actual practices could change from institution to institution you should take provisions for proper keeping, cleaning and maintenance of involved tools whether there are laboratory assistants for help or not.

3. Document your stage findings and explain how you performed the required steps

• Student Suggestions and Tips:

-For reassembling the subject system:

-- Be especially careful about fragile parts and those difficult to reassemble.

-- Be careful that no product parts are left over.

-- Follow ordered and methodical product reassembly practices.

-- Install parts in the reverse order in which you disassembled them (if possible), this can actually be considered a test on your memory, journal completeness and common sense. Watch out for proper reassembly sequences whose failure requires redoing the process again

-- The product's service manual can be used for the reassembly but your own instructions previously written should be taken into account too.

-- Try not to overtighten bolts; small bolts can be easily broken off and usually require only "finger tight" pressure, look out though, for other types of bolts that might need tools like a torque wrench or be tightened in a specific order.

-- If needed use special tools (e.g. Ring compressors) to put parts back into position

-- If necessary use small amounts of oil to lubricate mating parts when reassembling

-- Be careful of flying pieces

-- Be careful of small parts that easily lost and can be difficult to reassemble due to their size

-- Be careful when handling springs since they are stretched very tightly causing them to fly away easily and they might hurt you

-- Be careful when reassembling mechanisms that require specific adjustments (e.g. Timing marks on cam shafts in motors) check its repair manual to clarify any doubt or ask your instructor

-- Clean all needed tools, inventory them, find if there is one missing or return where they belong and extra tools with you

-- For examining the reassembled product:

-- Once the product is completely together and you have no parts left over, operate it. If it does not sound or feel like it did before, or if a strange smell develops, stop immediately and figure out what is wrong.

• Stage 9: Product Performance Test II

• Goal:

To test and measure the performance of the reassembled product under analysis and explain any change detected in it

• Student Tasks:

1. Perform as much as possible the same tests done at the Product Performance Test I stage to the reassembled product

2. Document your stage findings and explain how you performed the required steps

• Student Tips:

-Most of the tips and suggestions from Product Performance Test I stage apply here, just prepare for the planning of new tests in case new information about the product under analysis becomes available.

- Consult with your professor for the best practices when using measurement and test equipment

- Asses if your reassembled product operated smoothly, or else make whatever adjustments are needed to convince your instructor that the product is running properly, if the product underwent a destructive analysis then consult with your professor about the course of actions for the next stages of the methodology.

• Stage 10: Knowledge Synthesis

• Goal:

To achieve a clear empirical knowledge not only about the history of the product under analysis but also about its performance and the principles and natural laws relevant to it

• Students' Tasks and Suggestions:

1. Question and interpret every aspect of the product under analysis under the assumption that everything is there or was done the way it was for a reason, and that the final design is optimal and carefully thought

2. Consolidate your work familiarizing with brainstorming, mind-mapping, visual thinking and kinaesthetic thinking if necessary to perform smoothly this stage of the methodology

3. Exercise creative and intuitive instincts; come up with educated guesses and consult regularly with your instructor or any other advisor for the successful attainment of this stage

4. Apply systems thinking to synthesise all information about your subject system

5. Integrate knowledge from diverse sources to solve problems found at this stage

6. When trying to reconstruct a design plan about the product under analysis make use of your domain knowledge or that of your instructors to help filter out unreasonable yet possible design actions and reach only a level of detail that is suitable for the typical goals of an educational exercise

7. For detecting design choices in the product under analysis that weren't optimal but likely a trade off against a number of different situations; Keep in mind that in real design experience, design choices and decisions can be iterated only within limited resources and timeframes

• Stage Closure:

Document your stage findings and explain how you performed the required steps

• Stage 11: Redesign Suggestions

• Goal:

To provide a closing point to the analytical processes undergone throughout the educational experience by suggesting improvement ideas for the product under analysis and actually materialising them either in a mechanical prototype or a theoretical manner.

• Students' Tasks and Suggestions:

1. Be as creative as possible when coming up with suggestions for a superior product than the one analyzed

2. If an invention is conceived during the EREA ask your professor for guidance on patent application

3. When developing the ideas for the redesign of the product under analysis it is very easy to go into a typical case of forward engineering which entails the mechanical prototyping of ideas, consult with your professor whether that step would be needed or just a theoretical implementation of the improvement suggestions is enough

• Stage Closure:

Document your stage findings and explain how you performed the required steps

• Stage 12: Conclusions

• Goal:

This stage has two major goals one is to evaluate and be evaluated regarding the attainment of your performance goals set for EREA and the other one is to write down all relevant findings from previous stages in order to draw conclusions about the actual educational experiences the EREA and the chosen product for analysis provided you, so they can be eventually presented and evaluated by the right people at the following stage of the methodology

• Students' Tasks and Suggestions:

1. Review available bibliography on how to write technical reports or ask your professor for guidance

2. Start drafting the final report since the very beginning of the EREA

3. Submit your student's journal with all entries from previous stages, the journal should include among others answers to all questions; sketches of product elements and so on

4. Submit your professor / teaching assistant a hard copy of your work at the end of the EREA

• Stage Closure:

Document your stage findings and explain how you performed the required steps

• Stage 13: Results Dissemination

• Goal:

To present and disseminate all results, findings and conclusions from the EREA to an internal and external audience while laying the basis for an eventual expansion or formal publication of results

• Students' Tasks and Suggestions:

1. For the creation of displays / posters and written handouts properly quote all references used throughout your investigation

2. Always consider the nature of your target audience when addressing them

• Stage Closure:

Document your stage findings and explain how you performed the required steps

• Stage 14: Project Closure/Follow Up

• Goal:

To give a proper ending to the educational activity while at the same time planning for a strategy to benefit from all things learned throughout the EREA and make them easily reachable in case they are still needed in the long term

• Students' Tasks and Suggestions:

Try to increase your marketability for future professional opportunities (e.g. Internships / job offers) by fostering relations with donors and contacts in local industries by mentioning your abilities acquired abilities throughout the EREA

The information in this subsection then, is written in a style addressed to students and is full of actual advice collected from previous examples of EREA both from published research and the author's own experience

6.5.1.4 Additional Guidelines for the Success of Hands-On and Similar Activities

Although reverse engineering activities are already perceived as interesting and motivational [Dalrymple. 2009] experience dictates that the use of interesting subject systems; exploring everyday uses of materials, using anecdotes and stories, using visual animations to explain theories involved and planning industrial visits can help further spark the interest of students in EREA; additional to the information presented in this resource then, the advice by authors [Malmqvist et al. 2004] on the planning and execution of hands-on activities (to which EREA belong) is presented here in Table 6.3

below, the information therein however, has been slightly reworded just to fit the terminology of this collection of resources.

Stage	Guideline
Pre-Course Planning Aspects	Start the development of the reverse engineering experience/course well in time
	Do the development of the course in a team in order to get more ideas and to find possible traps
	Make a test run of the reverse engineering experience on a single project group, prior to using for a large student group with many groups
	Make sure that all supervisors are well educated and are aware of the course goals and design
	Make a time budget of the course from a student perspective, and plan to track time during the course
	Try to find critical situations that can appear in the course, and prepare actions for these
	Plan for renewal of project ideas – this is a key challenge
	Create a project-dedicated space as much as possible
	Make connections between the reverse engineering course and other courses in the curriculum. Ensure that the courses build on each other and create variation around a common core, and avoid repetition
	Vary task characteristics and team composition but use similar assessment practices
	Seek interesting projects, since interest is key

	to student motivation
	State learning objectives clearly and keep focus on learning outcomes rather than the product to be reverse engineered, The CDIO syllabus [CDIO Council. 2010] can be used to form a basis for the learning objectives
	Set up the reverse engineering project so that the stated learning objectives are taught and assessed through project deliverables, or as part of the process
	Carefully consider start conditions and end result, make sure these map well to the learning objectives
	State the reverse engineering project on the right level of difficulty. A too difficult task may result in an impressive analysis that is teacher-created, with student as implementers. A too simple analysis may not promote motivation nor build confidence from having met a challenge
	Set teams to work on a number of identifiable product subsystems and/or work packages. This will facilitate for all team members to make an identifiable contribution to the project
	Provide all students with similar opportunities to develop their skills. Avoid student overspecialization, e.g. honing their skills as the CAD expert in a team
	Carefully plan the reverse engineering tasks to teach non-technical skills such as teamwork and communication and include these elements in the learning objectives and pedagogical and assessment techniques employed
Course Execution Aspects	Carefully consider student team size and composition: Small team size implies emphasis on technical problem-solving, large team size

	means that project management and teamwork will be also considered
	Use generalized project models and tools and methods for very early and late project phases. Connect these to domain-specific tools and methods used in intermediate phases
	Prepare students to cope with the uncertainty and unpredictability of a development project
	Be prepared to manage conflicts within the student teams
	Introduce methods and tools at timely points in the project
	Decide checkpoints/deliveries to be able to track progress in the project work
	Carefully consider the communication flow in the course
	Teachers need high availability at delivery points in order to give fast feedback and decisions on project continuation
	Be prepared to improvise in terms of e.g. Problem solving workshops or extra lectures
	Include assessment tasks as early as possible
	Use frequent individual time reporting to facilitate the early detection of problems in the project
	Include self-evaluation of project success and working practices
	Request feedback on time actually spent
	Include adequate training in use of equipment

Table 6.3 Summary of guidelines for the success of hands-on and similar activities, Source: [Malmqvist et al. 2004]

Should the reader still needed additional support on the planning of an EREA the reading of the overall list of factors to take into account when preparing an educational activity by author [Linsey et al. 2006] is also recommended

6.5.2 Phase 2: Execution of an EREA

The second phase in the pedagogy for the teaching of EREA concerns the actual carrying out of it and it corresponds from the 2nd to the 11th stages of the suggested methodology for educational reverse engineering analysis presented in Resource 5 meaning that most of a professor's work done with students in an EREA will fall at this phase, in this section specific details about the corresponding stages of the methodology are presented, as well as a practical application of the teaching pedagogy of this resource associated to the guided example of an EREA shown in Resource 7

The execution of an EREA entails the setting in place of the management; tracking and corrective mechanisms of all relevant resources and actions leading to the completion of the EREA in a set timeframe (e.g. Resources, milestones, deadlines, teaching times, etc.) and that will allow students to reach the desired learning objectives throughout the stages that involve the actual handling of the subject system; this phase is subdivided by stages to support the actions needed therein, each of the stages mentioned in the next sections then, contain suggestions for the safe and efficient development of the EREA but the professors' own experience in managing groups and academic activities should provide valuable too.

Listed below are the individual stages that comprise the execution phase of the teaching of EREA along with the advice on the pedagogical aspects of their teaching and in accordance with their correspondence to the suggested methodology for EREA in Resource 5, namely:

6.5.2.1 A Suggested Pedagogy for the Teaching of the Product Procurement Stage

The following advice is of a general nature and should help students and professor better decide which product to choose for analysis and for what reasons. Further below in this same section practical advice concerning the guided example of Resource 7 is also provided, namely:

- Select a product that helps fulfil the objectives set for the activity

- Select a product that at minimum contains both electrical and mechanical components
- Choose an operation-safe, working product from which something valuable can be learned
- Old products to reverse engineer are good in that their technologies are more transparent and easy to see
- It is positive to have similar products from different manufacturers or even generational products from the same manufacturers so that students can see changes from one generation to the other and how different manufacturers approach the same needs
- If needed also collect competing products or specific product parts for areas of subsequent, detailed comparison and analysis
- Keep in mind that some products for example have an inherent disposition to show certain design philosophies more easily than others (e.g. Disposable cameras emphasise design for mass production features; coffee makers emphasise design for cost; personal multimedia device emphasise design for functionality, etc.)
- Look for potential sponsors/donators of products

A. Effect of the Results of This Stage in the Subsequent ones Comprising the Phase

The clearest effect from the results of this stage concerns the information regarding the tools and equipment that will be needed to test and analyse the product being chosen, and although the final list of resources for this purpose will be only know once the product starts being operated (e.g. Product testing, disassembly and reassembly stages) the results from this stage will help start gathering the right resources for the fulfilment of this teaching phase

B. Information about the Specific Example Shown in Resource 7

B.1 Suitability of Disposable Cameras to Exemplify an EREA

Single use cameras were first invented by Kodak and they are a good example of a high volume, low cost product designed to have a high content of re-used parts and recycled materials. A Kodak Flash and a Kodak Waterproof camera were indeed used for the guided example of a reverse engineering exercise presented in Resource 7, because, in fact a number of authors have independently chosen disposable cameras as a source for product dissection exercises , reasons for this include their low cost , high availability, familiarity of students with this product, simple electromechanical components on the inside and being a generational product with easy to see improvements over the years (students can dissect two consecutive versions and identify product improvements), additionally, they are said to be the most recycled product in history [Van De Moere. 1992] and even the modification of disposable cameras itself has been subject to a law suit which wasn't won, because of the argument that the owner of a patented item is allowed to fix the item whenever it breaks, but not to essentially build a new item from the parts of an old one [Photo Corp. v. United States International Trade Commission, 2001], not to mention that, there are available resources in the web for disposable cameras such as pictures, CAD drawings and so on, all these reasons make the use of disposable cameras very convenient when embarking on a reverse engineering project.

One more reason for choosing disposable cameras is that there are two kinds of dissection processes, destructive and non-destructive, the disposable camera was chosen because it contain a film that if opened it will be exposed to light thus damaging it , in this sense the dissection process could be considered destructive and a reassembly of the camera would not be possible , still if care is taken and the camera is disassembled in a darkroom the camera can continue to be used; it is not expected to be disassembled by everyone in this way though , it is just to illustrate students that reverse engineering is not an straightforward process and indeed manufacturers set traps and locks so their products cannot be reverse engineered , with the example of the camera then, students get a reverse engineering activity as close to real life as possible.

Finally, and based on the findings by [Lamancusa & Gardner. 1999], it is worth highlighting the general areas of technology that can be exercised with such products, namely:

1. Analysis
2. Business concerns, marketing
3. CAD drawing
4. Chemical processes
5. Competitive analysis
6. Design for manufacture
7. Design for manufacture / assembly
8. Design for recycling
9. Design process
10. Electric/electronic machines
11. Ergonomics

12. Green design
13. History of technology
14. Injection moulding
15. Journal record
16. Manufacturing processes
17. Materials selection
18. Mechanical hardware
19. Metrology
20. Sketching
21. Team skills

B.2 Suggested Tools and Equipment to Achieve the Goals of the EREA

A minimum list of materials needed for the analysis of a Kodak disposable camera (such as the one in the guided example of Resource 7, is listed next:

- Laboratory space
- A workbench for every team
- Protective gear (safety glasses, smock, etc.)
- One subject system per team (ideally)
- A screwdriver set, or at least a small flat head screwdriver (small ones will facilitate product disassembly and they can be shared with the class)
- A pair of needle nose and regular pliers
- Small storage containers, envelopes, or zip lock bags to hold smaller parts being disassembled from the devices
- White paper to create systems diagrams (larger paper may be easier for students to use and include more information)
- Bins or containers to collect metal, plastic, and other parts for recycling at the end of the activity
- Black electrical tape
- A rubber mallet
- Tweezers
- Measuring Tools and instruments (Such as a micrometer)
- Cutting tools (e.g. Utility knife; razor blade, a pair of metal clippers, wire cutter, etc.)
- Adjustable power supply
- Bright overhead lighting or desk lamp

- Cleaning supplies
- Glue
- Wrench
- Video recording equipment and computing resources to analyze and document the activity

B.3 Specific notes regarding the disposable cameras used in the guided example of Resource 7

- Emphasise you students that disposable cameras contain small gears and components which are interesting to learn about
- Explain your students that in a reverse engineering analysis it is very normal that any mock-ups, prototypes, and other physical models can be part of the collected data, (e.g. To trace the development of a product) and the actual focus can be on a particular aspect or on the product as a whole.
- Once the product for analysis had been chosen, give your students an introductory talk about it, its principles and where they can get information about it to level all students understanding about the subject system

6.5.2.2 A Suggested Pedagogy for the Teaching of the Team Selection Stage

In order to assemble a team of people to accomplish the goal of the EREA and assign roles and tasks accordingly please consider the following items:

- Have a talk with all team members to exchange contact information, pick team leaders and assess the knowledge level of all team members
- Give your students some team building advice on topics such as leadership; decision making and group success (e.g. Team members' cooperation; participation, sharing of information, communication and contribution to the project's workload)

A. How to choose team members:

They can be picked either by teacher's criteria (existing needs) or student's affinities (individual talents and skills)

B. How to decide the number of members in a team:

The number of members in a team is dependent on the total number of students enrolled; and the complexity, and availability of products so everyone participates actively in the tasks, in crammed classes for example groups of five or six members might need to be formed, this is a high number of students but with proper roles and tasks assignments every students should get a good share of hands on and team experience, indeed different authors suggest different numbers for team members, authors [Sidler-Kellog & Jenison. 1997] for example suggest teams of three to five members, authors such as Lamancusa state that 2 persons per group is best and three is all right if necessary [Lamancusa et al. 1996], In Kang's research, teams from two to up to six member in odd numbers have been documented already, [Kang. 2011] but in general four is the ideal number of team members for reason that will be explained further below

C. How to assign team roles:

Team roles are assigned in order to support the activity so all team members can have a disassembling experience and take equal turns irrespective of the product chosen; usual contribution roles include: Group leader; Presentation design, Parts analysis, Oral presenter, Disassembler/Assembler; 3D Modelling/Animation, Information collection/Research into the product under analysis, Photographer, Results disseminator (e.g. Posters, online, etc.), and the usual tasks are assigned for the Team Recorder (the one who writes down all the ideas and material generated during the working meeting), Team Timer (to make sure that team stays on its time budget for the various tasks), Team Gatekeeper (to makes sure that all members of the team are participating), Team Advocate (to make sure that opposing ideas are brought up and discussed, Team Encourager (to makes sure that everyone on the team is getting positive recognition for their contribution),and the Team Resource Holder (who is the one that holds team resources (e.g., Calculators, instructions, paper & pencils, etc.)), however all students should be provided with similar opportunities to develop their skills and avoid student overspecialization (e.g. Honing their skills as the CAD expert in a team)

An ideal team though, is made up of four members so each of them can work to reverse engineer the product under analysis. The assignment of roles for the hands on parts of the EREA (e.g. Testing, disassembling, assembling) is suggested as follows: One person should do the physical disassembly of the product; A second one should create a Disassembly Procedure describing the step-by-step process of disassembly, the third member of the team should use a digital camera to record images of individual parts and systems and the fourth member should carefully observe the disassembly process so that he/she leads the process of re-assembling the camera. The rest of the tasks of the other stages of the methodology should be equally distributed following the advice mentioned above. A notable exception though, and as mentioned by [Durfee. 2008]occurs when analysing very small products since it would be only one student actually disassembling it

; but still, everyone should try to be involucrate somehow, in the same way, if working in a group and dissecting a complex object, consider splitting into groups to tackle the dissection of subassemblies.

D. How to determine the role of the professor in an EREA

Reverse engineering projects help professors expand the type of interaction they regularly have with students, the role of the instructor, and the skills required for these exercises are different from the typical lecture-oriented class. Industry experience, particularly in a design or product development capacity is highly important, and so during an EREA the instructor serves in many non-traditional roles, for example:

- As a consultant: To guide students in their project and point them in the right direction
- As facilitator: To provide resources to get the job done

In learning about product design then, students can “borrow” the learning curve of professors so they can help their students go faster and learn from their experiences. In fact educators shouldn’t fear to state the obvious during an EREA, after all authors such as [Gick and Holyoak. 1983] have already proved that the addition or omission of perceivably simple cues makes a significant difference in the a student’s ability to notice correlations between two dissimilar situations.

In this regard, author Dalrymple also published how in her studies, students demonstrated spontaneous transfer in an increase from 43% to 68% if more guidance was provided to help them notice and abstract relevant features of their product under analysis which fro author Dalrymple concluded that professors guidance during a D/A/A activity was paramount, [Dalrymple.2009]

Last but not least, you should set fair labour division rules for potential differences in gender and cultural backgrounds thus after the teams have formed, members must prepare a document showing division of labour and ground rules for an effective teamwork experience.

E. Information about the Specific Example Shown In Resource 7

There is no fixed guideline concerning the distribution of roles and workload other than ensuring an orderly distribution of workload and a similar learning experience for al team members, whenever possible though, you should allow students with a natural inclination for tinkering lead the fairly inexperienced ones

6.5.2.3 A Suggested Pedagogy for the Teaching of the Data Collection Stage

The following is a list of items to keep in mind and that summarise the aspects that have proved relevant for the proper conduction of this stage, they are directed to the professors in charge of the activity and describe how and why support students at this stage, namely:

A. Instructors' Assignments

- Help your students expand and develop their research skills e.g.: By helping them bring in information from ``outside'' sources to help make decisions; by teaching them to use computer-based resources effectively to acquire needed information, by helping them seek information on a problem from multiple sources, or by helping them understand the importance of learning what has already been done to solve a given situation
- Help your students familiarise and gain experience in information retrieval and interpretation by giving them access and having them check the following (EKR's) engineering knowledge resources that provide relevant data about their product under analysis and that are as suggested among others by [Pahl et al. 2007]:
- Traditional printed publications (e.g. Local libraries): Design catalogues, stock sheets, trade journals
    - Manufacturers Data: Technical reports; CAD drawings, delivery instructions, user manuals, service manuals, brochures, manufacturer catalogues, bill of materials, vendor and components catalogues, original design/designer's documentation (but very hard to get outside the design team and by company outsiders overall), product information
    - Consumer Associations: Inquiries from customers; test reports, accident reports, trade organizations, test reports, accident reports.
    - Market Studies: Market analyses, trend studies, consumer focus groups, industry sources
    - Intellectual Property Resources: Patents, licenses.
    - Academic Resources: Technical journals; research results, concrete assignments, analyses of natural and artificial systems, calculations, experiments, analogies, computer data, document collections, handbooks, engineering texts, engineering databases, technical handbooks (e.g. Electrical engineers handbook, [Warne. 2000], Mark's handbook of mechanical engineering, [Avallone et al. 2007]), specialized societies, empirical tests, abstracts, document collections, etc.

    - Laws and Regulations: General and in-house standards and regulations, government documents.
    - Scientific encyclopaedias: e.g. McGraw-Hill encyclopaedia of science and technology, [McGraw-Hill Editors. 2013]
    - Indexes: e.g. Index of applied science and technology [EBSCO Industries. 2013], the engineering index, [Elsevier Inc. 2013]
    - Internet Queries: e.g. Articles; patents, journals, manufacturers' websites and catalogues, the Google scholar search engine at http://scholar.google.com/, etc.
    - Any other source of relevant data at your disposal.
- For the most elusive pieces of information or to come up with details of the operation and design of the product under analysis have your students to try talks and interviews with designers; reverse engineering practitioners, individual experts; users and / or certified servicemen of the product, or even insiders' knowledge or actual experience and accounts from the field in order to get further information and insight about the product under analysis

Tell your students that if only limited lab time is available students can gather all information about the product and study it at home, once all information has been gathered, classified and understood, they can bring it to the classroom to carry on with the methodology (e.g. The actual disassembling experience)

A.1 Information about the Specific Example Shown In Resource 7

If needed, give access to your students to published research about the subject system in case they couldn't find anything relevant on their own, for the specific example of this collection of resources the following paper is suggested: "Design for Recyclability: Kodak's Single-Use Camera" by [Van De Moere. 1992]

6.5.2.4 A Suggested Pedagogy for the Teaching of the Product Performance Test I Stage

To guide students through this stage it will become important to work on the safety and class order aspects of laboratory work, as well as on the necessary guidance on the technical aspects relevant to the use of laboratory equipment and their testing and data recording practices.

Given that testing a product calls for a method of its own that ensures the thoroughness and methodical approach in executing it the preparatory work for this stage should include a talk with your students about shop practices that covers at least the following points:

- A pre-activity briefing and explanation on how to behave and handle machinery during the EREA, (other regular measures for laboratory behaviour will remain valid too)
- A review of basic concepts on metrology, if needed
- Planning for straightening out actions after practices
- Explaining students how they should proceed with operating their device

After the students follow this advice and record every relevant result from this stage they should be able to continue without any trouble with the next stages of the methodology

6.5.2.5 A Suggested Pedagogy for the Teaching of the Product Disassembly Stage

The professors' main responsibility in this stage is to provide students with the support to manage the dissection process of their subject system so they can access all exterior components and those housed in the interior of it in order to lay the basis for further analyses in the subsequent stages of the methodology, the major aspects to keep in mind for this stage then, are summarised in the list below:

- Suggest your students to dissect the equipment into various components and then break into groups to analyze smaller components in detail, so students first get a big picture of how everything fits together and are later given the chance to examine smaller parts of the system with more attention to engineering principles. Also, as soon as students have attained a good understanding of their specific component ask them to move forward to look at the other components/systems.
- If there is time available ask your students to pair up with another group that is dissecting a different product and compare and explain the items they have just analyzed to other classmates
- Faculty and teaching assistants (if needed) must be present during much of the disassembly process to facilitate high levels of student/faculty interaction, during the dissection process then, circulate among the teams to provide extra guidance and answer questions
- Encourage each student to actively participate since many of them have never experienced this type of hands-on project and are unfamiliar with using tools and taking things apart
- Assist the students if necessary with removing or taking apart difficult pieces

- Ask your students to be aware of sharp parts or not lose track of small parts during the disassembly
- Remind your students that the purpose of the dissection and the desired level of detail will determine the specificity of the data collected
- During this stage, assign tool boxes per team or tell students to take turns and share turns if needed
- Suggest your students to make a three dimensional computer animation that provide information about the sequence in which the dissection of the subject system should proceed
- Prepare a Q/A session to answer any specific questions or calculations presented during the dissection stage

A. Information about the Specific Example Shown in Resource 7

- When asking students to generate a full set of measurements of their subject system keep in mind what author [Kutz. 2007] stated when referring to CAD models of a product under analysis, in the sense that such models "can often shed light on the designer's intent, but it is impossible to recreate the parts exactly, as there is no way to measure or know the tolerances or exact specifications for each part"
- When asking students to prepare an equipment-breakdown hierarchy in order to analyse their product's architecture, ask them to remember that it can be a document with the work-breakdown structure providing a mechanism to order the subsystems, their assemblies (including subassemblies), and parts of a subject system to expedite the development of specifications) this document also acts as a vehicle to guide the reverse engineering effort and is critical to the development of functional specifications.
- When asking students to sketch a systems diagram for the device under analysis tell students that an initial one may be done by hand but a more refined version done using computer software such as MS Word or PowerPoint using different shapes or colours to enhance their explanation and illustration could be included in the final report (e.g. at the "Results Dissemination" stage)
- When asking students to create a comprehensive BOM (Bill-of-Materials) remind them that the BOM can be later revisited at subsequent stages of the methodology to fill out any missing or newly relevant information about the subject system, in fact the final BOM should only be reported at the "Results Dissemination" stage, so just ask them to try to gather as much information as possible in this stage and complement it in later ones

- Table 6.4 below can be used as guide for what a BOM should contain in order to document the dissection of the product (e.g. Component functions; size and geometry, fastening and assembly, etc.)

Part Number	Part Name	Part Picture	Quantity of Parts	Sub Part of:	Part Description	Part Colour	Mass (oz/gr.)	Part Material(s)	Manufacturing Process	Relevant Physical Parameters				
										Length (mm)	Radius (mm)	Inner Radius (mm)	Height (mm)	Outer Radius (mm)
1...														
n														

Table 6.4 Sample BOM to Document the Dissection of a Product

- Evaluate if it is necessary for the dissection exercise to disassemble one-time fasteners such as rivets or glued joints. Advise students to break or force them only if necessary to determine internal workings or parts count of the product.
- When asking students to perform a Subtract-and-Operate procedure remind them that it is done to study and establish the functional dependencies of each component where one component is removed from the product and the effect of the missing component is analysed, and then the process is repeated for all components, as explained by authors [Otto & Wood. 2001]

A.1 Specific Safety Measures for the Analysis of Single use Cameras:

Additional to the safety suggestions mentioned in this collection of resources, the following ones are specific to the handling of disposable cameras and should be taken into consideration throughout this stage for the benefit of your students, namely:

- Ask your students to identify the flash unit and its component parts

- In order to prevent electrical shocks, the product’s capacitors (It stores 300 volts of electricity) should be removed and the use of the flash button avoided during its handling (e.g. Disassembly / reassembly)
- Ask your students to not activate carelessly the flash charging circuit while all housings are removed
- Suggest your students to remove the camera’s capacitors immediately after opening the camera. Disposable cameras with flash contain a large capacitor that can cause an electrical shock and so students should discharge the capacitor before disassembling the camera by following the next instructions: Discharge the flash; remove the battery, discharge the flash again (discharge it by placing an insulated screw driver across both leads of the capacitor)
- Suggest your students to remove the shutter and film-advance mechanisms slowly and carefully, noting the correct assembly order so that the camera can be easily reassembled. These small parts are easily lost and can be difficult to reassemble due to their size
- Ask your students to collect the batteries and film from the single use cameras for future use

6.5.2.6 A Suggested Pedagogy for the Teaching of the Product Analysis Stage

In this section you will see a collection of tips and advice for the analysis of a consumer product in the context of an educational reverse engineering activity; the explanations to the technical analyses presented in this stage then, are considered standard fare for engineering design practitioners and their inclusion into a reverse engineering exercise doesn’t change their nature, ultimate context or expected deliverables. For reasons of space and readability though a practical rather than a comprehensive explanation of the tasks listed below is shown in this document given that the steps to execute such analyses, exercises and tasks are considered standard practice in education, are well known in the field of engineering design and plenty of information exists about them anyway. The main items to consider for this stage then, are listed below, namely:

A. For the overall conduction of this stage:

The first task to set with your students is to determine what type of analyses are appropriate to provide insight into the quantification of the design of your subject system or into its strengths/weaknesses, you should ask them to consider analyses in the areas of mechanics; electronics, software, socio-economics, ecology (materials, production methods, cost impacts) and other related topics after this but before actually starting the analyses though, you should assume that the final design featured in your product is sold for economic benefit and as such it is expected to be optimal, this simple assumption will serve as a basis and starting point for the analysis of it.

B. For performing a design analysis on material use, fasteners and product structure:

Authors [Jeswiet et al. 2007] have created guidelines seen here in Table 6.5 below for material use, fasteners and product structure, you can direct your students to them to check for compliance should you decide to include this analysis in your EREA, and indeed this is an example of one more of the existing methodologies for product analysis available on specialized literature:

Guideline		**Reason for Guideline**	**Presence in Your Product**	
Materials	Minimize the number of different types of materials.	Simplify the recycling process; especially plastics		
	Make subassemblies and inseparable parts from the same or a compatible material	Reduce the need for disassembly and sorting		
	Mark all plastic and similar parts for ease of identification	Many materials' value is increased by accurate identification and sorting		
	Use materials that can be recycled	Minimize waste; increase the end of life value of the product		
	Use recycled materials.	Stimulate the market for recyclates		
	Ensure compatibility of ink where printing is required on plastic parts.	Avoid costly label removal or sorting operations		

	Eliminate incompatible labels on plastic parts	Avoid costly label removal or sorting operations		
	Hazardous parts should be clearly marked and easily removed.	Rapidly eliminate parts of negative value.		
Fasteners	Minimize the number of fasteners.	Most disassembly time is in fastener removal.		
	Minimize the number of fastener removal tools needed.	Tool changing costs time		
	Fasteners should be easy to remove	Save time in disassembly		
	Fastening points should be easy to access	Awkward movements slow down manual disassembly.		
	Snap-fits should be obviously located and able to be disassembled using standard tools	Special tools may not be identified or available		
	Try to use fasteners of material compatible with the parts connected	Enables disassembly operations to be avoided		
	If two parts cannot be compatible make them easy to Separate	Enables disassembly operations to be avoided		
	Eliminate adhesives unless compatible with both parts joined	Many adhesives cause contamination of materials		
	Minimize the number and length of interconnecting wires or cables used.	Flexible elements slow to remove copper contamination steel, etc.		

	Connections can be designed to break as an alternative to removing fasteners	Fracture is a fast disassembly operation		
Product Structure	Minimize the number of parts	Reduce disassembly.		
	Make designs as modular as possible with separation of functions.	Allows options of service upgrade or recycle.		
	Locate unrecyclable parts in one area, which can be quickly removed and discarded.	Speeds disassembly		
	Locate parts with the highest value in easily accessible places.	Enables partial disassembly for optimum return		
	Design parts for stability during disassembly.	Manual disassembly is faster with a firm-working base		
	Avoid moulded-in metal inserts or reinforcements in plastic Parts	Creates the need for shredding and separation		
	Access and break points should be made obvious	Logical structure speeds disassembly and training.		

Table 6.5 Guidelines for material use, fasteners and product structure, Source [Jeswiet et al. 2007]

C. For computing a product commonality index:

Request this analysis depending on your students knowledge; product dissection has been used before in a graduate level course of product family design to improve the students' understanding of platform commonality cf. [Simpson & Thevenot. 2007], so if several different models of products of the same brand are available and if student know how to, they can be asked to compute the commonality index of them by dissecting all products, laying out all of the parts side by side and then discussing the similarities and differences among the components in the cameras, for further information on how to calculate such index check the abovementioned reference or the book “Product Platform and Product Family Redesign” by [Simpson et al. 2006] or check the resources mentioned in Table 6.6 below

Name of the Resource	Location	Notes
Designing Product Families	http://www.mne.psu.edu/simpson/courses/me546/syllabus.html	Online resources and class materials for Penn State’s course on design of product families prepared by [Simpson. 2013]

Table 6.6 Resources for the Study of the Design of Product Families by Using Disposable Cameras, Source: [Simpson. 2013]

Additionally and for your reference, Table 6.7 below shows a sample calculation of a Product Commonality Index for a family of Kodak disposable cameras

Table 3. Example of completed spreadsheet for Kodak one-time-use product family.

Parts	Water & Sport		Max Flash		Max Outdoor		FunSaver 35		ni	1/ni^2	Size & geometry f1	Material & Manufacturing f2	Fastening & assembly f3	ni*f1*f2*f3
Back Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	0.750	1.500
Battery		0	1	1		0	1	1	2	0.250	1.000	1.000	1.000	2.000
Cam	1	1	2	1	2	1	3	1	4	0.063	0.500	0.500	1.000	1.000
Exposure Counter Wheel	1	1	2	1	3	1	4	1	4	0.063	0.250	1.000	1.000	1.000
Film	1	1	1	1	1	1	1	1	4	0.063	1.000	1.000	1.000	4.000
Film Axle	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000
Flash Assembly		0	1	1		0	2	1	2	0.250	0.500	0.500	1.000	0.500
Flash Cover		0	1	1	0	1	1	1	3	0.111	1.000	1.000	1.000	3.000
Frame	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	1.000	2.000
Front Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	0.750	1.500
High Energy Lever 1	1	1	2	1	3	1	4	1	4	0.063	0.750	0.500	0.750	1.125
High Energy Lever 2	1	1	2	1	2	1	3	1	4	0.063	0.750	0.500	1.000	1.500
High Energy Lever Spring	1	1	1	1	1	1	2	1	4	0.063	0.750	1.000	1.000	3.000
Lens	1	1	2	1	2	1	2	1	4	0.063	0.750	1.000	1.000	3.000
Lens Holder		0	1	1	1	1	2	1	3	0.111	0.667	0.667	1.000	1.333
Metal Clip	1	1	1	1	1	1		0	3	0.111	1.000	1.000	1.000	3.000
Picture Frame	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	1.000	2.000
Shutter	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000
Shutter Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	0.750	1.000	1.500
Shutter Spring	1	1		0	1	1	1	1	3	0.111	1.000	1.000	1.000	3.000
Sprocket	1	1	2	1	1	1	3	1	4	0.063	0.750	0.750	1.000	2.250
Thumb Wheel	1	1	2	1	2	1	3	1	4	0.063	0.500	0.500	1.000	1.000
Top Cover		0	1	1	1	1	2	1	3	0.111	0.500	0.667	1.000	1.000
Viewfinder	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000

Sum ni*f1i*fi2i*f3i	46.208
Sum 1/ni^2	2.118
Number of non-differentiating parts P	24
Number of products N	4
PCI	**47.0**

Table 6.7 Sample Calculations of Product Commonality Index for a Family of Kodak Disposable Cameras, Source: [Simpson. 2013]

D. For finding out alternate uses for the subject system:

When asking your students them to find out what are other potential applications of the product or its subcomponents and how might the product be misused it is important to explain to them that this question can be answered at the "Product Performance Test I" stage if the product is operated as intended, but once it is disassembled the individual inner components can be used for other purposes and such question can only be answered at this stage

E. For conducting a product troubleshooting assessment of the subject system:

One of the problems with product-specific exercises is that learning about a given product itself (e.g. A disposable camera) is not a goal of an EREA (their goal is the students' acquisition of abilities and skills relevant to engineering design irrespective of the product chosen for analysis), still the value in this kind of exercises comes from the disassembly aspect of them which at the very least will familiarise and provide hands-on experience to the students with the use of the tools and procedures that are indeed common to all educational reverse engineering analyses

F. For executing a technical systems analysis of your product:

Suggest your students to formulate all the product requirements in a solution-neutral way (working principles should only be determined if really necessary from the point of view of the overall functionality).

G. For executing an analysis on your product with a systems approach overall:

When analysing the subject system first suggest your students to distinguish different levels of abstraction or system levels, the system functioning as a whole and the system as a set of relationships between interacting parts, then ask them to see the system as a whole, treat it as a black box and deduct its overall behaviour by submitting inputs and observing the resulting outputs; finally ask them to see the system as a set of relationships and analyse the system's construction, internal structures and processes in order to understand how the system's overall behaviour is produced

H. For executing a functional analysis of your subject system and its components:

When performing the functional analysis of the subject system ask your students to answer all important questions about the device such as which components are responsible for providing which functions; remind your students to focus on the fundamentals, not to restrict alternative solutions and also to identify repeated functions and combine them or eliminate them. Also remind them that a wealth of resources such as the "Function: Definition and Analysis" monograph by [SAVE International. 1998], the research by [Parker. 1994], the tables by [Kaufman & Woodhead. 2006] or any other known resource can be used for a comprehensive list of typical verbs and nouns for defining functions.

Also, when determining the structure and role of individual components advice your students not to assume any specific functional relationships between individual components at least at the beginning of the analysis since the structure and role of individual components can only be determined based on its relationship to the function of the product as a unit. Indeed, ask your students to decide what actually constitutes a "part" on your product since your product can be broken down completely into elemental parts, and sometimes it makes sense to leave things as a subassembly, as stated by author [Durfee. 2008]

I. For creating a systems diagram:

Ask your students to create a diagram that shows systems and interactions in it and that describes the operation and control of the product under analysis, for this they should use different shapes to illustrate different types of subsystems and arrows or lines to show connectedness and/or interaction between subsystems. For a refresher on systems diagram designed for technology education, teachers and students the following link is suggested: http://www.technologystudent.com/designpro/system1.htm by author [Ryan. 2010]

J. For developing a Design Structure Matrix (DSM) analysis:

Another tool that comes from the technical systems analysis side of reverse engineering is the Design Structure Matrix which according to authors [Sharman & Yassine. 2004] provides a matrix representation of an assembly diagram for a product. Such matrix then, is used to capture the physical connections between each of the camera components and author [Kutz. 2007] points out that in practice, a detailed assembly diagram would accompany this matrix to illustrate the types of connections between components, which he states “is especially important for more complex products that employ a variety of connection types (e.g., Screws; rivets, welding, soldering, brazing, snap fits, press fits). Table 6.8 below can be given to students to serve as guide when creating their own example. (Note: The matrix is symmetric about the diagonal and so only the lower half is presented)

Kodak Water & Sport	Advance arm	Shutter arm	Arm retainer	Back panel	Cam	Exposure counter	Film	Film advance gear	Film advance wheel	Film advance wheel 2	Film base	Film holder	Front panel	Identification label	Lens 1	Lens 2	Lens 2 cover	Lens cover	Rubber band	Shutter	Shutter cover	Spring 1	Spring 2	Viewfinder	Washer	Waterproof back cover	Waterproof front cover
Advance arm																											
Shutter arm																											
Arm retainer	1																										
Back panel																											
Cam	1	1																									
Exposure counter																											
Film																											
Film advance gear					1		1																				
Film advance wheel	1						1																				
Film advance wheel 2									1																		
Film base	1	1	1		1	1	1																				
Film holder							1				1																
Front panel				1																							
Identification label				1									1														
Lens 1																											
Lens 2											1																
Lens 2 cover																1											
Lens cover															1												
Rubber band																											
Shutter																	1										
Shutter cover															1					1							
Spring 1											1									1							
Spring 2		1									1																
Viewfinder											1																
Washer										1																	
Waterproof back cover				1						1									1								
Waterproof front cover										1			1												1	1	

Table 6.8 Design Structure Matrix for the Kodak Water & Sport One-Time-Use Camera, Source [Kutz. 2007]

K. For developing a Function Component Matrix analysis:

Explain your students that according to author [Strawbridge et al. 2002] a function component matrix provides a mapping between a product's components and its subfunctions and is created by combining the information obtained from the function structure analysis plus the components listed in a BOM. Author [Kutz. 2007] also adds that this matrix represents the product architecture for the subject system as it indicates how the different functions of it are mapped to its physical components. Table 6.9 below shows a sample function component matrix for a Kodak Water & Sport Camera which can be given to students as an aid in the creation of their own

KODAK Water & Sport	Arm retainer	Advance arm	Shutter arm	Waterproof front cover	Cam	Exposure counter	Film advance gear	Spring 2	Battery	Back panel	Film	Film advance wheel	Film base	Film holder	Front panel	Viewfinder	Lens 1	Lens 2	Lens 2 cover	Shutter	Shutter cover	Spring 1	Film advance wheel 2	Rubber band	Waterproof back cover	Washer	Identification label
Actuate me		1	1					1												1	1	1					
Convert he to me				1																			1				
Guide me	1				1	1						1		1													
Import em																1	1	1									
Import he				1																			1				
Position solid				1											1										1		
Regulate em																	1	1	1	1							
Store solid											1		1														
Store visual										1	1				1												1
Translate solid							1																1				
Link solid																								1			
Stop liquid				1																					1	1	

Table 6.9 Function-Component Matrix for the Kodak Water & Sport One-Time-Use Camera, Source [Kutz. 2007]

L. For performing a Function Relation analysis:

Explain your students that the function relation analysis is a design method that allows the designer to think of a product in terms of the function and subfunctions that the product or system has to perform and not on a particular solution. In this approach the designer works from a function to form a hierarchy that goes from the overall function and is distributed among multiple sub functions. The goal in a function relation analysis then, is not only to examine the relationships between the various subfunctions, paying attention to their logical sequence or interconnections but also to show how the main functions serve the overall function directly and how the auxiliary functions contribute to the overall function indirectly, both of them are supportive or complementary and are often determined by the nature of the solution. Authors [Comparini & Cagan. 1998] have devised a procedure to perform a function relation analysis which is used in this collection of resources.

Figure 6.2 below shows a sample function relation analysis of a Kodak disposable camera with flash with the inputs, outputs, main and auxiliary functions shown in detail and can be given to students as an aid in creating their own one

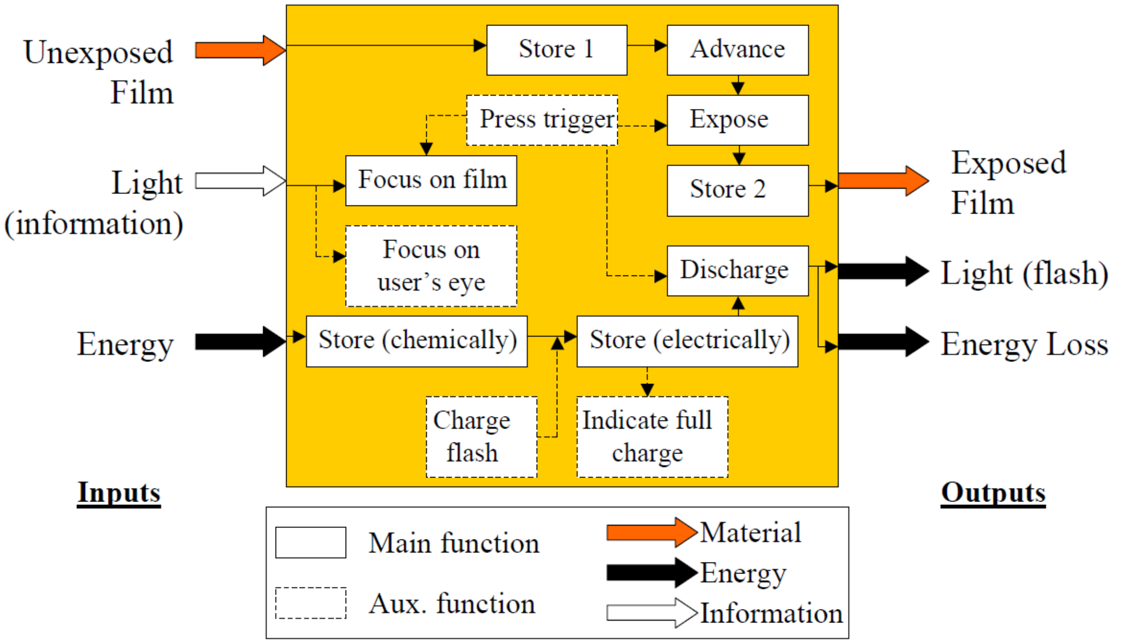

Figure 6.2 Function Relation Analysis of a Kodak Disposable Camera with Flash, Source: [Comparini & Cagan. 1998]

M. For performing a Function Structure Analysis:

Explain your students that according to [Pahl et al. 2007] the function structure seeks to provide a form-independent representation of the product that describes how the product functions at a sufficient level of abstraction and that just as author [Hirtz et al. 2002] complements, the function structure in such figures uses terms from the functional basis to describe the functionality shown on the far right-hand side of them. Figure 6.3 below shows a function structure for a Kodak Water & Sport Camera and can be given to students as an aid in creating their own:

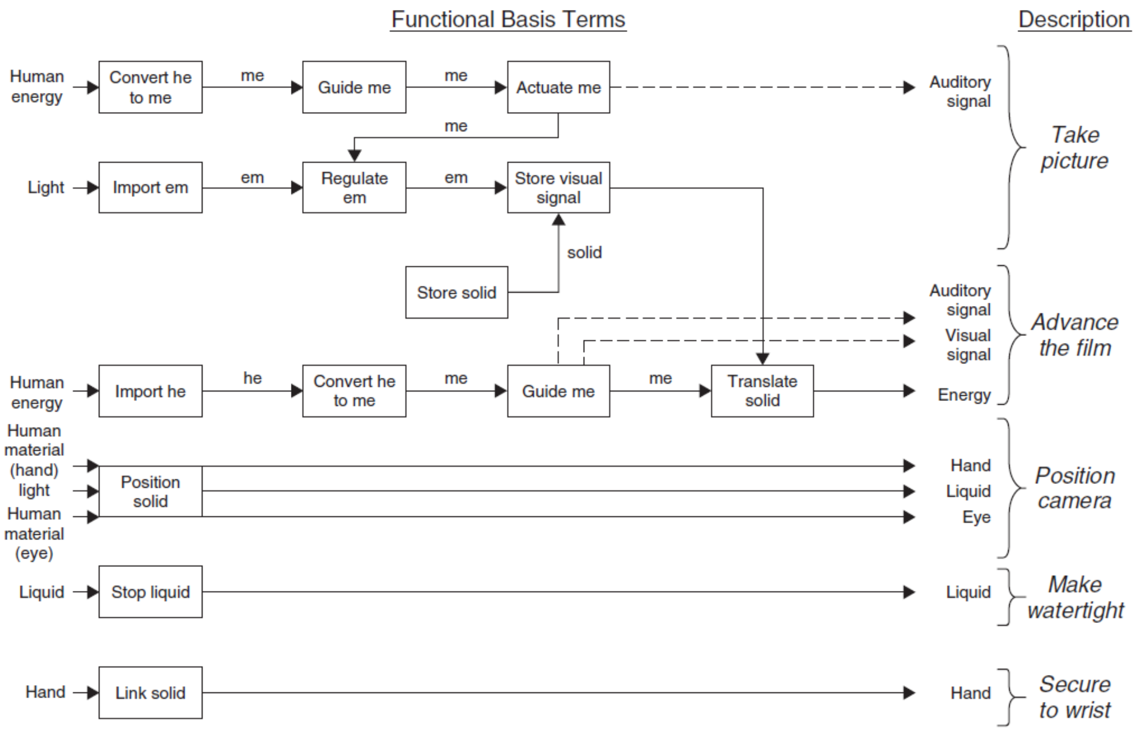

Figure 6.3 Function structure for the Kodak Water & Sport Camera, Source: [Kutz. 2007]

N. For performing a morphological analysis of the subject system:

A morphological analysis process according to authors [Dalrymple et al. 2011] is a standard part of engineering curricula that involves decomposing a design into sub-functions, and mapping the sub-functions to their potential means and/or components in a table (morphological chart) and so a populated morphological chart serves as a tool for generating and capturing multiple design possibilities.

N.1 For creating a morphological matrix (constraints and solutions) for the subject system:

According to authors [Dalrymple et al. 2011] a morphological matrix is a tool used during a morphological analysis process to capture the information used to generate design ideas, the chart utilizes a table structure where the first column contains the sub-functions to be performed by the product, each on a separate row, the subsequent columns contain various means that can be used to accomplish the identified sub-functions, then a sub-function and all related implementation means are listed on the same row (e.g. Functions are listed in one column, components in an adjacent column, and related function(s) and component(s) listed on the same row.) A design concept for example, is formed by combining a means for each sub-function and repeating this process with every possible combination of sub-function means that can generate an exhaustive list of design concepts

O. For executing a subtract and operate (SOP) procedure for the subject system (as part of a functional analysis of it):

Remind your students that Otto and Wood's Subtract-and-Operate procedure (SOP), [Otto & Wood. 2001] is a bottom up approach to developing a function tree and it's one of the easiest ways to check the effects of parts in a system and better understand the function of its components but it is not the only one, so, help them choose an appropriate method based on resources available, their knowledge and expected learning outcomes

P. For determining the manufacturing process(es) of the product under analysis:

Ask your students to perform a physical analysis of a product's manufacturing marks and to look for individual characteristics that manufacturing processes and raw materials imprint on manufactured objects (e.g. Machining and moulding leave characteristic imprints related to the tooling and raw materials (plastic, metal, etc) used to produce a given part), also have them look for visible manufacturing marks; traces of known materials, characteristic odours and other visible signs that can be detected through visual inspection alone and can help as a starting point for identifying a product's composition and manufacturing history. Alternatively students can try to identify simple microscopic differences in the product's surfaces by experience alone or try to detect more complex ones through automated software and mathematical algorithms that can recognize specific patterns, through these past actions then, students can extract every possible bit of information from the physical markings of a product to help come up with a rather plausible reconstruction of what the original engineering decisions might have been.

Q. For hypothesizing on the subject system's volume of production

Ask your students to consult the product's manufacturing marks and selection of materials to help answer this question

R. For determining the materials of the product under analysis and its components:

The identification of commonly used materials in product manufacturing is a complex task, students can and should rely on part identification and markings indicated by the manufacturers since they are vital in helping identify the materials themselves however, specialized resources exist for it .Suggest your students for example to make use of the published tables and research by authors [Otto and Wood. 2001] and [Ashby. 2005] concerning the properties and identification of engineering materials found on common consumer products to come up with a reasonable approximation to the composition of the parts and components in your product in case no other analytical tools are at hand for the determination of the materials in the product's parts. Indeed you could just straightly ask them to consult Ashby's tables: "Names and applications of metals and alloys"," Names and applications of polymers and foams" and "Names and applications of composites, ceramics, glasses, and natural materials" since they list the names and typical applications of materials commonly found in every day consumer products. In fact, even when trying to determine the material composition of your subject system, just by checking author Ashby's process-material matrixes, and in case a sound, rational, economic and technical decision was taken in the manufacturing of your product's parts, then the use of his published selection charts will also provide a quick approximation to what the actual manufacturing process applied was. Thus, author Michael Ashby's book "Materials Selection in Mechanical Design" provides a wealth of information on how to correlate material properties to their identification, the reading of such book is strongly suggested for those interested in further information about verification of materials and manufacturing processes in reverse engineering. Additionally, students should also consult the table "Common Elastomers and Supporting Information (Fillers)" in the Material Identification Tools (Fillers) section on the online resources by [Otto & Wood. 2001] since this table helps reverse engineering students identify common elastomers (fillers) found in consumer products and which manufacturers need to specify them by combining a material and shape label into 2 letters and dashed into the base material label to name them so students can simply compare the ISO label to the corresponding material and shape. Also they should consult the Tables "Identifying Plastic Types"; "Common Plastics and Supporting Information" in the Material Identification Tools section on the online resources also presented by [Otto & Wood. 2001] since these tables serve as a first starting point in trying to determine the material composition of a part under study and they could become, along with an educated internet search and a visit to a local library the easiest sources of information for determining a material's composition. Finally, unconventional thinking should be tried when identifying materials , in the book "Identifying Wood: Accurate Results with Simple Tools" by [Hoadley. 1990] for example, the identification of over 180 types of wood is done with only a loupe or microscope and unconventional methods such testing the floatability of woods are used to identify different types of woods. Try to identify the material used for each of the product's parts, and be as specific as you can, but If you can't identify it, determine at least the properties (stiffness, hardness, clarity, and so on) of it as suggested by author [Durfee. 2008]. In any case, the identification of materials is a common analysis in engineering, its contextualisation into an EREA doesn't change its nature and as such no new knowledge is contributed to it from this collection of resources instead it only provides a quick way to perform such an analysis via selected tasks and links to existing resources on the topic. The information about materials presented in this collection of resources then serves only as a first step in the approach to decoding materials and processes in consumer products, and the resources presented in the "Miscellaneous resources" section of this same document intend to provide comprehensive information about the topic.

S. For checking your subject system's for compliance with DfX and suggested design and usage guidelines:

Ask your students to check their subject systems in the following areas to name a few: DfAssembly; DfManufacturing, DfEcological impact, DfRecycling, DfProducibility, DfMass production, DfCost, DfFunctionality etc, as per their relative importance given at your syllabus so only those DfX analyses relevant to your subject system get full attention and the rest are only performed at very basic level.

Additionally, remind them that they should start the DfX analyses assuming that many of the parts that constitute a product are already standardized ones and they must have followed some of the widely known DFX principles.

T. For performing a Design for Manufacturing / Assembly of your subject system:

Depending on the resources or knowledge available a fully fledged DFMA analysis can be excessive to ask to your students so only tasks and questions that provide a good introduction to the topic and their answer is well within the reach of students should be attempted

U. For performing a Design for Assembly analysis of your subject system:

Ask your students to try to identify the following rules in Table 6.10 below compiled by author [Jounghyun. 1994] and identify if some of them may conflict with each other or with unavoidable design decisions, For example DFA (Design for Assembly) rules for design of orienting surfaces may contradict another known DFA rule in the design of symmetric surfaces (e.g. By inducing asymmetry); In the same way, design of stacked products as DFA suggests, can reduce assembly costs but might as well increase the manufacturing ones:

DFA Rule	Present in the Product under Analysis	Tradeoffs at

	Yes	No	particular circumstances / Conflicting rules detected?
1. Reduce number of parts			
2. Design a stacked product			
3. Design a good base component			
4. Use easy mating method			
5. Use symmetrical parts			
6. If parts cannot be symmetrical use increased asymmetry			
7. Provide means to easily grip and hold the part			
8. Design particular orienting surfaces			
9. Avoid parts that tangle, nest or topple.			

Table 6.10 Examples of DFA Rules, Source: [Jounghyun. 1994]

Alternatively, suggest your students to check their product's design for compliance against the following list of DfA' best practices by authors [Boothroyd & Dewhurst. 2002] seen in Table 6.11 below.

Best Practice	Product Design's Compliance	
	Yes	No

1	Minimize the number of parts in the assembly.		
2	Minimize the number and types of fasteners used.		
3	Avoid components that are difficult to assemble (springs, tie wraps).		
4	Standardize fasteners and components.		
5	Use modular sub-assemblies.		
6	Use multifunctional parts.		
7	Use self locating features.		
8	Minimize reorientations for assembly.		
9	Minimize tooling requirements.		
10	Maximize accessibility to parts and subassemblies		

Table 6.11 Design for Assembly Guidelines by [Boothroyd & Dewhurst. 2002]

V. For checking your subject system's compliance with Design for Disassembly principles:

Tables 6.12 and 6.13 below can be given to your students to aid in the analysis of DfD compliance by asking them to check their subject system's design against the principles listed therein, namely:

DfD Principle	**Possible Cases**	**Compliance of Product under Analysis**	
		Yes	**No**
Less Disassembly Work	Integration of parts of same material		
	Avoid subassemblies with non-compatible material combinations		
	Minimize number of joining elements		
	Use compatible materials		

	Group harmful materials into subassemblies		
	Limit unfastening forces for easy manual unlocking		
	Provide easy access for harmful, valuable and reusable parts		
	Provide easy access to disjoining, fracture or cutting points		
Foresee event	Avoid ageing and corrosive material combination		
	Protect subassemblies against soiling and corrosion		
Easy Disassembly	Use joining elements that are detachable or easy to destroy		
	Use the same fasteners for many parts		
	Avoid multiple directions and complex movements for disassembly		
	Minimize number of fasteners		
	Standard and simple joining techniques		
	Linear and unified disassembly direction		
	Avoid turning operations for disassembly		
	Enable simultaneous separation and disassembly		
	Avoid necessity for simultaneous disassembly at different connections		

	Open access and visibility at separation points		
	Accessible drainage points		
	Operating spots for destroying separation tools		
	Include nominal breakpoints		
	Base part product structure		
	Centre-elements on base parts		
	Marking of central joining elements for disassembly		
	Sandwich structure with central joining elements		
	Avoid metal inserts in plastic parts		
Easy handling	Leave surface available for grasping		
	Standard gripping spots near centre of gravity		
	Avoid non-rigid parts		
	Enclose poisonous substances in sealed units		
	Parts should be easy to pile or store to save room		
	Design of parts for easy transport		
Easy separation	Avoid secondary finishing		
	Provide marking or different colours for materials to separate		
	Avoid parts and materials likely to damage machinery		

	Use of parts with narrow tolerances		
Variability reduction	Use standard subassemblies and parts		
	Minimize number of fastener types		
	Limitation to number of different materials		
	Standardize parts for multiple use		
	Limit material variability		

Table 6.12 Design for Disassembly Guidelines, Source [Willems. 2005]

Table 6.13 from author [Chiodo. 2005] is shown below:

Guideline		**Product Design's Compliance**	
		Yes	**No**
1	Choose recycling-compatible materials (as far as possible).		
2	Avoid using materials which require separating before recycling (re-use is ok, subject to performance testing).		
3	Use as few components and component types as possible (without compromising the structural integrity or function of the product).		
4	Integrate components (which relate to the same function) where possible.		
5	Standardise the use of fasteners – use commonly available parts and maintain consistency within the design.		
6	Make components easily separable.		
7	Apply non-contaminating markings (e.g. Through etching or moulding) to materials for ease of sorting.		

8	Maintain good access to components and fasteners. Consider making the plane of access to components the same for all components.		
9	Do not paint plastic parts or other coatings which may contaminate other plastics when recycled.		

Table 6.13 Design for Disassembly Guidelines, After: [Chiodo. 2005]

W. For checking your subject system's compliance with design for end-of-life principles:

Have your students check the paper "Design practices for improving the end-of-life disposal of telecommunications equipment" by [Low et al. 1996] as one of the available resources to get information, guidelines and best practices on disassembly; recycling, recovery or remanufacturing topics.

X. For trying to find design patch-ups in your subject system:

Tell your students that conventional DfX suggestions tend to provide localized design patch-ups while most useful and cost saving redesign strategies are those that globally redesign the product. Ask your students to try to find this kind of patch-ups as an exercise.

Y. For performing a Life Cycle Inventory analysis:

A life cycle Inventory analysis is defined by authors [Graedel & Allenby. 2003] as "An evaluation of the environmental effect of raw materials taken from the environment (inputs) and the waste released back into the environment (outputs) by an industrial system" and the execution of this analysis in a reverse engineering exercise is suggested by authors [Comparini & Cagan. 1998] whose basic approach (Inventory: Quantification of inputs (energy, raw material) and outputs (environmental releases) to the environment throughout the life of the product or activity + Impact Assessment: Quantitative and/or qualitative assessment of the effect of the environmental loads identified in the inventory component) is easy; comprehensive and well suited to this educational activity and thus it is shown here in Figure 6.4 below.

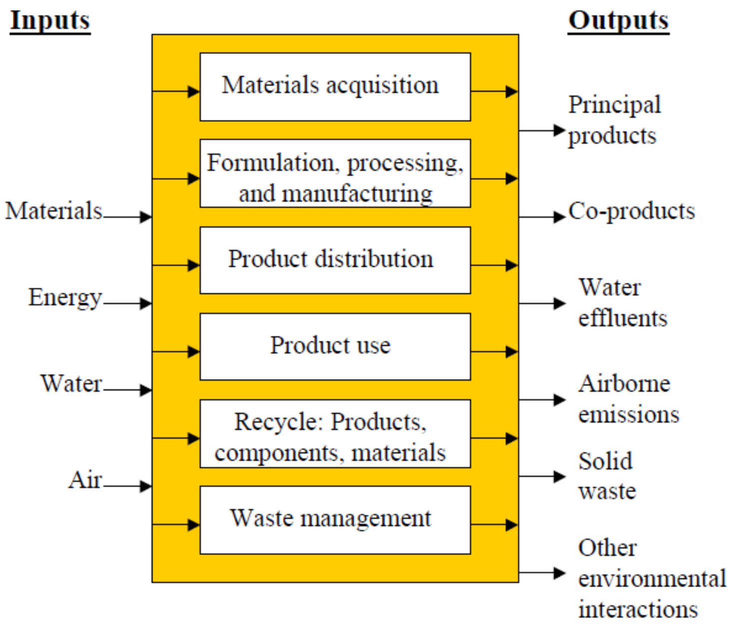

Figure 6.4 Generic Example of a Life-Cycle Inventory, Source: [Comparini & Cagan. 1998]

It can be said that the material inventory along with the information from the extraction, processing, transportation, use and waste management stages comprise the inventory of relevant environmental inputs and outputs.

Figure 6.5 below then shows the stages of a life-cycle inventory analysis of a Kodak single use camera by [Comparini & Cagan. 1998] and can be given to students as an aid in creating the analysis specific to their own subject system

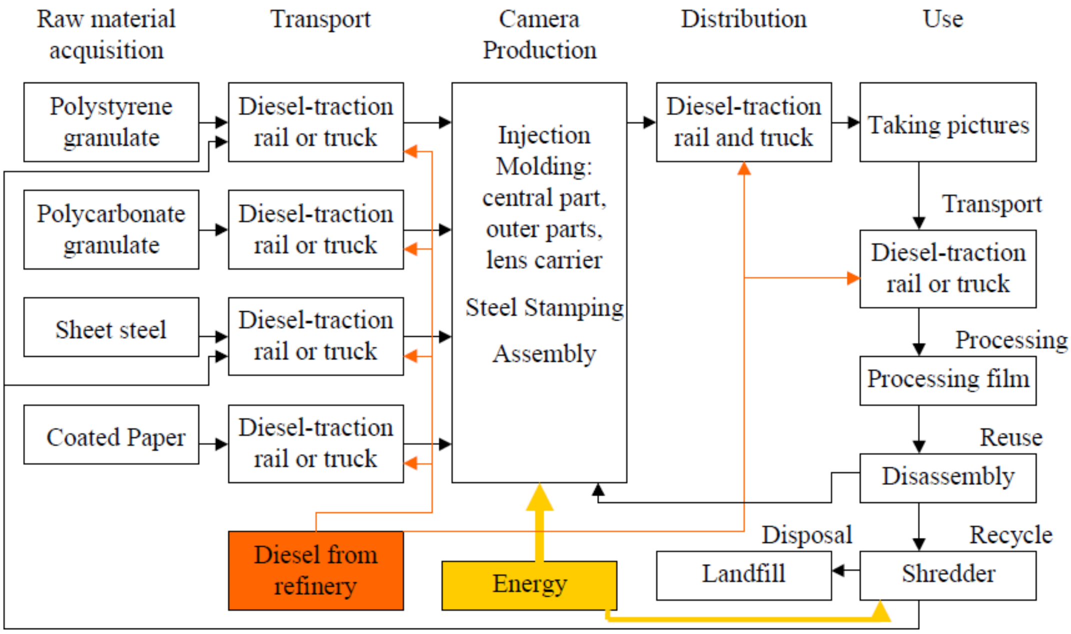

Figure 6.5 Stages of Life-Cycle Inventory Analysis of a Kodak Single Use Camera, Source: [Comparini & Cagan. 1998]

Z. For the benchmarking of the subject system:

If resources allow it, have every team analyse a competing product or have different team analyse different products so the whole class can access the results about competing products and compare them against their own

AA. For performing a costs analysis of the subject system:

You can ask students to determine the prices of their product's components by using value techniques or just simply basing it on their size, relative complexity in terms of manufacturing, as well as the material that they are made of. Additionally, when determining if your product can be considered cost effective based on customers and market demand you'll need an approximation to the real cost of the product which can be derived by yourself or your students or obtained from product teardown webpages available on the web or indirectly referenced in the "Miscellaneous Resources" section of this collection of resources

BB. For recovering, developing and reporting Potential PDS (Product Design/Data Specifications) a.k.a "Requirements List" for the product under analysis:

Ask students to prepare a document to record the performance specifications for the item by formulating a specification tree with the same structure as an equipment-breakdown hierarchy or structure. (at all levels but the lowest (e.g. Piece components) specification-tree entries describe the item's functional aspects. At the piece-component level, the entries in the performance specification are basically of the dimensional kind)

CC. For digitizing and modelling your subject system:

Ask your students to create computer models of the product under analysis given that the rise of computer assisted tools in the area of engineering design benefits from having a fully disassembled product to create a computerised version of it and that allows for the simulation of its workings. Alternatively suggest your students to engage in a "big picture" reasoning (e.g. basic reasoning + analytical tools) instead of a model based reasoning in case the creation of models is outside of their reach or of the depth of analysis set by the instructor

DD. For determining the major scientific, physical principles behind the full development of the subject system:

Ask your students to identify a library of general principles or common modules that make the product work and that serves them as reference for the drawing of conclusions or further analyses

EE. For identifying modifications to an initial design a.k.a "Side effects":

Refer you students to authors' [Chikofsky & Cross. 1990] research where it is stated that: "Side effects or modifications to an initial design can lead to unintended ramifications and side effects that impede a system's performance in subtle ways" and that "some types of information (such as the already mentioned unplanned ramifications and side effects) are not shared between forward and reverse engineering processes, however reverse engineering can provide observations that are unobtainable in forward engineering and can help detect anomalies and problems before users report them as bugs."

FF. For positioning your subject system on Kano's model of customer requirements:

This is a task for advanced students, implement it as deemed pertinent and refer your students to the research by author Noriaki Kano, [Kano et al. 1984] if need be.

6.5.2.6.1 Suggested Questions and Analyses Specific to the Guided Example Presented in Resource 7

Although the methodology presented in Resource 5 is already comprehensive enough, it is written in a general style intended fit any type of product under analysis, the questions below though intend to be a practical representation of that general approach and help professors to come up with meaningful questions about disposable cameras. Students undergoing an EREA with a disposable camera as subject system then, should get the answers to the questions suggested below, namely:

- See the differences between disposable cameras (similar products) from different manufacturers
- Discover how the camera takes a picture. Sketch the entire mechanism that controls the shutter. Explain how this works from the instant you touch the button to the time the film is exposed and what determines the exposure time
- Determine the type of electric components used in the flash unit
- Describe the overall construction of the camera and compare it and contrast it to analogue cameras (or even digital ones) on the following items:
  - Technology: Electronic vs. Mechanical or evolution and integration of both
  - Mechanical design of body, shutter, etc.

- Product complexity
- Ease of assembly/servicing
- Labour content
- Features
- Ease of use
- Styling

- Determine what the main functions of the product components are, (e.g. What is the function of the capacitor in the flash of a camera?)
- If you have access to the full product family of Kodak's of Fujifilm's disposable cameras; Identify common elements or even subsystems in all of them
    - If two or more different single use cameras are available (even from different manufacturers) compare their components and answer how many parts are the same; how many parts are different, try to explain the similarities and differences, compare their ease of assembly and disassembly, which is easier and why.
- Identify design deterrents that impede the user to reload the camera with a different brand of film or that impede to reload the camera at all
- Evaluate if the fact that parts snap together instead of being welded helps the recycling of the process, and if so, why?
- Identify colour codes in the camera parts or any other actions to make the product easy to sort out and more recyclable
- Identify elements of a high volume production in the design of the camera
- Determine when the camera was manufactured
- Analyse what materials were used for the housing, how it was manufactured and why the front piece has different surface finishes.
- If possible compare different generations of disposable cameras by the same manufacturer and discuss any design change (an alternative is to compare old drawings of them against current ones)
- Determine what the shutter blade is made of and how is it manufactured
- Determine what fastening and joining method is used for most of the camera parts. Why you think this was used and what advantage it had?
- Discuss the question "How do Kodak's new cameras compare to the original design?" in case dissecting an old camera and one of the newer models is possible
- It may be that the disposable cameras' internal pieces are already numerated, can you guess why?

- Assess whether it is helpful to know how many times the camera parts have been used and why?

6.5.2.6.2 Minimum Case Analysis of the Subject System

Presented above, practical advice for the analysis of a consumer product in the context of an educational reverse engineering context was given , however if you'd like to try your own approach to analyzing a consumer product, the following information based on the findings from the doctoral research from which this collection of resources originates is presented.

PDS (Product Design/Data Specifications) items serve as the main guiding effort in executing the analysis part of the methodology for educational reverse engineering analysis presented in this document because the analysis of each of such items produces data about a product under analysis that in conjunction with technical tests and educated assumptions of your own yield a better understanding about it. Table 6.14 below shows the set of PDS items that if analysed will result in a level of knowledge about the subject system minimum enough to carry on with the educational analysis of it with acceptable results and the least consumption of resources (e.g. lab time, tools, people involved), you can try your own combination of tests that as long as they cover the areas mentioned therein

In Table 6.14 below to name but one example, it can be seen that by analyzing the patents of a product, information about the product itself in the areas of (Function and feature; context, usability, processes and materials) as well as information from the manufacturer in the area of competitive intelligence will be obtained.

It should be kept in mind though that the methodology presented already in this collection of resources, includes a variety of analyses beyond those recommended for a minimum effort case and Table 6.14 below should only be considered in those information wealth vs. effort scenarios where resources available are rather limited.

PDS ITEM	**Product**						**Manufacturer**	**Total Count**
	Function and Features	**Context**	**Personality**	**Usability**	**Processes**	**Materials**	**Competitive Intelligence**	
Costs	x				x	x	x	**4**
Geometry	x	x	x	x				**4**

Market Constraints	x	x	x	x				**4**
Patents	x	x		x	x	x	x	**6**
Performance	x			x	x	x		**4**
Target Cost	x	x	x				x	**4**
Total Count	**6**	**4**	**3**	**4**	**3**	**3**	**3**	

Table 6.14 Product criteria against information it provides Minimal case analysis

Table 6.15 then, expands on the PDS items mentioned in Table 6.14 above to understand why they were chosen for a minimum case analysis and what they entail in the comprehensive scheme of an EREA

Heading	Description	Examples	Associated Reverse Engineering Test	Provides insight mostly about: Product, (Functions and features, context, personality, usability, processes, materials) Manufacturer (Competitive intelligence) -Listed in Order of Relevance-
Costs	Related to maximum permissible costs bearable by the product producer	Manufacturing costs; cost of tooling, investment and depreciation, ex-works	Value analysis	Product processes Product materials Product functions and features, Competitive intelligence
Geometry	Related to size of the product and the relation to its environment	Height; breadth, length, diameter, space requirement, arrangement, connection, extension	Measurements, domestic and international standards and guidelines	Product functions and features Product context Product personality Product usability
Market Constraints	Different markets conditions that may modify the PDS to suit different	Unsuitable commercial names, symbols	Analysis of global products from a given company	Product functions and features Product context Product personality Product usability

	countries			
Patents	World search and verification that the product design must not infringe any relevant rights	Patents; copyrights, intellectual property, etc.	Patent search, use of competitive intelligence tools	Product functions and features Product materials Product processes Product context Product usability Competitive intelligence
Performance	Related to the operating characteristics and limits for safe and satisfactory use of a product	Speed; power, positions, orientations, resistance to tampering, types of communicati on with user	Standardized laboratory tests	Product functions and features Product materials Product processes Product usability
Target Cost	The desired price range, considering average retail prices of present devices , allowing for overhead costs and unforeseen events	Targeted manufacturi ng costs per completed and packaged device	Value analysis, benchmarking data	Product context Product personality Product functions and features Competitive intelligence

Tables 6.15 PDS Items; Description, Examples, Associated Test and Derivable Information

6.5.2.6.3 Alternative Methods of Analysis for the Product Analysis Stage

Alternative to the general method of analysis suggested already for the product analysis stage of an EREA several other options are presented here that also provide meaningful results and that allow the continuation of the proposed methodology for the educational reverse engineering analysis of consumer products of this collection of resources without any major knowledge gaps

For example, another “minimum case” scenario for the analysis of a consumer product can be derived from author Michael Ashby’s research on the assessment of the ‘Product Character’ of a product which he defines as “a measure of the degree to which a product meets (or exceeds) the expectation of the consumer in all three of these: (requirements)

Functionality, usability, and satisfaction", [Ashby. 2005], his method of analysis can be used instead of the method proposed here by the author of this collection of resources, and once done, the work on the rest of the method for EREA presented in this document can continue. The sole answer to the assessments listed below then, will bring an accurate representation of the product's character and will allow you to continue with the other stages of the methodology presented in this document, namely:

1. Rate the user satisfaction after operating this product (e.g. Product must be life-enhancing)

2. Rate the usability of the product (e.g. Product must be easy to understand and use)

3. Rate the functionality of the product (e.g. Product must work properly, be safe and economical)

4. Rate the user's final experience, beyond proper technical design

5. Rate the following qualities about the product under analysis

5.1 Context (Intentions of the product)

5.1.1 Who? (e.g. Men; women, children, elderly)

5.1.2. Where? (e.g. Home; office, Europe, Africa)

5.1.3. When? (e.g. Day; night, all the time, occasionally)

5.1.4. Why? (e.g. To fill a basic need, to meet an aspiration)

5.2. Personality

5.2.1. Aesthetic (e.g. Colour; transparency, form, symmetry, feel, texture, sound)

5.2.2. Associations (e.g. Wealth; power, learning, sophistication, plants, animals, high tech)

5.2.3. Perceptions (e.g. Playful; serious, feminine, masculine, expensive, cheap, youthful, mature)

5.3. Usability

5.3.1. Physical matching

5.3.1.1 Bio-metric (e.g. Scale, movement, posture, work height)

5.3.1.2. Bio-mechanical (e.g. Force, energy, attention span)

5.3.2 Information transfer

5.3.2.1. Operation (e.g. Text; icons, symbols)

5.3.2.2. Feedback (e.g. Audible signals; visual signals, tactile signals)

5.4. Manufacturing Processes (all that apply.)

5.4.1. Joining (if applicable)

5.4.2. Shaping (if applicable), (e.g. Casting; deformation, moulding, composite, powder, rapid prototype, etc.)

5.4.3. Surfacing (if applicable)

5.5. Materials (all that apply)

5.5.1. Ceramics (if applicable)

5.5.2. Polymers (if applicable)

5.5.3. Metals (e.g. Steels, alloys, etc.)

5.5.4. Natural (if applicable)

5.5.5 Composites (if applicable)

If complemented with as much information about the inner construction and working of the subject system (even if it is obtained through data collection only), author Ashby's approach provides a right approximation to general the goals envisioned for this stage. If Ashby's method is skipped at this stage though, it can still be used at the subsequent "Knowledge Synthesis" stage as a sort of "checklist" for the synthesis of everything known about the subject system so far.

Another method for product analysis, alternative to the one suggested in this collection of resources can be derived from the recommendations for analyzing the societal and economical aspects of a subject system by authors' [Devendorf et al. 2011] who state that for engineers to be successful in the future they must understand the influences that determine how engineered products and systems are deployed, such influences are defined in Table 6.16 along with questions for a sample analysis. Note that for comparison purposes in the overall analysis method suggested in this dissertation even more factors are considered that those by [Devendorf et al. 2011] but it is left to the criteria of the professor in turn which ones to choose and investigate.

Influence Group	**Definitions**	**Sample Questions**	**Your Findings**
Global Factors	The influences that result from cultural and geographic features specific to a region or originating from the interaction of two or more culturally/geographically distinct regions	What is the purpose of the product, how does it work, what are the intended global market segments, and how are cultural needs addressed with the product?	
		How do people with different cultures and demographics use the product and what are the functions that the product fulfils?	
		How does the manufacturer address global market needs in the design of their current line of products?	
		How can the manufacturer address these issues better in their future global product lines?	
Economic Factors	The influences that result from the economic conditions at the time of a product's development and its past, present, projected sales and	What were the economic conditions at the time this product was designed and manufactured and how are economic issues reflected in the	

	support life cycle	product’s design?	
		What tools are required, how many steps are needed and how easy is it to dissect the product?	
		What are the competing products, and how are these economic issues reflected in the design of the product?	
		Given current and projected economic conditions, what can engineers at the company do to enhance the economic impact of the product on the company?	
Environmental Factors	The influences that result from the product’s environmental impact during development, manufacturing, sales, operation and disposal	What are the planned environmental impacts of this product and what are the environmental factors engineers had to consider in the design of the product?	
		What material type and manufacturing process was used for each major component or group of components?	
		What are the actual environmental impacts of this product and	

		what are the environmental factors engineers had to consider in the design of the product?	
		How can the company reduce the cradle to grave environmental impact in future products and product lines?	
Societal Factors	The influences that result from considering the impact like safety, ergonomics and lifestyle on the people and society within which a product is being used.	What is the planned impact of the product on the culture and lifestyles of the customer base?	
		What is the primary function of each major component or group of components? (Noting how its structural form helps fulfil its function)	
		What is the actual impact of the product on the culture and lifestyles of the customer base?	
		How can the company address social use issues such as safety, ergonomics, product use experiences, and lifestyle impact better in future products?	

Table 6.16 Analysis of Factors that Influence the Design of a Product, Source: [Devendorf et al. 2011]

Again, if complemented with a technical analysis of the inner workings of the subject system the research by authors [Devendorf et al. 2011] can also serve as a substitute to the analysis methodology suggested in this resource to reach similar results.

The last of the alternate method for the analysis of a subject system in the context of an EREA can be derived from the research by author [Khandani. 2005] who suggests the analysis of a subject system with an emphasis on the evaluation of the components of a design solution and from which a set of questions and tasks exemplifying such approach are listed below

1. Functional analysis: Determine and evaluate how the given design solution will function properly
2. Industrial Design/Ergonomics: Determine how people interact with the product
3. Product safety and liability: Evaluate the safe design (e.g. Embedded safety, protection for users, warning messages) measures to avoid damage to humans, property or the environment
4. Economic and market analysis: Understand a product's profit, sale features, potential market, cost of manufacturing, advertising, etc.
5. Mechanical/Strength analysis: Understand a product's mechanical features such as static, maximum and repetitive loads, shocks, heat transfer, deformations, etc. and their behaviour across the product life cycle.
6. Electrical/Electromagnetic: Understand its interaction with other electronic devices without affecting them
7. Manufacturability/Testability: Evaluate its design features and suitability for production; operation, maintenance, and disposal along the product's life cycle
8. Regulatory and Compliance: Understand about the product's target markets and uses

Like in the alternate methods of analysis mentioned above, if this particular one is chosen, once it is done, the rest of the stages of the EREA methodology suggested here can be continued. If the method is skipped altogether though, it can still be beneficial to the purposes of an EREA since the answer to the questions listed above can be used as a sort of checklist to aid in the synthesis processes of the "Knowledge synthesis" stage of the methodology

Finally it should be mentioned that if truly needed, a reverse engineering analysis in its absolute minimum expression can be done through an analysis of the patents of the product.

6.5.2.7 A Suggested Pedagogy for the Teaching of the Product Reassembly Stage

The following advice has proved successful in the past for the attainment of the goals of this stage and is categorized here for an easier reading by professors in charge of EREA, namely:

A. General Advise for the stage:

- If for some reason, workload distribution at the disassembly stages was not equal ask your student that those that didn't have enough hands-on experience in past stages to be the ones allowed to touch the product at this stage and take turns with each task
- If time is not an issue you could ask your students to try to assemble other teams' devices by following their reassembly instructions, in this way students get familiarized with a varied number of consumer products in one session.

B. For reassembling the subject system:

- Ask your students to be especially careful about fragile parts and those difficult to reassemble.
- Ask them to be careful that no product parts are left over.
- Advise students to follow ordered and methodical product reassembly practices.
- Suggest your students to use small amounts of oil to lubricate mating parts, if necessary
- If needed use special tools (e.g. Ring compressors) to put parts back into position
- Be sure to use the recommended tools when needed (e.g. a Torque wrench)
- If using a torque wrench ask your students the following:
    - To finger tighten bolts before using the torque wrench
    - To try each torque wrench on an exterior bolt before using it for real to see how it works.
    - To torque all bolts to the factory specification (e.g. Given values and pattern)
    - To not over-tighten any of the bolts, some parts may be made of aluminium or plastic and the threads can get stripped very easily.

C. For examining the reassembled device:

Once the product is completely together and students have no parts left over, ask them to operate it, if it does not sound or feel like it did before, or if a strange smell develops tell them to stop immediately to figure out what is wrong.

D. For straightening out once the stage is done:

Although actual practices change from institution to institution ask your students to take provisions for proper keeping, cleaning and maintenance of involved tools whether there are laboratory assistants for help or not, remind them that the necessary tools for the next stage should be kept at hand though. the following actions are suggested once the product has been reassembled, namely:

- Remove all products from the table or working area
- Return all tools where they belong and no empty tool slots remain
- Lock toolboxes and check everything is in order
- Wipe any oil or dirt off the table and dispose of the cleaning cloths
- Ask your students to do a tool inventory so they count and record all tools in their tool box and compare this with the tool list they were are given, ask them to list any shortages and overages of it if needed

6.5.2.8 A Suggested Pedagogy for the Teaching of the Product Performance Test II Stage

The following aspects to note have proved useful in the past to attain the goals of this stage, namely:

A. For testing the performance of the reassembled Product:

Ask your students to perform as closely as possible those tests of the Product Performance Test I stage or to prepare for additional measurement and testing in case new information becomes available at this point

B. For storing the subject system and auxiliary tools once the stage is finished:

Suggest your students to store the devices in a place where they are able to access them for the next class session in case more than one class period is needed to test the device.

6.5.2.9 A Suggested Pedagogy for the Teaching of the Knowledge Synthesis Stage

The advise presented here for the proper development this stage is strongly based on a varied of findings by researchers dispersed across several domains of knowledge, the execution of the sequence of tasks suggested for this stage then, requires a minimal knowledge of the reasons why they are asked and the background under which such tasks are performed, and as such the tips and suggestions presented below intend to provide an explanation of why the steps in the suggested methodology for educational reverse engineering analysis were asked, how such steps should be executed and why preliminary, cumulative results from previous stages (e.g. Disassembling , testing and analysis stages) can be finally synthesized and contextualised at this point, namely:

A. For gathering and integrating all relevant data, information and knowledge about the product under analysis:

Tell your students to consult all available sources and to integrate everything, suggest them for example, to make use of dynamic representations such as formatted templates independent of ontology engineering tools that can provide the overall view necessary to infer the original needs the product under analysis fulfils and make sense out of the interrelated features of a product in terms of materials; functions, aesthetics and interfaces.

Table 6.17 below shows an example developed specifically for this collection of resources of what could be considered a “Knowledge worksheet” which is one of the many possible options to help organise and contextualise all available data in support of an EREA. Indeed such table was developed based on the previous work by [Zachman. 2002] and [Urbanic & ElMaraghy. 2008] and it consists of central columns headed by an assortment of wh- questions that intend to uncover the rationale and history behind a product, and left columns listing the life phases of a system/product that are used as the guiding criteria for answering the wh- questions along the full lifecycle of the product under analysis, the intersection in the central columns then are filled by the students with the information obtained for group analysis and interpretation, and one table at a time can be created and populated focusing only on one PDS aspect of the product at the time

The advantage of such structure is that it establishes definitions rather than a process that transforms inputs to outputs, and as such, it is predictable and produces repeatable results irrespective of the practitioner’s skills; what’s more, it allows the accumulations of information about a product under analysis at different levels of abstraction and the resulting data can still be further grouped at different levels of detail to associate them to design ,manufacturing, or usage domains so that by asking questions such as what (data); how (function), where (interconnection) and why (motivation) about a product’s components and their features, the final design data can transform ideas into implementations and can then be interpreted, contextualized and made useful by common problem solving techniques of systems analysis.

Another advantage of such structure is that it also serves as a basis for a product’s architecture since it is the representation of the fundamental structure of complex products and can yield the total set of descriptive representations relevant for describing them. The intersection between cells then, are the classifications that help describe a product.

Finally and given that product design entails the integration of different systems in consumer products they can be of a mechanical, electrical, electronic or computing nature and they in turn will be integrated by further subsystems at different levels of resolution. It makes sense then, to employ a system analysis approach to the reverse engineering of consumer products and do so through each of the life phases of a system in order to gain a full understanding of a product from its origins to its ends. Guideline VDI 2221 for example [VDI Verlag GmbH. 1987], lists the life phases of a system which proves suitable to the analysis of a consumer product, namely: Preliminary study (Market need task, Company potential/goals, Product planning, Task clarification), System development (Design), System production (Manufacture, Assembly, Test), System installation (Sales, Service, Distribution), System operation (Operation, Consumption, Maintenance), and System replacement (Recycle, further use, Environment disposal) Table 6.17 then, shows such phases in the context of an EREA to provide a structure for the organization and further design intelligence reconstruction of the product under analysis

PDS Item under analysis		What?			How?		Where?		Who?		When?
Life phases of a system	Indicative phase ideas and concepts	Object	Idea	Action	How	Process transformations	Place	Networks	Organization members	Target people	Timing
Preliminary study	Market need / Task										
	Company potential / Goals										
	Product planning										
System development	Design										
System production	Manufacture										
	Assembly										
	Test										
System installation	Sales										
	Service										
	Distribution										
System operation	Operation										
	Consumption										
	Maintenance										
System replacement	Recycle										
	Further use										
	Environmental disposal										

Table 6.17 Standardized Template for the Organization of Design Data in a Reverse Engineering Analysis

B. For identifying what kind of scientific study method will be selected to start an analysis and synthesis process:

Tell your students that according to the type and breadth of empirical knowledge available to the analyst, two types of methods can be selected, being them: Analytic, whose approach draws conclusions about causes on the basis of given effects, or synthetic whose approach infers effects from known or given causes

C. For explaining why the main problem the subject system must solve has nothing to do with its construction per se:

Explain your students that it is advisable not to assume any specific functional relationships between individual components at least at the beginning of the analysis process since the structure and role of individual components can only be determined based on its relationship to the function of the product as a unit

D. For positioning all the information obtained about the product at the design stage where it generated:

Direct your students to the research by authors [Buura & Myrup. 1989] who provide several examples for it, namely:

- Function principles and subsystems are tested in experimental laboratory setups
- Appearance and ergonomics are evaluated in design mock ups
- Product functions are evaluated in function models
- Usage, functions, reliability, marketing properties and the such are evaluated on prototypes
- Manufacturing properties and quality indicators are tested on preproduction series

E. For finding possible design patch-ups in the subject system:

Tell your students that conventional DfX suggestions tend to provide localized design patch-ups while most useful and cost saving redesign strategies are those that globally redesign the product.

F. For detecting design choices in the product under analysis that weren't optimal but likely a trade off against a number of different situations:

Explain your students that in real design experience, design choices and decisions can be iterated only within limited resources and timeframes.

G. For identifying conservative, non optimized design solutions in the subject system:

Refer your students to [Calderon. 2008] where it is stated that "Uncertainties in design during initial stages force designers to work on conservative, non optimized solutions that can lead to inefficient designs and eventual lack of competitiveness so these uncertainties need to be identified and avoided as earlier as possible in the design process"

H. For finding out if the subject system is a generational device:

Remind your students that those are products that feature cumulative system technologies (e.g. Hard drives)

I. For reporting what features differentiate your subject system from other competitors and what features are the same:

Suggest your students to consider in their assessment features as well as operation; handling, assembly, and similar aspects.

J. Design Rationales:

J.1 For sketching a plausible design rationale for the product under analysis based on the available information: Explain your students that the conjectural reconstruction about the underlying actions taken in the designing of a product is similar to the concept of design rationale and benefits for the research already done on the latter; a Design Rationale then, is the detailed documentation of the contributing reasons, justifications, underlying motivations, alternatives, excuses, logic, tradeoffs and argumentations behind the decisions to select a certain strategy or design feature when designing a product. Authors [Burge & Brown. 1998] for example list a number of possible uses for a design rationale, namely: design verification, design evaluation, design maintenance, design reuse, design teaching, design communication, design assistance and design documentation, among these, the design teaching use ,is in line with the goals of this research project since the design rationale can be used as a resource to teach people, unfamiliar with a given design, the details of it even if the original designers are not available anymore.

J.2 For creating a design rationale statement about the subject system: Also, tell your students that authors [Gruber & Rusell. 1992] have collected a set of questions that effectively characterize the broad range of knowledge used to create a design rationale statement for the information categories usually requested by designers about a design under analysis, the version listed below though is a summarized one where all questions have been rewritten in a general way and that fits the terminology of this research but that at all times it should be understood to reference the product under analysis and its components. The consultation of the original source then, is suggested for further information:

1. Requirements
    a. What are the given requirements?
    b. Determine if “x” constraint is a requirement
    c. Detail the parameters of the operating environment.
    d. List assumed facts about the operating environment and why
    e. Find out the requirement constraints on “x” parameter
    f. Find out if given parameters are constrained by external requirements
    g. Find out what is the expected behaviour of the subject system in the scenario of use
    h. Determine if given product functionalities are actually required
    i. Determine if you can modify a given requirement
2. Structure/Form
    a. Determine the product’s components
    b. Determine what class of device or mechanism are the product parts
    c. Define the geometry of the parts (qualitative)
    d. Determine what materials are the parts made of
    e. Explain how the components interface
    f. Determine what the locations of parts, connections, etc. (for constraint checking) are
    g. Find out what the known limitations (strengths) of the part/material’s class are
    h. Determine what affects the choice of product components

3. Behaviour/Operation: What the product does

    a. Documents what the behaviour of given parameters in the operating conditions are

    b. Find out what the behavioural interaction between given subsystems is

    c. Determine the range of motion of given parts

    d. Determine causes the overall behaviour of the product and its parts

    e. Determine what the expected failure modes in the scenario of use are

4. Functions

    a. Determine what the function of given parts in the design is

    b. Determine what the function of a feature of a part in the design is

5. Hypotheticals

    a. Explain what happens if given parameters change to given new values

    b. Explain what is the effect of this hypothetical behaviour on a given parameter

    c. Adapt possible equations to the changed parameter and recompute it

    d. Explain what would have to change in the design if a given parameter changed to a new value

6. Dependencies

    a. Document what the known dependencies among the product parts are

    b. Document what the constraints on given parameters are

    c. Determine if given parameters (involved in a dominant constraint) are critical

    d. Determine how given subassemblies are related to given parameters

    e. Determine what are the sources of detected constraints

7. Constraint Checking

    a. Find out if given constraints are satisfied

    b. Find out if given structures have behaviours that violate constraints

c. Document what the known problems with your design are

d. Explain if a part with a given functionality would satisfy a given constraint

8. Decisions

a. Document what the alternative choices for a given design parameter are

b. Document what decisions were made related to given parameters

c. Find out what were earlier versions of the design

d. Find out what decisions were made related to satisfying given constraints

e. Find out which parameter, requirement, constraint, or component should be decided first

f. Find out what design choices are freed by a change in a given input parameter

g. Find out what alternative parts that satisfy a given constraint could substitute for a given part

h. Find out where the idea for a given design choice came from

9. Justifications and Evaluations of Alternatives

a. Explain why the current design parameter values

b. Find out why design parameters are at value V1 instead of a “normal” value V2

c. Find out why was a given alternative chosen over other alternative

d. Investigate what is person P’s evaluation of given alternatives

e. Speculate on why not other alternatives were tried

10. Justifications and Explanations of Functions

a. Explain why is a given function provided

b. Explain why a given function is not provided

c. Find out why can’t the current design achieve a given new value of a given functional requirement parameter?

11. Validation, Explanations

a. Find out how are given requirements satisfied

b. Explain how are given functions achieved

c. Explain how are given functional requirements achieved

d. Explain how given parts will be maintained

12. Computations on Existing Model

a. Compute a parameter value given other parameters

b. Document what the trajectories of parameters are

13. Definitions

a. Explain what given terms in the documentation mean

14. Other Design Moves

a. Search for information expected to be in documentation (e.g. Equations or diagrams)

b. Change given requirement constraints and update design.

c. Find out if all the arguments for/against a given alternative have been checked

J.3 For writing a design rationale that justifies the design process that led to the specific device structure of the product under analysis: In complement to the abovementioned information on design rationales, refer your students to the research by [Garcia & Howard. 1992] who in their studies recognized patterns that represent the desire to know what was done in the design of a product, and from them students can start asking the right questions, namely:

- What? (The desire to know what was done, e.g. Values, scenarios, etc.)
- Why? (The context in which decisions were made, e.g. Issues considered stages of the design process where decisions were made, etc.)
- Why not? (The designer's conjectures on what should have been done, e.g. What would be the impact on the design if instead of "X", we chose "Y"?)

Additionally, the authors also suggest to include in the writing of a design rationale the following items in order to add clarity and support to it, namely:

- Hypotheses proposed

- Assumptions made
- Constraints that had to be relaxed in order to make valid a decision
- Source of those constraints (such as specifications and preferences)
- Evaluation functions applied
- Changes in previous parameter values
- Designer's preferences, represented either as constraints or as evaluation functions (frequently derived from experience)
- Decision history (the pattern created by the previous decisions create a unique scenario for the specific decision)

K. Design Plans:

K.1 For proposing a possible design plan for the subject system:

Tell your students that it can be done through experience, knowledge and educated conjectures about its design and manufacturing (e.g. By making default assumptions about the process of the design or possible redesign alternatives), the information listed further below though, provides a good starting point for the creation of it.

K.2 For reconstructing a default design plan for the subject system by using default knowledge:

Explain your students that design plans are defined as probable design states that lead to the creation of a subject system (the product under analysis in this case) and given that the design plan to arrive at a specific stage of a design is not unique and the original design process is assumed to be unknown, a domain independent default plan using default knowledge can be constructed at a coarse level that leaves room for changes that will satisfy design constraints as more and more information about the product becomes available and is added to it. A manual reconstruction like the one that will be shown below then, requires the help of available information, inference and a strong domain knowledge that contextualizes all possible clues. The steps listed in this regard in Section 5.4.10.6 to reconstruct a default design plan (as opposed to a true design plan) by using default knowledge (design information that cannot be confirmed to be true at the time it is suggested) were devised by the author of this document by studying, expanding and contextualizing to the domain of engineering design an original idea by author [Jounghyun. 1994]. The algorithmic approach listed below is a knowledge-based one and can be further enhanced and complemented by local problem solving heuristics. The level of specificity of the design plan then, should be appropriate for the domain knowledge of the product under analysis, which is usually at the middle of the spectrum in cases of educational exercises.

K.3 For listing a sequence of probable design actions that could have happened during the actual design of the subject system: Explain your students that such actions commonly include potential design stages; design parameters, design objects, global (product) vs. local (part) design decisions, and so on. Of course not all plausible design action and their interrelationships need to be identified and students should only try until a reasonable extent of common design actions is reached to a level of specificity previously agreed upon, between instructors and students. In fact, some knowledge domain will help filter out unreasonable yet possible design actions.

K.4 For mapping design problems / design particularities to a given stage of the design plan: Remind your students that in general, problems that map to early or middle stages of a design require global changes (function) to a design, whereas problems or particularities in the final stages require changes of a local nature only (form)

K.5 For making use of descriptive design models, tell your students that they are domain independent systematizations of the design process that identify sequences and patterns of events likely to happen in most design projects, they reflect the successive abstract refinements at each stage of design and they usually advise techniques and methods to assist in the design process by providing guidelines, rules and procedures and that if followed are expected to result in better designs and optimization of design resources. Author [Jounghyun. 1994] for example provided some insight about these models and their relevance to reverse engineering analysis, namely:

a. Prescriptive design models are domain independent or are applicable to many domains
b. They gradually refine designs by guiding them from sketches up to detailed designs
c. They prioritize target objects by their functional importance (e.g. Main, auxiliary, assembly, special, etc.)
d. They explicitly separate form design and layout design
e. Certain types of design actions are applied early in design, while others are applied later.
f. Designers rarely reason about physical forms before functions
g. Features are usually added after parts are created

It is this kind of localized insight then, what can help reverse engineering students construct a default design plan that can be useful as a starting point in reconstructing a product's design history.

K.6 Refer your students concerning design actions in a typical design space to the examples listed by [Jounghyun. 1994] and explain them that they are related to the fact that in engineering design, the possible design actions predefined at an appropriate level of specificity are called the "Design Space" and they can be useful to describe design strategies (without much geometric reasoning) that lead to the final design thus providing your students with another possible description to help them reverse engineer a product. At every stage then, and for the relevant design objects of the product under analysis, some of the high level design actions might be identified by associating all available information to the categories shown in Table 6.18 below:

Types of Design Stage	Types of Design Objects	Design Actions
Conceptual	Function	Create function, Decompose function
Function-to-Form Mapping	Form	Create form
Embodiment	Part, Feature	Select form
	Assembly	Select assembly method
Layout	Part, Feature	Locate form
Detailed	Part	Dimension form, Select material
	Feature	Dimension form

Table 6.18 Examples of Design Actions, Source: [Jounghyun. 1994]

K.7 Explain your students regarding the possible types of design plans used on the product under analysis that: According to author [Mostow. 1989] many designs are created by either adapting previous successful designs or by modifying candidate designs that failed to meet previous design goals to meet new ones; and suggest your students that based on all previous information they should guess how the original designers' plan of the product was, e.g. "Record and Replay" cf. [Jounghyun. 1994] that is, the replaying of a previous design plan and modifying it wherever necessary in order to meet the new specified design goals; “Acquire and Generate” cf. [Gruber & Russel. 1992] which tries to automatically infer the design rationale based on knowledge-based inference methods such as simulation or qualitative device behaviour models and it requires a strong domain knowledge about the task designs, or “Create and Debug” c.f. [Jounghyun. 1994] which is the common paradigm for machine planning where a default design plan is first generated and subsequently modified, if your students find out it was of a different type ask them to explain how they reached their conclusions.

Finally, the following resources should be mentioned to your students as a suitable starting point for listing probable design actions, namely:

- The standard design stages found at guidelines such as VDI2221 [VDI Verlag GmbH. 1987]
- An ordered sequence of design decisions and design actions from a previous design process of a similar product
- Partially derived design actions from CAD screens or blueprints illustrating different stages of design (a design plan based only on this though, would need to be augmented with much more information and conjectures)
- Well known DfX recommendations / principles / criteria / guidelines for design optimization
- Common sense design actions and assumptions
- Knowledge and experience from the professor at work
- Strong domain knowledge about engineering design and ideally about electro-mechanics, manufacturing, or any other related area related to manufacturing and production technologies
- Conjectures and educated guesses about the design rationale of the original designers
- Descriptive design models

L. For uncovering the ununderstood aspects of the subject system’s design:

Remind your students that there are pieces of information at the highest level of abstraction such as comments, descriptions or committed design decisions that cannot be retrieved or recreated through a reverse engineering analysis so it is ok to assume, speculate and put forth educated guesses about the ununderstood parts of the product design

M. Advise for Constructing Knowledge from a Design Assessment

For analysing and listing examples of how constraints vs. criteria were satisfied in the design of the subject system: Explain your students that one example is that to keep costs low many optional features are left out of consumer product, e.g. picture dating or automatic timers in single use cameras

N. Advice for Synthesising of Information

For synthesising all available information about the product under analysis:

Help your students exercise creative and intuitive instincts as well as coming up with educated guesses during this stage, also advise them to consult with you; any other instructor, experts, advisors, or consultants who can help acquire knowledge for the subject system and uncover its history (e.g. Manufacturing, distribution, etc.) and its design rationale (e.g. Design process and why it came to be the way it is).

Authors [Grosso et al. 1999] for example, provide additional guidance for this task by suggesting the application of the techniques for knowledge acquisition from the discipline of knowledge engineering which help synthesise knowledge from the product under analysis based on the information acquired from it but always dependant on the depth of knowledge to be constructed, the pointers listed below then, exemplify such synthesis approach and should be attempted by your students, namely:

- By becoming familiar with the problem domain
- By characterising the reasoning tasks necessary to solve the problem
- By identifying the major domain concepts
- By categorizing the type of knowledge necessary to solve the problem
- By identifying the reasoning strategies used by experts
- By defining an inference structure for the resulting application
- By formalizing all of the above in a generic and reusable way

O. For drawing inferences from the particular representation of data obtained from the product under analysis:

Direct your students to the research by authors [Miles & Huberman. 1984] who suggest specific tactics for drawing meaning from a particular representation of data, and who suggest among other things:

- To see what is there
- To see what goes with what
- To integrate and differentiate data

- To see things and their relationships more abstractly
- To assemble a coherent understanding of the data

P. For interpreting all available information:

Direct your students to the research by authors' [Blessing & Chakrabarti. 2009] who advice the following actions to attain such purpose:

- Use simple enumeration or descriptive statistics
- Link the findings
- Identify correlations and possible causal relationships
- Find explanations and draw inferences

They warn however that for putting forth Inferences about causality, the analysts will require evidence of time order between concepts; covariance between concepts; and exclusion of rival factors (spurious relationships)

Q. For making use of traditional design ideation methods:

Show your students Fig 6.6 below by author [Shah. 2006] who has classified methods such as those used in (forward) engineering and can help synthesize all information resulting from the reverse engineering analysis of the subject system and to help come up with design cues and bearings about where the design decisions might come from and why, namely:

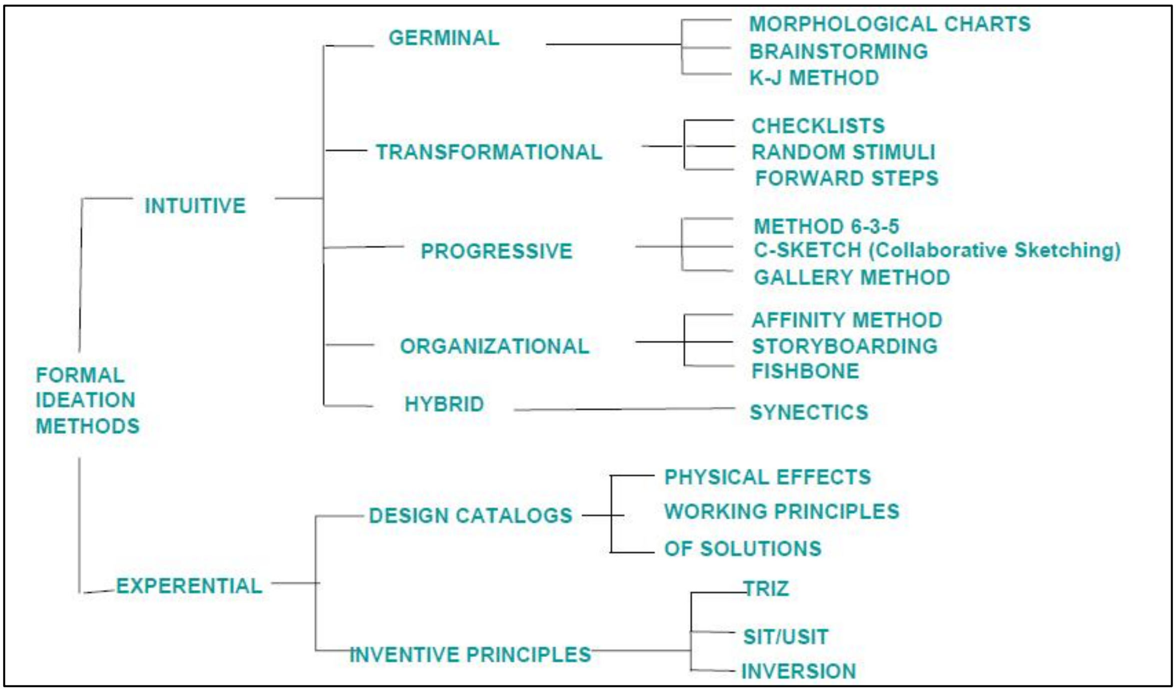

Figure 6.6 Classification of Design Ideation Methods, Source: [Shah. 2006]

R. For comparing proposed PDS (Product Data Specifications) in a subject system against their actual implementation in order to retrieve design information:

Direct your students to the research by [Tomiyama. 1985] who explains that design processes contain exception handling operations in order to achieve the desired design goals, according to him these operations are called:

- Backtrack (retracing of the design path)
- Addition of specifications (addition of overlooked or misunderstood requirements)
- Relaxation of specifications (giving up on unattainable goals)
- Conflict resolution (understood as the deviations from the actual to the planed design path)

They result either from identifying hidden or unclear specifications in the early stages of the design process or from balancing requirements such as cost and performance at the later stages. In practice It means design specifications are usually incomplete, inconsistent and even infeasible and they'll have to be further tested, revised and augmented. Until the design is completed then, specifications can be considered to be incomplete. Hence, the designers role in the design process lies in augmenting, correcting, relaxing, refining and compromising the given specifications, the resulting experience, knowledge and lessons learned comprise much of what is known as "Design Rationale" and it can be partially retrieved by the reverse engineering method proposed here by conjectural reconstruction of missing pieces of information along the design process. In the end it is the drift of the initial product design specifications from the final ones materialised into the finished product what stores information for reverse engineering analysis. The same can be assumed about the manufacturing and production processes where similar operations and compromises are likely to happen until a final product is achieved.

S. For using the "Inference to the best explanation" reasoning framework in order to contextualize all available data:

Explain your students that once the information collection and organisation steps have been done, an analysis and contextualization of the available data is necessary, the reasoning framework that supports this process is called "inference to the best explanation" and it is a method of abductive reasoning used in science, identified by Harman c.f. [Harman. 1965] that helps scientists; so they can elect hypothesis which would, if true, best explain the relevant evidence. The model of inference to the best explanation requires that the hypothesis not merely entail the data but explains it. So according to this model, a hypothesis is confirmed if the hypothesis would, assuming it to be true, provide the best explanation for the observed data (or evidence). Author Harman explains how it corresponds approximately to what other authors call "abduction”," the method of hypothesis," "hypothetic inference," "the method of elimination," "eliminative induction," and "theoretical inference." However he considers these terminologies to be misleading.

This is for example, the kind of reasoning employed by fictional character Sherlock Holmes in Arthur Conan Doyle’s stories, but there, it is misleadingly called “deduction”, the inference to the best explanation model then, allows hypotheses about unobservables to receive evidential support too (e.g. Evidence for the presence of an electron as streaks appearing in a cloud chamber used for detecting particles of ionizing radiation). In the philosophy of science then, hypotheses that qualify as “best” typically provide simple, coherent, and causally adequate explanations of the evidence or phenomena in question. For this, refer your students to the research by author [Fogelin. 2007] who for example, describes the seven traits of highly successful explanations that are considered more compelling when using the inference to the best explanation method; so when trying to make sense of the available information, this reasoning model helps arrive to the best hypothesis and further explain why given product properties are found the way they are, such traits are shown below in Table 6.19:

Trait	Description
Empirical breadth	The ability to address a wide variety of observations and multiple lines of evidence while accounting for large numbers of highly similar phenomena
Generality	The ability to use the same kind of explanation in a wide variety of cases
Modesty	Explanations should not overreach or try to explain too much, they should simply not apply to everything.
Refutability	Explanations should be able to show to be wrong in order to be trusted as a valid explanation

Conservatism	They should not throw out well-established explanations or principles on a whim
Simplicity	Explanations should not try be simple by decree but should not be any more complicated than necessary
Multiplicity of foils	Foils are contrasting elements of an explanation so an explanation that can account for both where and when a particular event occurred is usually better than an explanation that only accounts for when a particular event occurred.

Table 6.19 Traits of Highly Successful Explanations, Source: [Fogelin. 2007]

T. For avoiding inference from spurious relationships:

Ask your students to draw valid inferences about what has been observed through careful consideration and detailed attention and to try to avoid any spurious relationships (those identified when an observed relationship is actually caused by a factor other than those described in the relationship). In this regard, direct them to the research by authors [King et al. 1994] who emphasise that the rules of scientific inference can and should be applied in both qualitative and quantitative research and that using these rules should improve the reliability, validity, certainty, and honesty of the conclusions. Quantitative research then, is used to investigate the degree to which phenomena occur, whereas qualitative research is used to investigate the nature of phenomena; your students should be reminded that the combination of both can obtain a richer picture of the phenomena

U. For drawing preliminary conclusion about the subject system:

Remind your students to constantly consider the customers' side

V. Specific Tasks, Questions and Analyses for the Guided Example Shown in Resource 7

Although the methodology presented in Resource 5 is comprehensive enough to reverse engineer a subject system from most relevant perspectives, the following items listed below can serve professors as a guideline to come up with the kind of specific tasks that will elicit the most knowledge about disposable cameras and help synthesis all available information about them, thus you should ask your student to:

- Think about what happens to the cameras after they are dropped off for developing.

- Assess what are the advantages and disadvantages of single use cameras against conventional analogue/digital ones?
- Assess how can the environmental impact of the camera be further reduced?
- Knowing that the manufacturer does not reuse the lenses and the battery, answer how you think a faulty lens or battery would affect the consumer's perception about the product?

6.5.2.10 A Suggested Pedagogy for the Teaching of the Redesign Suggestions Stage

The following pieces of advice intend to remind professors in charge of EREA that the students' ideas about what a better subject system would be should receive a fair judgement through the consideration of their actual knowledge and experience of the engineering design process in relation to their suggested improvements

A. Overall considerations for this stage:

Whenever students suggest improvements to the product they have analysed it is expected that their suggestions begin with simple imitation of what others have already suggested, however, as confidence and proficiency in the process develops, more creative approaches and innovative solutions can emerge as a result of triggering more cognitive processes in them

B. For the overall attainment of this stage, suggest your students to:

- Look for inspiration from competing products (e.g. Based on preconceived product improvement ideas) in case comparative analysis proves useful to achieve the goals of this stage
- Add new improvement ideas, after screening, combining, modifying and expanding existing ones to also come up with an improved redesign of the subject system
- Create innovative solutions for redesigning the subject system
- Apply creative problem solving techniques in the suggestion of design improvements for a superior product than the one analyzed (e.g. Challenge the way things are normally done; Improve on what has been done before; Generate many potential solutions to a given problem, Suggest new approaches to solving problems, etc.)
- Consider different technical alternatives to the improvement suggestions while bearing in mind cost, environmental concerns, safety, and other constraints
- Compile promissory, improvement suggestions for further culling and development later in this stage

- Hold team discussions where formal ideation methods are use to come up with plausible changes to improve the subject system

C. For identifying weaknesses and improvement opportunities for your subject system:

Suggest your students to operate under the assumption that the design under analysis has been already streamlined and is efficient to achieve a certain goal considered by the original designers, in this way coming up with improvement suggestions becomes a more conscious effort and thus more thought is put into it by students

D. For conceptualizing new functions and/or solutions to the current configuration in your subject system:

Suggest your students to use design methods to hypothesize current and future functions, for example a design concept for a redesigned product can be done benefiting from previous work done in performing a morphological analysis of your subject system and recording functions and subfunctions on a design concept table to finally describe each design concept generated

E. Suggest you students to make use of typical analytical tools available in engineering design:

For example if students choose to eliminate a subject system's part to improve its design, ask them to explain verbally what changes would need to take place to eliminate such part but if possible ask them to explain their answers via a morphological matrix

F. For selecting the most promissory improvement concepts for further refinement and allocation of development resources:

Suggest your students to make use of analytic tools, for example:

- House of quality: To find the most appropriate product area to address in the redesign process as suggested by [Otto & Wood.2001], also direct your students to the example by [Edwards et al. 2010] who have used a house of quality to evaluate the perceived value or importance of redesign concepts in the context of a product dissection activity and also provide examples on concept generation, screening and scoring
- Pugh's concept selection charts [Pugh. 1991]
- Weighted sums, etc.

G. For dealing with potential students' invention:

If an invention is conceived during the EREA, provide your students with guidance on patent application

H. For additional support to come up with a product redesign of the subject system, ask your students to:

- Consult authors' [Otto & Wood. 2001] research on product redesign tasks and their examples.
- Benefit from their own experiences and consult with other professors or specialists on the field
- Consider that incremental improvements to the subject system have their place too (i.e. Of the type that adds features without changing much the original design; recycling process, manufacturing costs, or final price tag)
- Consider that usually the improvement aspect to consider about existing consumer products deal with: Ergonomics; size, weight, cost, and portability.

I. If during the disassembly stage your students found product parts that were hard to disassemble:

Explain them that according to authors [Comparini & Cagan. 1998] this situation usually indicates not only that the manufacturer is preventing the user from servicing the unit but also that disassembly for servicing; reusing or recycling is clearly not an objective in this design, and that in fact Design for Disassembly is not usually considered, unless regulatory pressures come into effect (one of the reasons manufacturers contend is that the logistics of a take-back program would be too costly), this situation in itself can serve as a source of improvement ideas for the subject system

This is the end of the second phase of the pedagogy for the teaching of EREA dealing with the execution of it, the next phase though, will deal with the grading aspects of it.

6.5.3 Phase 3: Evaluation of an EREA

Engineering Design is a multidisciplinary activity with varied application areas that requires not only its teaching strategies to be diverse but its evaluation to be flexible just like the goals and nature of design projects themselves. The third phase in the pedagogy for the teaching of EREA then, corresponds to the stages 12th (Conclusions) and 13th (Results Dissemination) of the methodology for educational reverse engineering analysis suggested in Resource 5 and covers its main task which is the evaluation of the achievement of the goals set at the beginning of the EREA both at the students (e.g. Team and individual performance) and professors (e.g. Learning objectives) level.

Based on original results and on the benefits reported by previous researchers of the topic, after performing an EREA students are expected:

1. To improve the understanding of simple information (Vocabulary; facts, equations, quotes)
2. To improve the understanding of complex information (Differentiation; comparison, contrasting, synthesizing of information)
3. To improve their theorizing, analyzing, and problem solving performance
4. To improve the use of tools and procedures
5. To investigate the natural and industrial world
6. To improve their communication and team work skills

The information presented here then, gives the elements to detect and evaluate the abovementioned improvements in students and indeed, it intends to cover all relevant cases for the evaluation of EREA and thus, proper guidance on their assessment including the possibility of both internal and external evaluations is shown here along with details specific to the two individual stages comprising the phase. Later in this same section, a practical application for the evaluation of the example showed in Resource 7 will be suggested in order to support the readers' eventual development of their own assessment tools

6.5.3.1 Fundamentals of the Evaluation of Educational Reverse Engineering Activities

No matter how new EREA could be to some of the students they still need to be evaluated under the regular grading mechanisms of the host institutions, some pointers then, for the examination of the teaching and learning performance during an EREA are presented in this section. Indeed, the advice given here could be considered to apply to all cases of EREA irrespective of the depth pursued or the product analysed, and it relates to the specific educational needs of professors, students and academic institutions involved; such advise then, is presented in this section, separate from the two individual stages comprising this phase, to highlight its foundational nature and thus the contents listed in here should be of special importance to first time participants and instructors of reverse engineering activities, however, and as usual, experienced professors can skip this section altogether and evaluate their students according to their specific requirements. Additionally, and later in this section , specific advise on the two individual stages comprising this phase, and on the guided example presented in Resource 7 will be also given, namely:

A. Instructors' Overall Advice for the Completion of this Phase:

- Explain your students your assessment patterns, that is how learning will be evaluated and what constitutes a passing or failing performance
- Give students detailed feedback on their performance individually, as a team and if possible as a whole class
- Clarify task requirements and expectations as needed
- For tracking and reporting purposes to your academic institution, keep a close look on the number of student completing the activity, withdrawing it or failing it (a.k.a Attrition rates) although EREA are usually well perceived among students cf. [Dalrymple. 2009]
- Try to give your students the opportunity to talk to invited speakers or go into an industry tour in order to wrap up their knowledge of the product under analysis and support their writing of conclusions

B. Suggested Aspects to Evaluate the Students' Learning and Performance in the Attainment of the goals of the EREA

The following list of items and recommendations summarise those aspects relevant to the evaluation of students in an EREA, namely:

- Evaluate you students' class participation (but the criteria for quantity, quality and what determines both of them should be stated to students beforehand)
- Evaluate the creation of engineering graphics and documents for their subject system: e.g. Systems diagram of the product under analysis, product schematics, disassembly and reassembly instructions, suggestions for the improvement of the product throughout its lifecycle (e.g. Before; creation, disposal, etc.)
- Evaluate your students' design journal which should include answers to all questions and tasks of the methodology for educational reverse engineering analysis suggested in Resource 5
- Evaluate your students' homework and other assignments
- Evaluate your students' performance throughout the EREA by considering their creation of derivative products and the creation of an improved product specification

The major categories of graded activities in an EREA then, include but are not limited to: Session deliverables; intermediate reports, laboratory work, class discussions, public presentations, demonstrations, and final project reports; specific examples of them worth mentioning would be class attendance; participation in discussions, team activities, homeworks, and so on

B.1 Alternate aspects to assess on an EREA: Depending on certain conditions of the EREA in turn (e.g. Students' limited, technical proficiency or lack of access to technological equipment) an alternative way to assess the learning of students rather focusing on the development of non technical traits might be need. The following list for example, shows some of those criteria that can help the professor in charge evaluate students and potential signs of their growth, namely:

- Evidence that students achieved certain learning goals
- Evidence of their most / least successful learning objective
- Effect on student's interest, motivation, values, study habits and interpersonal relationships from the EREA
- Evidence that students are prepared for subsequent courses on the area of Engineering Design
- Students' ideas and proposals on what changes should be made to EREA to better benefit from them

C. Suggested Tools and Techniques for the Assessment of Students' Performance on Course Objectives and Goals

It refers to the way students will be evaluated, and it is suggested to evaluate using a mixture of student ratings (e.g. Tests, ungraded activities, interactive periods in lecture, short writing assignments, group work, success of product's reassembly, self evaluation, student interviews, achievement of learning outcomes, students' retention, examinations; reports, oral examinations, student's presentations, student reports, students feedback (about what they did), etc.), the following options though, are favoured for their use in an EREA, namely:

- Oral reports
- Team experiences
- Written reports
- Team presentation

D. Suggested Grading Policies and Standards for Evaluation to use in an EREA

Grading rules are set according to the requirements of the host institutions but they are usually devised to explain how the activity will be assessed, under what criteria, and to ensure the quality of the students' work in aspects such as completeness; correctness, organization, timely submission, and so on

- Suggested distribution for marks: They usually depend on the professor in charge but for an EREA the usual grading percentages are 50% for laboratory work, 25% for the quality of redesign suggestions and 25% for quality of the final report. In this regard it is worth keeping in mind that the weighting for the different assignments and tasks given to students will have a major impact on the distribution of their efforts and thus the distribution of grades should be explained to them beforehand
- Suggested grading scales: Common options include the American A to F scales or the European 5 to 10 scores where a minimum passing mark should be at least 70% of the maximum possible total
- Suggested policy for extra credits: Since one of the objectives of this activity is to introduce the profession of engineering design to the students, a possible idea for extra points is their attendance to approved student and professional technical meetings, congresses, presentations and so on, inside and outside their chosen engineering discipline where in order to obtain the extra points the student must provide proof of his attendance or of what he/she learned.

E. Perspectives to Consider in the Evaluation of an EREA

In order to get a comprehensive view of the actual learning and growth of a student throughout an EREA, three different perspectives to evaluate should be considered and which are briefly explained here so the professors in charge eventually develop a strategy that covers them based on their own experience and supported by the resources presented in this section, namely:

• Evaluation from Professors to Students

Evaluation to students must be done considering their acquisition of abilities in line with those shown in Table 4.10; the students' final knowledge about the subject system though should be considered a side-benefit and consequence of an EREA but never its main aspect to evaluate.

• Evaluation from Students to Students

Students must evaluate themselves in regard to their performance throughout the EREA and in terms of their individual contributions to the attainment of the goals of the EREA, or in accordance with the fulfilment of their assigned roles, if they seem it appropriate though, a combination of both can also serve as a measure of their performance

• Student’s self evaluation

The student must evaluate himself/herself according to his/her appreciation of the bits learned from the activity as well as from the individual contributions to the attainment of the goals of the EREA.

F. Summary of Major Evaluation Criteria in Relation to Goals of a Typical Engineering Design Curriculum

The information listed below intends to summarise those aspect to be evaluated in students undergoing an EREA and that have proved to be some of the most important ones in relation to the learning goals of typical engineering design programmes (earlier versions of this document included varied examples of questions to asks for the evaluation of an EREA, however since all the relevant aspects have already been integrated into the methodology of Resource 5 for purposes of clarity now only few pointers and examples are included below to guide the instructors in their evaluation of an EREA), namely:

1. About the engineering design process: e.g. To determine how scientific principles; material properties, manufacturing techniques, cost, safety requirements, environmental considerations, ethical, intellectual property rights and other considerations of engineering affect the design of a system, component or process
2. About awareness of engineering practice: e.g. To acquire the knowledge required to set up any necessary tests and be able to challenge results from a formal analysis
3. About a systems perspective: e.g. To unify dispersed knowledge and tie together other fields that normally are perceived as unrelated, To be able to analyze the component systems and subsystems of a device, to create a systems diagram to describe the operation and control of a device, and to identify the purpose of subsystems as input, process, output, or feedback.
4. About consumer products themselves: e.g. To understand the workings of the product analyzed and suggest ideas to improve the value of it
5. About Technology: e.g. To increase the knowledge of trends and recent developments in key technologies and to explain a product’s lifecycle in terms of technological impacts.
6. About information collection: e.g. To exercise resourcefulness to access relevant sources of information; engineering expertise, know-how and skills at all stages of the

reverse engineering analysis through the use a variety of information resources (i.e. Interviews to potential sources, effective database searches ,observing, questioning, and so on)

7. About Design for X: e.g. To learn about the varied Design for X approaches for the achievement of economic; neat, well structured, designs
8. About a product's' assembly: e.g. To learn how products are assembled and about their assembly plans (e.g. To classify the component parts of a device according to varied criteria)
9. About product's manufacturing: e.g. To recognize the basic principles of selecting manufacturing processes for a particular component
10. About product's materials: e.g. To learn about selection and properties of construction materials for consumer products
11. About inter-personal interactions: To discover the advantages and disadvantages of working with others and collaborating
12. About adaptive dispositions: e.g. To transfer the knowledge and skills learned during the EREA to future situations or to provide a context for new learning
13. About cognitive development: e.g. To determine what type of analysis was appropriate in support of synthesis, evaluation and decision making
14. About creativity: e.g. To exercise creative and intuitive instincts
15. About intellectual property: e.g. To realize that reverse engineering is not a straightforward process and indeed manufacturers set traps and locks so their products cannot be reverse engineered

All of the information presented in this section then, is of a foundational nature and is applicable to both stages comprising this phase; individual, specific advice for each stage comprising this phase though is given next too, followed by a practical application of the advice presented here and in support of the guided example presented in Resource 7

6.5.3.2 A Suggested Pedagogy for the Teaching of the Conclusions Stage

Given that it is the students who'll do all the work at this stage, the professors' role falls in guiding them so they can come up with a comprehensive set of conclusions that are both meaningful and revealing about what they learned throughout the EREA, the following tips and suggestions then are given to the professor in charge, namely:

A. General advice for writing the conclusions report:

- Suggest your students to produce a report that documents and discusses all relevant findings and impressions from previous steps of the methodology at the appropriate level of detail following their own sense of comprehensiveness and relevance of the conclusions presented (e.g. Oral and written reports directed to classmates, peers, and well informed yet general audiences).

- Remind your students that particular attention should be given to update the final report with findings from early stages of the methodology (e.g. Data collection) and with complementary information revealed at later stages (e.g. Product analysis)
- Ask your students to leverage from all findings and conclusions documented for each previous stage of the methodology
- Suggest your students to brush up their technical writing skills and apply them on their final report
- Suggest your students to start drafting the final report since the beginning of the EREA itself and thus benefit from team and individual entries in their design journal(s) from all stages
- Suggest your students to keep future classmates in mind so the essential findings and results in their report can benefit them too (e.g. By describing in chronological order what your team did during all phases; how tasks were distributed and how decisions were made)
- Ask your students to organize the written materials in a logical sequence to enhance reader's comprehension

B. For writing the final conclusions about the subject system analysed:

- Suggest your students to benefit from the umbrella categories suggested by authors [Pahl et al. 2007] acknowledged as related knowledge domains that support design and development, and suggest them to place all their findings under the appropriate category, namely: Natural Science / Engineering Science; Production Science / Technology, Materials Science, Industrial Design / Art, Information and Communication Sciences, Experiences / Engineering Applications, Economics and Management Science, Social Science. Additionally you could suggest your students to comment on the following domains also mentioned by the authors, namely: Mechanics; ergonomics, marketing and psychology; finally, you could also ask them to state their final impressions about the subject system by answering authors' Pahl items on the description of a product under analysis, namely: The use of specific materials to attain certain concept solutions; The application of possible design methods, The use and knowledge of existing design solutions, The design history of the product until its last incarnation, The product's aesthetics, and Potential user trials.

- Remind your students to incorporate material; mechanical, electrical, and assembly factors into their team discussions and eventual writing of conclusions

In summary, conclusions about the EREA at this stage will vary in reach; scope, length and detail, but at a personal level students usually report enthusiasm and motivation to finish the EREA since they see it as a “Practical” experience, whereas as learning bits they report a familiarization with varied aspect of the design of a consumer product which they consider to be a “representative” experience of the engineering design process overall

6.5.3.3 A Suggested Pedagogy for the Teaching of the Results Dissemination Stage

The dissemination of results marks the stage where classmates and the general public get to know about the outcomes from the students’ work on the educational aspects of reverse engineering and as such it is of paramount importance to present all results in a proper way that includes a clear explanation of why such activities are done, how they are done, and what benefits they bring to engineering design education overall, the advice presented below then, intends to help clarify what the requirements for appropriate presentation of results from an EREA are and thus help professors better publicise good works from their students that can help increase the department’s/university status ,namely:

A. For the overall communication of conclusions:

- Suggest your students to communicate effectively their information by using all available means (e.g. Oral presentations, written reports as well as graphical; verbal, written and electronic tools)
- Suggest them to include in their conclusions an explanation of the items they analyzed
- Advise your students to present relevant information in a variety of audience-friendly formats and always keep the nature of the audience in mind when addressing them
- Remind your students to add any additional information they might consider useful to the readers of their work
- Ask your students to provide good documented information about the about the subject system
- Suggest your students to properly quote all references used throughout their investigation
- Suggest your students to understand “global/general audiences” as non technical but well informed ones

B. For the creation and showing of display boards in academic settings:

For creating a display board with the results of successful EREA projects suggest your students to mount the components of their subject system and include brief explanations of how the parts interact and work together as well as graphics of their findings to add credibility and attract interest to those looking at their results

C. For the creation and showing of posters in academic settings:

Suggest your students to hang them at a suitable location(s) for other students to see it

D. For the creation of an oral presentation:

Suggest your students to follow the next recommendations for an effective transfer of information and reinforcing of their presentations, namely: To plan to deliver an effective oral presentation; to apply presentation tools effectively (e.g. By creating visuals for oral presentations), to make the most out of their presentation skills, and to use and present their design working files and follow-up reports in their presentation of results

E. For the writing of dissemination hand-outs:

Ask your students to try to comply with currents standards of technical writing

F. For writing a document directed to future designers / redesigners of their chosen subject system:

Suggest your students to give advice that helps the readers to avoid repeating past mistakes; that provides them a direct means for determining the impact of proposed design changes, and that helps them in the communication of goals, assumptions and final system specifications.

As a professor it is important not only to support your students in disseminating the right results from their work and to help them present the results appropriately according to their target audience (e.g. By suggesting them to give classmates supporting handouts before a presentation) but also to profit at this point from the opportunity to collect their final reactions and impression about the EREA, in order to set a baseline from which you as a professor can keep improving for future collaborations and projects on the topic of educational reverse engineering.

6.5.3.4 Sample Students' Evaluation Tests Specific to the Guided Example of Resource 7

To reach a thorough knowledge about the product under analysis is never the main goal of an EREA but rather an effect from it and thus the success of students undergoing an EREA cannot be evaluated on that aspect alone (although, arguably there is no better way to know about a consumer product other than disassembling it), still and as shown by researchers such as [Dalrymple. 2009] well planed subject system-based exercises can actually contribute to the comprehensive evaluation of a student in an EREA and in relation to the attainment of the actual goals of a typical engineering design programme

The four following exercises for example were devised and used by author [Dalrymple. 2009] to evaluate students and prove among other things the ability of product dissection activities to the elicit transfer (the ability to extend what has been learned in one context to new contexts cf. [Bransford et al. 2000]) in her students, namely:

A. Mapping functions-to-components exercise
B. Variant design (modifying the camera to achieve new functionality) exercise
C. Product troubleshooting exercise
D. System Decomposition exercise

Any of the abovementioned exercises will help students acquire and develop skills, abilities and concepts relevant to all hands-on activities in engineering design irrespective of the product chosen for analysis and as such the results from said exercises can complement other aspects of their evaluation (e.g. Laboratory work, improvement suggestions, presentations of results, etc.) thus getting a fair, comprehensive assessment of their performance throughout the EREA

The exercises are presented here in a format addressed to the professor in charge and represent the way they should be delivered to your students, namely:

A. Sample Mapping Functions-to-Components Exercise, Source: [Dalrymple. 2009]

During the design process, engineers may map the desired functions of a device to specific components that will accomplish those functions; this is an educational exercise to simulate that experience and helps exercise skills such as spatial awareness or familiarization with mechanisms

• General instructions to students:

1. Write your name and team

2. Map the functions of a single use disposable camera of your choice to the specific components used to accomplish those functions

3. Submit a hard copy of your work to your Instructor/Teaching Assistant at the end of the allotted time

• Directions:

The pictures of eight components of the Fujifilm QuickSnap Outdoor 1000 disposable camera are shown in Fig 6.7 below, for each of the following questions take a look at their form and attempt to identify the component that performs the listed function

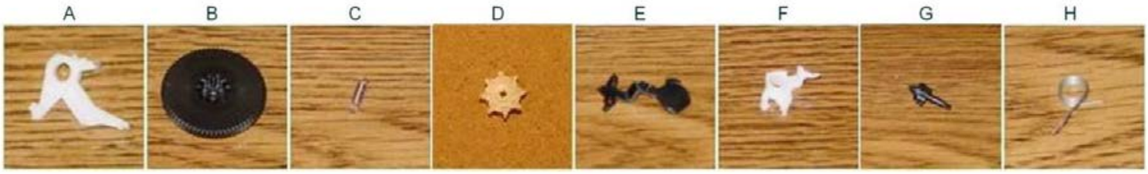

Figure 6.7 Selection of Fujifilm Disposable Camera Components, Photocredits: [Dalrymple. 2009]

1. Resets device that prevents unused film from transitioning into film casing:_____

2. Returns shutter to closed position:_______

3. Holds unused film frame behind shutter until a picture is taken:______

4. Controls the transmission of light to the film:______

5. Moves film counter wheel and resets the device that opens the shutter:___

6. Transitions exposed film back into film casing and situates unused film frame behind shutter:__

7. Moves shutter to open position when button is depressed:_______

8. Rotates spindle when exposed film transitions into film casing:______

B. Sample Variant Design Exercise, Source: [Dalrymple. 2009]

• Introduction:

Variant design (modifying the subject system to achieve new functionality) is another common exercise in engineering design courses, it involves the changing of the parameters (e.g. Features, components, etc.) of certain aspects of a product to develop a new and more robust design.

• Background information:

A disposable camera has a constant shutter speed which allows good pictures to be taken in well lit areas or whenever the subject is stationary or moving slowly, outside these conditions the shutter speed would need to be varied to keep taking good pictures, in low light conditions for example, a slow shutter speed is required but for fast moving subjects a fast shutter speed would be required. Also, index fingers captured in pictures are a very common occurrence in cameras where the viewfinder doesn't show exactly what the lens is aiming at but rather an approximation to it.

Additionally, taking multiple shots on the same photo frame is called superimposing of images, and it can produce some cool effects as shown in Fig 6.8 below:

Figure 6.8 Superimposed image, Photocredits: [Dalrymple. 2009]

However, superimposing images is usually a feature that most cameras are designed to prevent, in this exercise, the elements that allow / don't 'allow such feature will be analysed.

• Instructions:

Individual exercise on variant design, Time allocated: 15 minutes. (Given that the implementation of this type of exercise is very common in engineering design programmes, the indications given here are only indicative and a full implementation of the exercise is better left to the professor in charge)

• Steps:

1. Write your name or you team's name

2. Generate variant design ideas for one-time use cameras that at minimum allow for the following

2.1 Variable shutter speeds, fast; moderate and slow (user can select how much exposure time the film has)

2.2 Superimposing of images (user can take one picture on top of another), determine for example what components (select all that apply) from the Bill-Of-Materials of the disposable camera under analysis prevent multiple images from being taken on the same film frame and how the identified components should function to allow the user the superimposing of images

2.3 Alter the disposable camera design to allow the user to see in the viewfinder any object blocking the lens (e.g. Fingers on corners of the picture)

3. For each scenario describe how you'd modify the original design of the camera to achieve the new functionality

4. Show your work to your Instructor / Teaching assistant, to be collected at the end of the allotted time.

Conditions (optional): The camera should maintain some of its original functions (you choose)

C. Sample Product Troubleshooting Exercise, Source: [Dalrymple. 2009]

• Introduction:

Disposable camera manufacturers reuse most of the components from previously used cameras to make new ones. To ensure that the re-used components still function satisfactorily they undergo a thorough cleansing process to remove imperfections and restore them to their original working condition, the reused components are only moved to the assembly line if they pass inspection, [Dalrymple. 2009]

A re-loaded one-time-use camera is a camera that has been manufactured by a third party company using the used camera components that were originally manufactured by Kodak, Fujifilm and other reputable companies. After obtaining the camera shells from the photo-developers, these third party companies re-assemble the parts, and load the cameras with new film. Although these re-loaded cameras may look similar to those from the original manufacturers, they are very different because the re-used components have not undergone the same stringent cleaning and inspection processes to ensure the same quality. Developed film often reveals the imperfections with reloaded cameras, Source: [Dalrymple. 2009]

• Tasks:

Four examples of pictures taken with reloaded cameras are shown; each picture reveals an imperfection; suggest a plausible scenario where the product might have failed in attaining its functions satisfactorily and diagnose the problem for each example. Three sample questions/tasks to answer are suggested, namely:

-Identify which user / camera action likely malfunctioned leading to the error (Aim; shoot, wind, or protect film)

- Identify the specific components from the BOM that may have functioned poorly

- Describe a reason for the imperfection (what may be happening with the camera for the error to occur)

• Example 1:

A picture with a dark rounded spot in the top left hand corner is shown in Fig 6.9, the image progressively fades and becomes more blurred towards the bottom right hand corner (Note: Dark spots have not been exposed to light and faded blurred spots have been overexposed to light)

Figure 6.9 Example 1, Picture. Photocredits: [Dalrymple. 2009]

-To get this defect a malfunction most likely occurred in which user/camera action?

Aim___ Shoot_____ Wind_____ Protect Film______

-To get this defect which components from the BOM may have functioned poorly, select all that apply:

-Describe what may have happened within the camera for this defect to occur:

• Example 2:

The picture below in Fig 6.10 has discoloured streaks along the sides (Note: Discoloured streaks occur with prolonged over exposure to light)

Figure 6.10 Example 2, Picture. Photocredits [Dalrymple. 2009]

- To get this defect a malfunction likely occurred in which user / camera action?

Aim___ Shoot_____ Wind_____ Protect Film______

-To get this defect which components from the BOM may have functioned poorly, select all that apply:

-Describe what may have happened within the camera for this defect to occur:

• Example 3:

All developed pictures from a roll of film contained the same dark line in the same position. The user did not see this line when he looked through the viewfinder to take the picture. Three pictures from this roll of film are shown below in Fig 6.11

Figure 6.11 Example 3, Picture. Photocredits [Dalrymple. 2009]

- To get this defect a malfunction likely occurred in which user / camera action?

Aim___ Shoot_____ Wind_____ Protect Film______

-To get this defect which components from the BOM may have functioned poorly, select all that apply:

-Describe what may have happened within the camera for this defect to occur:

• Example 4:

An image is split between two pictures as seen in Fig 6.12. Part of Picture 1 is completely dark and the other part has the first part of the image. The second part of the image is on Picture 2 along with a completely dark segment

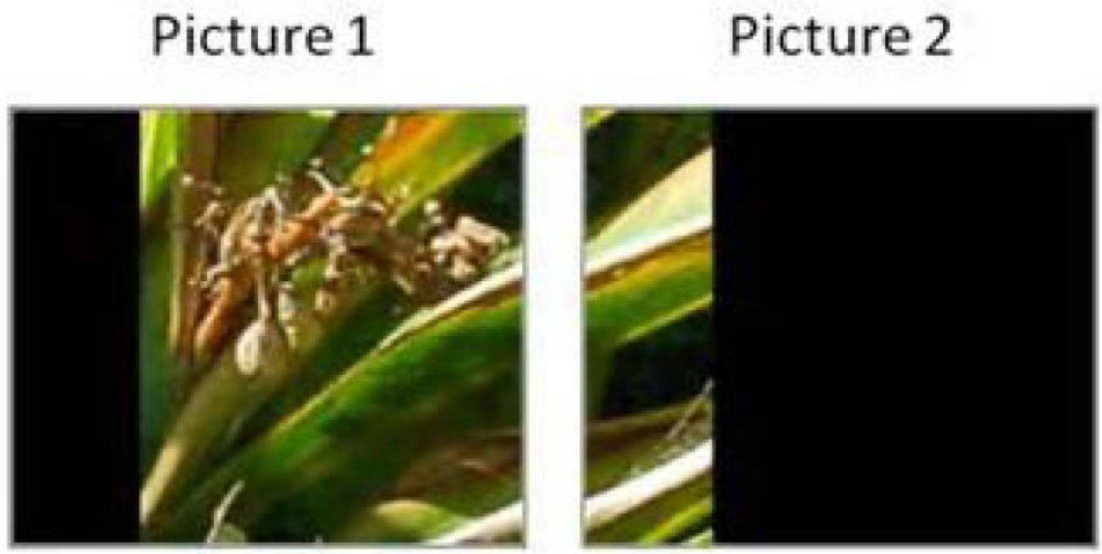

Figure 6.12 Example 4, Picture. Photocredits [Dalrymple. 2009]

- To get this defect a malfunction likely occurred in which user / camera action?

Aim___ Shoot_____ Wind_____ Protect Film______

-To get this defect which components from the BOM may have functioned poorly, select all that apply:

-Describe what may have happened within the camera for this defect to occur:

Finally, show your Instructor / Teaching Assistant a copy of your work to end this exercise

D. Sample System Decomposition Exercise, Source: [Dalrymple. 2009]

• Introduction:

To reduce the complexity of a design problem, engineers divide the problem into smaller, simpler sub-problems which makes the design process easier to manage. The disposable cameras' design problem can be divided into three basic user actions and one product action, namely:

User action: Aim (Focus image)

User action: Shoot (Take a picture of image)

User action: Wind (Reset camera to repeat previous actions)

Camera action: Protect film (From unwanted light and other environmental elements)

• Instructions:

From a collection of images of disposable camera components like the one shown below in Figure 6.13 or from the product's BOM:

Figure 6.13 Sample Fujifilm Single Use Camera Parts, Source: [Dalrymple. 2009]

1. Identify and select all the components that function to allow the user or the camera to:

Aim (Focus image):____________________,_______,_________,_______

Shoot (Take a picture of an image): ______, ______,______,_____

Wind (Reset camera to repeat previous actions):______,________,______,______

Protect film (From unwanted light and other environmental elements):_______,________,_______,____

2. Note if some of the components can support multiple actions

As seen from the four different exercises above product-based tests can help students acquire relevant skills and abilities necessary for the development of the profession of engineering design.

This is the end of the third phase of the pedagogy for the teaching of EREA dealing with the evaluation of it, the next phase though will cover the following up aspects of it so all knowledge gained from an EREA can be kept reachable for whoever deems it useful in a future situation.

6.5.4 Phase 4: Follow up of an EREA

The fourth and last phase in the pedagogy for the teaching of EREA concerns the actions involving the ending of the students' work in an EREA and the following up of its results by the professors that were in charge in the sense that all relevant knowledge and findings obtained from the EREA can remain available until they are needed again (e.g. To improve the planning of resources for future EREA; to know what to expect from them under given circumstances or to know how to analyse a certain family of products). This phase then, correspond entirely with the 14th and last stage (Project Closure / Follow Up) of the suggested methodology for educational reverse engineering analysis proposed in Resource 5 and so it marks the end of both the methodology and the pedagogy for EREA suggested in this collection of resources

Major categories for the actions to carry out at this stage from a professor's perspective and that have proved successful in the past in keeping the experience gained from an EREA readily available include: Documenting the knowledge obtained from an EREA both at the students and instructors level; disseminating the findings from the EREA in academic circles, putting in place feedback mechanisms for students in order keep improving the teaching of EREA, and the developing of guidelines for the creation of

Reverse Engineering-based educational activities based on the results from professors having given them a try

6.5.4.1 Project Closure/Follow Up

The advice presented below intends to support professors in charge of EREA to set up the mechanisms that will allow all knowledge gained from an EREA to be kept and reachable; the specific actions for professors to do at this stage then, include:

- To analyse the feedback from your students about their overall impressions from the EREA
- To try to foster connections between local industries and your institution by requesting any form of support such as donated physical equipment, company tours, or experts visits
- To think of future themes for EREA
- To consider the possibility to exchange EREA-projects with partner schools and learn from each other's experiences
- To consider the possibility to deliver EREA to students of the same university not only from engineering design programmes but also from different engineering disciplines
- To incorporate changes to the teaching curriculum of EREA (if needed) after the experiences gained from them
- To plan for renewal of project ideas
- To prepare a strategy to reuse projects from past semesters in case of need or at least to keep them arranged as a repository of past projects for students to consult, provided that each semester different, varied products are suggested to students to choose as subject systems
- To prepare your findings so they are transferable to other classes/professors and universities
- If convinced of the benefits of EREA or if you detect new uses of them, to try to disseminate them and to always look for different applications of them

The last piece of advice to give professors reaching this point of the pedagogy then, is to allow their students to conclude the EREA whenever they feel there is nothing left to be taught under the available resources and the professor is ready to move on with the assurance that everything relevant that was learned won't be lost and will be of benefit for future professors and students of EREA.

6.6. Resource Conclusions

Educational reverse engineering activities -Just like engineering design itself- are multidisciplinary activities with varied application areas that require their teaching strategies to be diverse and their evaluation to be flexible just like the goals and nature of design projects themselves.

It is believed then, that a structured approach to the teaching of EREA like the one presented in this resource (cf. Preparation; execution , evaluation, and follow up of them) that is set in a real-life like scenario and where students can plan their own tasks and the professors' role mainly falls in supporting an orderly sequence of events by providing them with technical and organizational input, not only helps ensure that the learning experiences inherent to EREA are actually acquired and that the workload and roles needed for them are evenly distributed among team members and professors in an effective and safe way, but also that such structured approach can help mitigate not only some of the attributes of poor instruction in engineering identified by authors [Seymour and Hewitt. 1997] such as the "Predominant use of one-way lectures", "Lack of discussion", and "No indicated application or implication of material" ones but also to help lessen the deficiencies of typical lectures reported by [Bligh. 2000] with respect to "Promotion of thought" and "Inspiring interest in a subject".

The advice presented in this resource intends to support professors of engineering design willing to give EREA a try by providing them with the advice and information necessary to plan, teach, evaluate and follow up the work and results from their students under the existing administrative and pedagogical frameworks already enforced at their workplace.

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RESOURCE 7: INTEGRATED EXAMPLE OF AN EDUCATIONAL REVERSE ENGINEERING ACTIVITY ON A DISPOSABLE CAMERA

7.1 Resource Introduction

This resource is presented as a self-contained example of an educational reverse engineering activity using a disposable photographic camera as a subject system; it is intended to show professors of engineering design in an integrated, practical way what an EREA would look like in an educational setting (i.e. Tasks and questions suggested in the methodology are translated into specific actions done to a disposable camera) thus each step of the example, how it is handled and what the results from it are, should be understood both as an indication of what an EREA would comprise and how experience recommends to deal with. Each of the fourteen stages of the methodology for the development of an EREA already explained in Resource 5 is presented here in an expanded three-subsections format in order to include suggestions for its teaching, and examples of results from it.

• The subsections showing the self-descriptive stages of the suggested methodology for the reverse engineering analysis of the subject system are written in a style addressed to the analysts in turn (cf. Undergraduate students of engineering design)

• The subsections showing a proposed pedagogy for the teaching of the abovementioned methodology are written in a style addressed to professors in order to support the development of each of the stages (e.g. By including the theory and explanation behind them)

• The subsections showing sample results, deliverables and conclusions for each of the stages of the methodology are presented in the same way as students would submit them for evaluation to their professors

The information presented in this resource then, complements that previously shown in Resources 5 and 6, and in the rest of the collection of resources overall to support the testing and eventual implementation of EREA in existing engineering design curricula.

7.1.1 The Methodology Subsections

As mentioned already, from the battery of tasks, questions and analyses suggested in the methodology for the development of EREA, the professor in charge must select only those that provide a beneficial tradeoff between information gained and resources invested, in this guided example one can see how experience dictates single use cameras should be analysed in a reverse engineering activity and what sequence the analyses would follow and to what depth they would be pursued

7.1.2 The Suggested Pedagogy Subsections

Different from Section 6.4 where the fundamentals of a pedagogy for the teaching of EREA is presented , in this resource's example those specific suggestions and explanations are transformed into specific tips and suggestions on how to conduct each of the stages of the methodology when using a disposable photographic camera as a test subject, from the comparison of the specific actions here to the general guidelines presented at the previous resource one can see how a theoretical approach is transformed into a real life application.

7.1.3 The Sample Deliverables Subsections

Earlier versions of this collection of resources considered the inclusion of the solutions to the full battery of tasks, questions and analyses suitable for the disposable camera used as subject system in this example, however the idea was quickly discarded because of readability and length constraints in this document, instead, a more focused approach is considered here where only those analyses known to most professors; with a certain degree of difficulty, and that provide the most information about the product under analysis are attempted in this example; what's more, and in order to benefit from the work by past researchers on disposable cameras, now fully developed exercises are included only whenever deemed necessary, but in the rest of cases only snippets showing the most relevant data, and pointers for the development of a given analysis are shown; additional to this and as much as possible, the author of this document has tried to include relevant analyses already solved and published which can indeed serve not only as references and inspiration for the target audience but also as leads to discover the work of other researchers on the topic; indeed several authors have worked in the past on disposable cameras and finally in this collection of resources can the readers coherently link the work of all of them and complement it with the original findings from this collection of resources.

7.1.4 Specifics of this Resource

As mentioned in Section 6.4.4, EREA can support students' learning at any stage of their studies, however their recommended time of inclusion falls during their first year so they can use the activity as a fast track to familiarise with the topics of their educational curriculum as well as with the analyses and approaches likely to be found later in their careers, the level of detail and comprehensiveness of the analyses presented here then, reflects this approach while still providing at the same time significant pointers for the development of several advanced analyses expected from last year and graduate students of engineering design.

It is also worth mentioning that the Kodak single use camera with flash was chosen as the subject system for this example not only because it features electromechanical components as well as a chemical device (the photographic film), but also because it's been the subject of analysis by past researchers and as such, newcomers to reverse engineering can compare their own results to those previously published to check how they are doing; however, it was later brought to the attention of the author that this model was not sold in all markets, so additional examples for the Kodak single use waterproof camera (a complementing member of the same product line available worldwide) were also included to present an example that feels closer to professors in academic institutions all over, indeed in an EREA with more than one team or where plenty of resources are available this approach is actually taken where the simultaneous analysis of similar, competing products by different teams of students provides a greater chance to expand the sources of learning for the whole class, in the end though, it is worth keeping in mind that learning about disposable cameras themselves (or about the chosen product for analysis for that matter) is not a goal of an EREA (though disassembling a specific product to learn about it is a great way), but they are rather considered a vehicle for the acquisition of abilities and skills relevant to engineering design irrespective of the product analysed.

Finally, all due credit should go to the past researchers who have worked on disposable cameras as an aid in the teaching of engineering and from which this specific section of the collection of resources draws heavily, namely: The lesson plan "Reverse Engineering of a Common Product a CIESE collaborative project" by [CIESE. 2008]; the examples "Kodak Waterproof One-Time-Use Camera" by [Castellani. 2006], "Single-Use Camera Dissection" by [Simpson. 2009], "Group 32 - Kodak Funsaver Camera" by [CIBER-U. 2012] and the dissection of a Kodak Water & Sport camera by [Kutz. 2007], the pioneering product dissection examples by [Lamancusa et al. 1996], the research on reverse engineering for green design of products by [Comparini & Cagan. 1998], and the findings by [Dalrymple. 2009]; their past publications along with the ideas and findings pertaining to the doctoral research from which this collection of resources stems aim to represent most of the best practices, experience and innovations available in the area of product dissection and hands-on activities for the teaching of engineering design.

7.2 Integrated Example of an EREA

The example below explores how a single use camera works; how it came to be and its impact in society, the main objective of the activities listed below is to provide students with an opportunity to develop their basic abilities in engineering design and as such this activity is planned as a complement not a substitute to their traditional instruction.

7.2.1 Stage I: Task Clarification

7.2.1.1 Methodology

From the battery of tasks, questions and analyses available for this stage it was decided to go ahead with those that provided a general understanding of the situation and whose results are seen in Tables 7.1 and 7.2 below.

7.2.1.2 Suggested Pedagogy

The professors' work at this stage is mostly comprised of helping their students understand the nature of the task they are being asked, and of helping them to plan the actions to meet project milestones & deadlines

7.2.1.3 Sample Deliverables

A. Students' understanding of the situation:

	Understanding of the Situation
What	To understand how the single use Kodak Flash Camera came to be, for what reason and how it has impacted society
Why	As a way to quickly familiarize with the topics and engineering tasks likely to find throughout the undergraduate years and later in our careers
How	By performing a reverse engineering analysis to a disposable camera and determining among other things its components; functions, features, materials and manufacturing processes involved and eventually suggesting improvements to it
When	At the second semester of our engineering studies and for which a timetable for the execution of the tasks is shown further below in Table 7.2

Where	At several venues but most of the work being at the university lab and the usual classroom itself
Which	The consumer product chosen for reverse engineering analysis is a disposable Kodak Flash camera
Who	Based on the size of the class several teams were created each of them with four members

Table 7.1 Students' Understanding of the Situation

B. Student's statement of goals and expectations from the EREA:

To have an educational activity in a safe environment where we can learn the trades of our career and advance in the acquisition of abilities and knowledge related to it

C. Timetable for the completion of the activity (8 Sessions of 1h duration at least)

	Stage of the Methodology	**Major Activities**	**Resources Needed**	**Venue**
Session 1	Task clarification, Product procurement, Team selection	Introduction and overview of the activity; team setting, first contact with the product	Disposable Kodak Flash camera	Classroom
Session 2	Data collection	Collection of information and contact with experts	Internet access, published resources	University library, classroom, home
Session 3	Product performance test I, Product disassembly	Testing, measuring and dissection of camera	Laboratory tools	University laboratory
Session 4	Product analysis	Testing, inspecting	Laboratory tools, Internet access, published resources, external advisors	University laboratory
Session 5	Product	Assembly, tuning	Laboratory tools	University

	reassembly, Product performance test II	and measuring of the camera		laboratory
Session 6	Knowledge synthesis, Redesign suggestions	Team discussions, consultation with experts	Internet access, published resources, external advisors	University library, classroom, home
Session 7	Conclusions	Team discussions, documenting, drafting of report	Personal computers; internet access, published resources, external advisors	University library, classroom, home
Session 8	Results dissemination, Project closure / Follow up	Team presentation	Projector, screens, personal computers, boards	Classroom

Table 7.2 Expected Timetable for the EREA

7.2.2 Stage II: Product Procurement

7.2.2.1 Methodology

Although students can choose the product they wish to analyse, it will be also a common case when the professors themselves provide the subject system to their students; be it because of personal preferences or because certain products are already provided by the academic institution, in this case the latter case is presented.

A disposable Kodak Flash camera was given to students as subject system because they are commonly found products and while not an overly complex one they can be used as a vehicle for understanding some of the key concepts of systems and the engineering design process

7.2.2.2 Suggested Pedagogy

- If students choose their own product for analysis ask them to think about their immediate environment and identify an engineered system that at a minimum contains both electrical and mechanical components (e.g. Home appliances), once it is chosen ask them to comment individually on how familiar they are with it

- If the professor / academic institution / sponsor provides the product, give each team one device, and deliver a presentation to your students showing its main features and the reasons for choosing it

Additionally, most of the times the number of students in a course will call for the setting of more than one team so different, competing / complementing products should be assigned so more devices can be covered by the same class and thus students can learn from the different approaches of each other

7.2.2.3 Sample Deliverables

A. Subject system:

The product chosen for analysis is a disposable Kodak Flash camera provided by the professor and shown in Figure 7.1 below:

Figure 7.1 Disposable Kodak Flash Camera

A.1 In case two teams are formed by class the disposable Kodak Waterproof camera seen in Figure 7.2 is also chosen because it is a complementing product in the same line by the same manufacturer

Figure 7.2 Disposable Kodak Sport Camera

A.2 In case three or more teams are formed by class, a mix of products that include the disposable Fujifilm QuickSnap Superia shown in Figure 7.3 below is suggested since it is a similar but competing product by a different manufacturer (alternatively a disposable Kodak Zoom camera can be used, it won't bring enough diversity to appreciate how a competing product is manufactured but it will allow, among other things, the study of product commonality features across product lines)

Figure 7.3 Disposable Fujifilm QuickSnap Superia camera

B. Initial work planning:

After a first contact with the product, potential tools and analyses for its disassembly and testing were considered, and requested the allocation of such resources to the professor, namely:

B.1 Potential tools: Zip lock bags, black electrical tape, a pair of needle nose pliers, small slotted screw driver, pocket knife

B.2 Potential performance tests: Tests to measure shutter speed, test to measure flash output power, tests to de determine the objective's equivalent focal length, etc.

7.2.3 Stage III: Team Selection

7.2.3.1 Methodology

From the varied activities suitable for this stage five major tasks were sorted out, namely:

- Setting the number of teams and team members in the course
- The function of the professor for the attainment of the goals of the EREA
- The assignment of students' roles in performing the stage activities of the EREA
- Ensuring the wilful participation of all team member
- Setting fair labour policies

7.2.3.2 Suggested Pedagogy

In this stage the professor's role falls in helping students organize themselves in teams for the successful attainment of the activity, three different aspects have to be overviewed, namely:

- Determining the role of the professor himself/herself throughout the activity which experience dictates will be that of a facilitator to allocate the resources needed for the activity and that of an advisor who will provide technical input for the development of the EREA whenever needed
- Building teams based mostly on available resources for the completion of the EREA but also strongly influenced by the number of students enrolled in the course; they can be grouped either by affinity, randomness or by professor's decision, and team roles must be distributed so all of them carry an equal share of responsibility
- Ensuring that differences in gender, background and knowledge are respected and everyone gives their best effort towards the completion of the activity

7.2.3.3 Sample Deliverables

A. Team setting

Because resources such as tools and available laboratory time are usually limited only two teams but with six members each were formed, the members were grouped by affinity for this case

A.1. Team roles and functions

Overspecialization in only one role throughout the whole activity was avoided, however each member was given a major role to fulfil and then he/she could support or be supported by other team members whenever required, the roles and functions were:

- Disassembler / Assembler: To lead the hands-on activities of the EREA
- Photographer: To videotape and photograph every relevant event in the EREA
- Analyst: To lead the use of analytical tools and tests to understand the product
- Drafter: To lead the creation of technical drawings and computer animations of the product
- Data collector: To lead the collection of information and interaction with external experts
- Presenter: To lead the effort in writing the final report and delivering its presentation

B. Professor's functions

It was decided that the role of the professor would be that of a facilitator to allocate the necessary resources for the completion of the activity, and also that of a consultant who would provide technical expertise and guidance in the completion of the activity.

C. Commitment to the activity

In order to ensure the wilful participation of all team members in the activity it was agreed to sign a document stating our commitment to the activity and undergo a 360 degree evaluation (c.f. From all team members) in case of disputes

D. Setting up of fair labour policies

After a talk with our professor about the importance of a fair distribution of workload and potential differences in gender and cultural backgrounds among team members a team building attitude was agreed among each other and we committed to avoid negative practices such as bullying or discrimination

7.2.4 Stage IV: Data Collection

7.2.4.1 Methodology

After reflecting on the first impression caused by disposable cameras, it was decided to pursue those activities that would yield the most information about their functionality and current place in the consumer market, to that end a search was organized to collect all relevant background and reference materials available at our reach; it turned out that the sources with the most data on the topic were manufacturers' brochures; intellectual property resources (patents), previously published academic results, interviews, and internet searches on engineering databases and journals; the collected information was later studied and organised in preparation for the next stages of the methodology where it would be better understood and integrated to the rest of information about the disposable camera. Finally at the end of the stage, the professor provided input on what additional information should be sought after, and how it could be acquired either through direct means (e.g. Testing and analysis) or through indirect confirmation (e.g. Benchmarking data from similar fields)

7.2.4.2 Suggested Pedagogy

The major work of professors at this stage deals with helping students develop their information gathering and integration skills by teaching them on the one hand how to use and benefit from engineering knowledge resources such as scholar internet searches or traditional printed publications, and on the other hand how to integrate all collected information into a coherent body of information from which preliminary results can support further investigation

7.2.4.3 Sample Deliverables

A. Identification, understanding and description of the primary function / need addressed by the product

The primary function of the Kodak single-use camera is to take pictures in a convenient (e.g. Portable / practical) and affordable way for both the consumer and manufacturer, (the function was derived by students' consensus and later confirmed via published research by [Van De Moere. 1992] on the design philosophy of disposable cameras) (see also Table 7.19 for complementing views on this)

A.1 Typical uses of disposable cameras

Beyond the evident uses of disposable cameras as a cheap alternative to a regular, digital camera or a waterproofed one it was discovered that it is actually recommended to carry one of them in the car to record details of accidents not only because of their reliability (cell phones cameras can get damaged or run out of battery) but also because photographs arguably present a physical evidence that is less prone to digital manipulation

B. General information about manufacturers of disposable cameras

Companies producing disposable cameras range from major ones such as Polaroid, Fuji, and Kodak, to those little known ones that actually supply the product to the directly to the customer, e.g. Zhejiang New Fine Industry Co. Ltd. and Henwei Industrial Co. Ltd. Disposable cameras can be custom made to match the demand of the customer with several variations that include underwater cameras; advertisement (e.g. Custom logo) cameras, disposable camera kits that include materials to create reports (useful for collecting data after incidents such as car accidents), and even special disposable cameras made elegant for weddings; disposable cameras then, come with certain generic features such as a flash, twenty seven 35mm exposures, but the addition of features such as waterproofing and custom designs make the market diverse and competitive.

B.1 Typical prices of disposable cameras

Prices can change from country to country as well as because of their varied design, disposable cameras for example, can range from US$6 (generic Kodak) to US$13 (Gold Rose Wedding Disposable Camera) or can be bought in bulk online from the manufacturer for prices that range from US$200 for a case of 24 (Polaroid Flash) units to US$ 300for a case of 24 cameras (AmeriCamera)

C. Information about the recycling process of Kodak disposable cameras

On this particular topic, the search for information yielded a significant amount of resources which after analysis and contextualization were arranged under the categories shown below, namely:

C.1 Recycling of the product:

- For recycling purposes some parts of the camera are tested and directly reused, cf. [Van De Moere. 1992]

C.2 Operations at a Recycling Processing Centre:

Author [Kutz. 2007] describes the operations at a processing centre as seen in Figure 7.4, where each returned camera is disassembled, inspected and reassembled for sale again and states that the camera components undergo the following process:

- Lenses, viewfinders, and external housings are grounded up and combined with raw materials to make new external covers.
- The chassis and camera mechanism (and electronic flash system, if present) are tested, inspected, and reused, if possible; otherwise, they are scrapped.
- New lenses (to ensure optical purity for high quality photographs) and new film (and new batteries if the camera has a flash) are added to make a “new” one-time-use camera, which is packaged and shipped to a retailer to begin the cycle all over again.

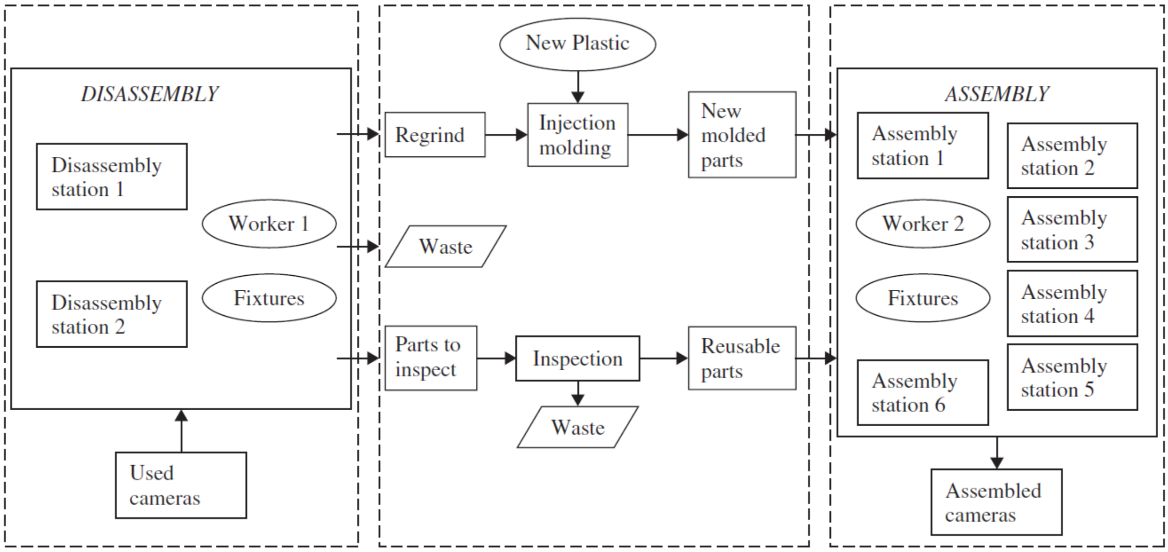


Figure 7.4 Camera Disassembly and Recycling Process, Source [Kutz. 2007]

C.3 Information regarding the perception in society about disposable cameras

According to [Kutz. 2007] Kodak’s disposable cameras were once considered to be ecologically offensive by many environmental groups due to the initial disposable Kodak “fling” perception but these cameras have since become the cornerstone of Kodak’s recycling, remanufacturing, and reuse efforts, providing the best example of a closed-loop recycling program in the world as seen in Figure 7.5

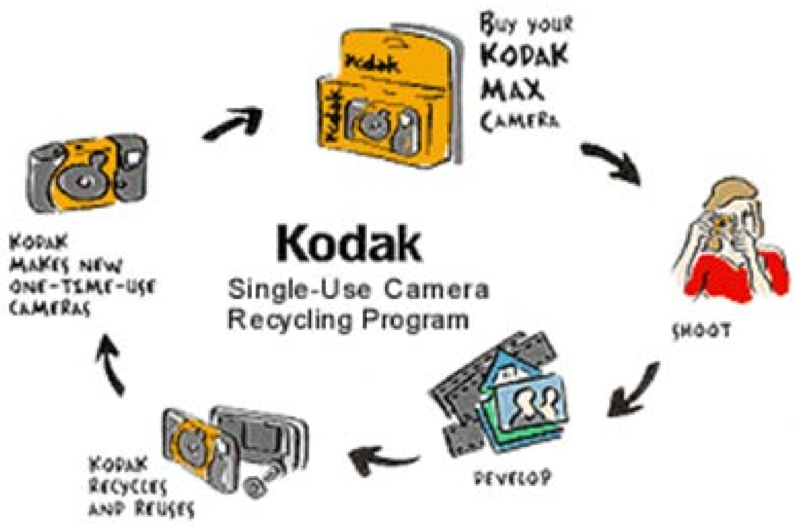


Figure 7.5 Graphical representation of Kodak's Closed-loop recycling program, From Use to Reuse, Source: [Eastman Kodak Company. 2013]

C.4 Recycling rate of Kodak disposable Cameras

In this regard, author [Kutz. 2007] cited Kodak's 2004 Annual Report where they stated that one-time-use cameras (a.k.a. OTUC) are recycled at a rate of 74 percent in the United States (60 percent worldwide), surpassing that of corrugated containers (73 percent), aluminium cans (63 percent), and glass bottles (33 percent), with total worldwide returns exceeding one billion in 2004 as seen in Figure 7.6 below:

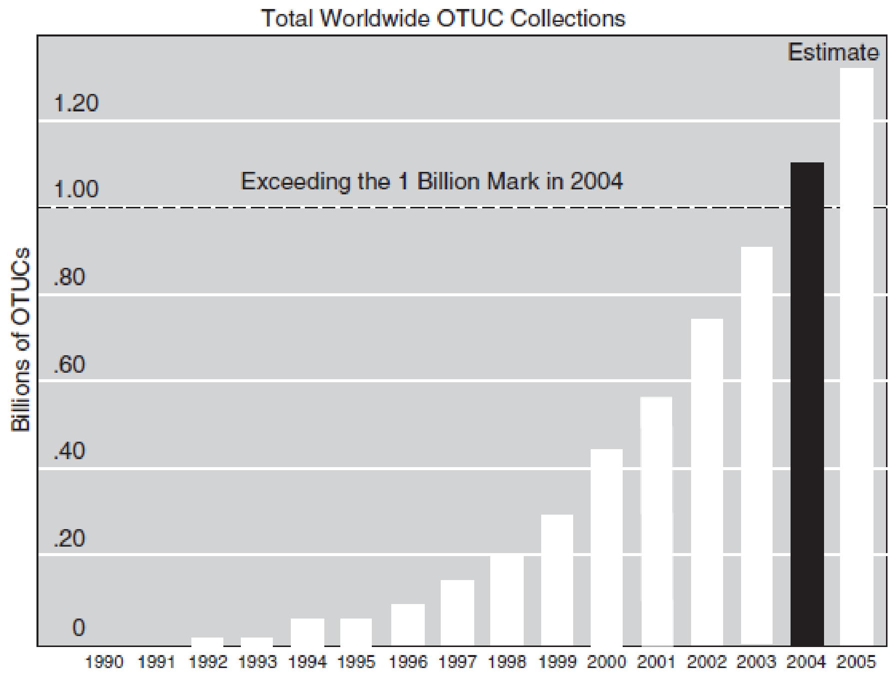


Figure 7.6 Cameras Returned Annually Worldwide, Source: [Kutz. 2007]

C.5 Varied, interesting facts about disposable cameras

• A single-use camera can be returned to the shelf in 30 days after collected from a developer (an aluminium can takes ~60 days), Source [Simpson. 2009]

• By weight, 74-90% of a Kodak single use camera can be reused, remanufactured or recycled (because film and battery in the camera (if included) are not re-useable after a standard usage), Source [Van De Moere. 1992] , [Kutz. 2007] & [Simpson. 2009], however, the rest of camera materials (e.g. Polystyrene) allow them to be reground into pellets of material and moulded again into new parts for the cycles of single use cameras, this rate is considered high compared to similar systems across industries (e.g. Varied aluminium components), in this regard, author [Kutz. 2007] ends up by stating that the extent to which these cameras can be reused and recycled continues to be improved, thanks to ongoing redesign efforts that were launched more than a decade ago by an integrated product development team composed of design, business, manufacturing, and environmental personnel, the analysis of different models of Kodak's one-time-use cameras then, provides insight into such products and how they have evolved to facilitate disassembly and part reuse while continuing to ensure high-quality photographs.

D. Patent Analysis of Disposable Cameras

Table 7.3 below lists the patents found relevant to the study of disposable cameras overall

Patent Number	Description	Date of Patent	Location
5,471,270	"Spool drive for film cartridge in single-use camera" This apparatus helps prevent the unauthorized recycling of disposable cameras.	Nov. 28, 1995	Patent Searching and Inventing Resources at http://www.freepatentsonline. com/5471270.html
5,325,366	"Photographic Film and Cartridge" Single-use photographic film package and cartridge that gives disposable cameras a packaging in which the camera cannot be reused without replacing key components. This also prevents the unauthorized	Aug. 10, 1993	Patent Searching and Inventing Resources at http://www.freepatentsonline.com/5192648 .html

	recycling of single-use cameras.		
4,890,130	"Lens-fitted Photographic Film Package" Lens-fitted photographic film package. This device includes a light-tight film case which prevents the film from being exposed to light, which in return would ruin the film	Dec. 26, 1989	Patent Searching and Inventing Resources at http://www.freepatentsonline.com/4890130.html

Table 7.3 Relevant Patents for the Study of Disposable Cameras

E. General information about Fujifilm cameras (in case they are used in your activity)

- Fujifilm applies DfE (Design for Environment) principles in the design and development of its line of single-use cameras, Source: [Dalrymple. 2009]
- Their single-use cameras are produced in an inverse manufacturing facility where 99% of used cameras are either remanufactured or recycled to produce new generations of the product, Source: [Dalrymple. 2009]
- The Fujifilm QuickSnap outdoor 1000 camera is one of the most recent upgrades to the Fujifilm lineup; it was released at the PMA 2007 Annual Convention and Trade Show in Las Vegas, USA and it incorporates the latest advances in the design of single use cameras

F. Information regarding the upcoming disassembly procedure of the disposable camera

Although the disassembly and reassembly of the disposable Kodak Flash camera is possible using standard tools it was found through interviews with film developers that authorized servicemen of the product use proprietary tools for the assembly/reassembly of the device not to damage it and return it to the manufacturer for further inspecting and sale

7.2.5 Stage V: Product Performance Test I

7.2.5.1 Methodology

After familiarizing with the safety procedures and use of measuring tools at the university laboratory the disposable camera was assessed in terms of packaging and industrial design aspects, later the camera was handled and inspected (but not actually operated, in order to salvage the film for further use), at the end of the stage then all information collected about the camera was interpreted and contextualized in a group session where the professor provided technical input whenever needed

7.2.5.2 Suggested Pedagogy

This is the first stage where the professor's role in helping ensure the safety of students at all times becomes noticeable so his/her major task here falls in working on the safety and class order aspects of laboratory work (e.g. Locating fire extinguishers and first-aid kits) as well as in providing the necessary guidance on the technical aspects relevant to the use of laboratory equipment, testing and data recording practices; additionally and depending on the number of enrolled students and of available resources the support of teaching assistants or laboratory technicians might be required

7.2.5.3 Sample Deliverables

A. Analysis of Customer Needs:

After the gathering of information about the camera and the actual testing of it was possible to consolidate the analysis of the customer needs it fulfils, so it was agreed that the typical factors about disposable cameras that are important to customers are categorized as:

- Ergonomics
    - Easy to hold
    - Comfortable fit in hands
- Image quality
- Misfiring protections
    - Reduce the risk to take a picture accidentally
- Image framing
    - Viewfinder matching the final framing of the image
    - Reduction of the risk to take a picture with the fingers over the lens
- Durability
- Flash
    - Enough flash power output
    - Red eye avoidance
- Camera aesthetics
    - Attractive to average customers
- Control of use of Film
    - Show number of exposures used/remaining

B. Performance parameters:

It was determined that the camera specifications are as follow:

- Equivalent focal length f=30mm; meaning it provides a field of view tending towards the wide end to cover as much ground as possible but still close to the traditional 35mm field of view ever present during the analogue film era
- Shutter speed of 1/100s; meaning that image blurriness due to camera shake is negligible since it exceeds by two stops the empirical suggestion of s=(1/f) and it is suitable enough to freeze everyday scenes, and with the right technique (e.g. Panning) even fast moving objects
- ISO film speed of 800 (Kodak Ultramax 800); to provide for latitude in the exposure given the fixed set of exposure parameters of the camera (shutter speed, aperture and film speed)
- Lens aperture: F10; 2 elements, 2 aspherical, moulded plastic groups, the small lens aperture in combination with the fixed focal length means that the depth of field of the camera ranges from three to eight feet from the lense/camera which in practical terms it means that unless pictures are taken at extreme “macro distances” everything in the scene will appear to be in focus
- Flash power output: The optimum range of operation of the flash output is from three to eight feet, these values are derived not only from observing examples of photographs taken with it enabled, but are also based on the depth of field value given by the combination of aperture and equivalent focal length of the camera; the output range of the flash unit was arguably planned that way in order to take the best possible self-portraits (e.g. Selfies, by covering the length of a fully extended arm) and group pictures (at distances where the heads and shoulders of the subjects are in frame). It must also be mentioned that the flash power itself is generated from a preinstalled 1.5 volt battery which can optimally produce a flash of light for the full 27 exposures of the camera film
- Usage environment: Those disposable cameras with a flash unit contain a very simple device, only suitable for regular use as explained already, most of cameras though, don’t feature a flash unit in them; because of this, one might think that disposable cameras are only suitable for daylight use and although in an interview with film developers it was estimated that 90% of all shots are taken in daylight the truth is that thanks to the ISO speed and dynamic range of the built-in negative print film which provides up to an estimated 4 stops of under/over exposure, the final image provided by film developers (even if it was taken under dark conditions) will still be a usable

one (with only perhaps a “grainy” aspect, typical to analogue film anyway) with a quality higher than expected from devices at this price range. For regular daylight conditions then, the camera’s fixed exposure parameters (lens aperture , shutter speed and ISO speed) allow for an exposure that seems to follow the “Sunny 16” rule (an empirical rule known to educated photographers that links aperture and shutter speed to the reciprocal of ISO film speed) which means a suitable exposure will be obtained on daylight.

B.1 Performance parameters for Fujifilm disposable cameras

Just as for the Kodak brand, Fujifilm also publishes the disposable camera specifications and are included here for the benefit of the reader using them as subject systems

- Number of Exposures: 27
- Lens: Plastic lens, 32mm f/10, fixed focus lens
- Shutter Speed : 1/140s.
- Subject-to-Lens Distance: From 1m to infinity
- Finder : Inverted Galilean-type plastic lens finder
- Flash: Built-in electronic flash, (Effective subject-to-flash distance: 1m - 4m)

Although the main camera specifications were published by the manufacturer, the team had already devised tests of a qualitative and quantitative nature to determine at least the shutter speed of the camera by photographing objects of a known speed (like stroboscopic lights or a car in movement) and then from the exposure parameters of the negatives of the resulting pictures derive everything else, in the end this was not necessary and only a regular use of the camera to assess it and familiarize with it was done, still it is worth mentioning that manufacturer’s specifications mean nothing on their own so the team had to learn the basics of film photography in order to contextualise and better interpret the available data.

C. Assessment of industrial design aspects:

After examining the camera’s packaging which was understood as a simple one and only intended to protect the product until its sale, the ergonomic and aesthetic aspects of the camera were assessed where it was agreed that the aesthetics of the product are rather “austere” in a typical case where “form follows the function” and where the containment of rising costs is paramount, however it was also noted when assessing the ergonomic aspects of the camera that a great attention to detail in specific areas of it was given, where for example different surface finishes would be found even in the same product part not only to improve grip in the presence of sweat or water but also to improve the perception of quality of the product overall.

7.2.6 Stage VI: Product Disassembly

7.2.6.1 Methodology

Most of the activities executed at this stage naturally fall on the side of documenting the dissection process of the disposable camera, be it for example in a digital way through drawings and video or by creating an inventory of the components as they are disassembled; however, several aspects regarding the workings of the camera start becoming evident through the simple observation of its inner components and so they should be note down too; in preparation for the more thorough analyses from upcoming stages then, some intermediate findings can still be reported here and be later complemented to come up with a definite report at the end of the methodology. The major categories for the results presented at this stage thus, were the identification of user/product actions; the documenting of the disassembly process (e.g. CAD files, BOM, disassembly instructions) and the actions taken to make this a non-destructive analysis (e.g. Salvaging of camera film for further use)

7.2.6.2 Suggested Pedagogy

As a professor, most of the work at this stage is of a supervisory nature; first off, it is about helping students devise a strategy to make this a non-destructive process or at least one that allows the subject system to be brought back to its original state; then it is about helping students go through this stage with the highest possible standards of safety while at the same time ensuring that a fair division of work is done; one last task though is to remind students that intermediate albeit incomplete results do have their rightful place and that later down the methodology there will be chances to integrate all resulting information into a final activity report

7.2.6.3 Sample Deliverables

A. System decomposition

A.1 Identified user / product actions

The major actions relevant to the camera are: Aim; shoot, wind and protect film

B. Disassembly instructions for a disposable Kodak Flash camera

Table 7.4 below describes the actual disassembly process of a Kodak Flash camera which can be read in tandem with the information provided in Table 7.5 further below for a quick cross reference between camera parts and instructions

Step	Process	Notes
1	Using the blade of a small knife cut the adhesive paper that covers the slits/planes where the front and the back cover meet all the way around the camera.	
2	Using a small slotted screw driver depress the locking mechanisms that are present around the back cover (located on the sides and the bottom of the camera).	
3	Firmly hold the respective front of the camera down and slightly pull upward on the back casing. It should detach with a little bit of wiggling.	Clearly mark the cover Part 1 and set it off to the side
4	Place the camera on the table flat on the front cover as to leave the newly revealed parts upward	
5	Using your thumb and index finger to remove the spool for unexposed film that is located on the opposite side from the film cartridge, it is removed by pulling it upward	Clearly mark the spool Part 2 and set it off to the side
6	Using your thumb and index finger grasp and remove the film cartridge by pulling it upward	Clearly mark the cartridge Part 3 and set it off to the side
7	Next using your thumb and index finger grasp and remove the battery from holders, this is accomplished by firmly pulling upward.	Clearly mark the battery Part 4 and set it off to the side
8	Now grasp the camera in both hands and rotate the camera 180 degrees as to present the front cover upwards	
9	Using your thumb and index finger remove the front cover. (it should be free from the rest of	Clearly mark the front cover Part 5 and set it aside

	the parts)	
10	Using a very small set of needle nose pliers release the tension on the copper spring that is attached to the Lens base. (this should be accomplished by slowly removing it from the hook it is attached to and slowly allowing it to recoil)	Clearly mark the spring Part 6 and set it aside
11	Grasp the top and bottom of the circuit board with your thumb and index finger and pull laterally away from the camera wiggling, and the circuit board will detach.	Clearly mark the circuit board/flash Part 7 and set it off to the side.
12	Rotate the camera 90 degrees so the viewing lens is on the top (the respective top is upward)	
13	Firmly grasp the viewing lens with your thumb and index finger and firmly pull upwards and it will detach.	Clearly mark it Part 8 and set it off to the side
14	Lay the camera on its respective back with the lens facing upward	
15	Rotate the lens fastener with your thumb and index finger and pull it upward	Clearly mark the lens fastener Part 9 and set it aside
16	Remove the lens by picking it up with your thumb and index finger	Clearly mark the lens Part 10 and set it off with the rest of the parts
17	Now return the camera to the respective upright position with the picture button in the upright corner	
18	Using your thumb and index finger grasp and pull upward on the gear protector/picture capture button (being careful not to remove any other parts in this process)	Clearly mark the gear protector/ picture capture button Part 11 and set it aside.
19	Using your thumb and index finger remove the unexposed film counter by pulling it upward	Clearly mark the counter Part 12 and set it aside
20	Next remove the film advancer that is located in the top right corner, it is removed by pulling it	Clearly mark the Advancer Part 13 and set it off with the rest of the parts

	upward with your thumb and index finger.	
21	Using some needle nose pliers remove the film advance locking mechanism by grasping it and pulling it upward off the shaft it resides on.	Clearly mark the locking mechanism Part 14 and set it aside
22	Using the pliers still, remove the revolving shaft that the other pieces were located upon. This is accomplished by simply pulling upward.	Clearly mark the shaft Part 15 and set it off to the side
23	Remove the film advancer gear that pushes the film along from the back of the frame by using the pliers and pulling laterally straight back	Clearly mark the gear Part 16 and set it aside
24	Next, remove the Locking Mechanism Release Lever by picking it upward with your thumb and forefinger.	Clearly label the Release Lever Part 17 and set it aside with the rest of the pieces.
25	Remove the resistance spring from the top corner section by grasping it with the pliers and pulling it upward	Clearly mark the spring Part 18 and set it aside
26	Return the camera to its respective back having the front face upward.	
27	Remove the lens base by depressing the locking mechanisms that are located around it with the small slotted screw driver.	
28	After the locking mechanisms are depressed pull upward with your thumb and index finger	Clearly mark the base Part 19 and set it off to the side
29	Remove the metal spacer that is present by grasping it with your index finger and thumb and pulling it upward	Clearly mark the metal spacer Part 20 and set it aside
30	Acknowledge the fact that there is a piece of metal jutting upward out of the top of the frame. (for putting back together purposes “the recoil shaft”)	Mark this recoil shaft part Part 21.
31	Count the internal frame as a part as well	Mark the internal frame as part 22 and set it aside

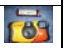
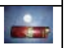
32	The camera is now completely taken apart	

Table 7.4 Disassembly of a Kodak Flash Camera, After: [CIBER-U. 2012]

C. Bill-of-materials (BOM) of the Kodak Flash camera

Table 7.5 below shows an advanced version of what a typical BOM includes, for example in this table a comprehensive overview of the parts that comprise a disposable Kodak Flash camera along with an analysis of their associated costs and functions is included. Indeed, some of the information included here cannot be obtained from the results from this stage alone, however, the findings from upcoming stages of the methodology can be included here at the end of the activity to end up with an example like the one shown here. For the populating of this table then, the reading of resources for the writing of verb-noun functions as well as of value techniques or the tables by [Ashby. 2005] for the estimation of costs is strongly suggested.

Part Number	**Part Name**	**Number of Parts Required**	**Material**	**Manufacturing Process**	**Estimated Cost in US Dollars**	**Function**	**Image before**	**Image after**	**Isolated image**
1	Back cover	1	ABS Plastic	Injection moulding	0.05	Protects and houses the internal (mechanical and chemical) components of the camera			
2	Spool for unexposed film	1	ABS Plastic	Injection moulding	0.05	Holds film that has yet to be exposed			
3	Film cartridge	1	Varied (Casing is Plastic)	Injection moulding for case, film is wound inside dark room	0.50	Provides a medium for capturing the image and holds film that has been exposed and ready for processing			

4	Battery	1	Casing is metal	Die cast casing, acids poured inside	0.25	Supplies power for flash circuit			
5	Front cover	1	ABS Plastic	Injection moulding	0.05	Protects and houses the internal (mechanical and chemical) components of the camera			
6	Small copper resistance spring	1	Copper	Heating and wrapping	0.01	Helps hold flash circuit in place			
7	Flash circuit	1	Silicone solder	Drilling, etching, and soldering	1.80	Charges the flash			
8	Viewfinder	1	ABS Plastic	Injection moulding	0.10	Allows for user to see the image that will be captured			
9	Lens fastener	1	ABS Plastic	Injection moulding	0.05	Fits over front of lens to hold in place			
10	Lens	1	ABS Plastic	Grinding and polishing method	0.15	Focuses light on the film			
11	Button	1	ABS Plastic	Injection moulding	0.05	Tells camera to take a picture and get ready to wind the film			
12	Unexposed picture	1	ABS Plastic	Injection moulding	0.10	Displays to users how many			

	counter					pictures they have left in their camera			
13	Film advancer	1	ABS Plastic	Injection moulding	0.10	Gear turned by customer to advance film after a picture has been taken			
14	Film advancer locking mechanism	1	ABS Plastic	Injection moulding	0.05	Locks into part 15 while winding film to tell film to be advanced			
15	Revolving shaft	1	ABS Plastic	Injection moulding	0.05	Rotates part 16			
16	Film advancer gear	1	ABS Plastic	Injection moulding	0.10	Moves now exposed film into film canister, designed to interlock with holes in film			
17	Locking mechanism release lever	1	ABS Plastic	Injection moulding	0.08	Allows for film to be advanced after button has been depressed			
18	Resistance spring	1	Metal	Heating and wrapping	0.05	Assists in locking the film advancing mechanisms after film has advanced			
19	Lens base	1	ABS Plastic	Injection moulding	0.10	Lens rests on top			
20	Metal spacer	1	Metal	Injection moulding	0.05	Used to help hold lens base in proper			

						position			
21	Recoil shaft	1	Metal	Injection moulding	0.05	Interacts with part 17 and helps with the locking/unlocking of winding mechanisms			
22	Internal frame	1	ABS Plastic	Injection moulding	0.20	Holds components of camera in contact with each other			

Table 7.5 Bill of Materials and Part Analysis for a Kodak Funsaver Disposable Camera, Source: [CIBER-U. 2012]

C.1 Parts' weights of a disposable camera

Additionally and if the BOM becomes cluttered in information, separate tables such as Table 7.6 shown below can be created to include relevant information from the camera components (in this case, a summary of weights from the Kodak Flash camera is shown).

Material	Weight (± 1g)
Battery	21 g
Cardboard	5 g
Circuit board (resins, fibres, copper, etc)	22 g
Film roll (polypropylene, polyacetate, etc.)	19 g
Polycarbonate	9 g
Polystyrene	52 g
Steel	2 g

Table 7.6 Sample Weights of a Disposable Kodak Flash Camera

C.2 Part Materials and Production Processes of an Earlier Generation Flash Camera

Additional to the information already presented, author [Simpson. 2009] has published a sample parts lists for an earlier generation of a disposable Kodak Flash camera with detailed information about the materials used in it which is shown in Table 7.7 below; if read in tandem with Fig 7.10 further below a better idea between the parts and corresponding images will be gotten.

KEY	PART NAME	PART #	MAT'L DESCRIPTION
1	FRAME	783390	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
2	ELECTRONIC SUB-ASSEMBLY	783764	---------------------
3	TOP COVER	783389	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
4	METERING LEVER	254508	0.762mm±0.05mm EK-207 COLD ROLLED BRASS STRIP
5	COUNTER WHEEL	254512	P1295 KAD COLOR CODE 200: POLYPROP., BLACK, 40% TALC
6	FRONT COVER	783387	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
7	REAR BAFFLE	254509	0.254mm EK63 COLD ROLLED STEEL
8	SHUTTER BLADE	254501	0.178mm±0.009mmEK-122, COLD ROLLED STAINLESS STEEL STRIP
10	TRIGGER LATCH	783391	P1040 KAD COLOR CODE 200: POLYCARB., MODIFIED, BLACK
11	THUMBWHEEL	254510	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
12	CAM	254504	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
13	TAKING LENS	642479	P1044 KAD COLOR CODE 100: ACRYLIC, (PMMA) MODIFIED, OPTICAL GRADE, ROHM & HAAS
14	FRONT BAFFLE	254511	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
15	SHUTTER SPRING	259789	EK-127, STAINLESS STEEL, 0.15mm DIA. WIRE
16	HIGH ENERGY LEVER SPRING	255891	EK-127 STAINLESS STEEL WIRE
17	SPROCKET	254503	P1023 KAD COLOR CODE 200: POLYSTYRENE,MODIFIED, BLACK
20	HIGH ENERGY LEVER	255890	P1040 KAD COLOR CODE 200: POLYCARB., MODIFIED, BLACK

Table 7.7 Sample Parts List and Material Description of an Earlier Generation Kodak Flash Camera, Source: [Simpson. 2009]

C.3 Additional, exploded views of the disassembled Kodak Flash camera

Figures 7.7 and 7.8 below shows sample pictures with an exploded view of camera after being dissected

Figure 7.7 Exploded view I of a Dissected Kodak Flash Camera, [Edwards et al. 2010]

Figure 7.8 Exploded view II of a Dissected Kodak Flash Camera, [Edwards et al. 2010]

C.4 Materials and Production Processes of a Kodak Waterproof camera

Additional to the information provided above, a summary of the materials and production processes employed in the Kodak Waterproof One-Time-Use Camera is shown in Table 7.8 below for the benefit of readers using such model as subject system.

Material Used	Associated Production Process
ABS Plastic	Injection Moulding
1040 Steel	Forming, Stamping
Rubber	Moulding

Table 7.8 Overview of a Kodak Waterproof Camera's Materials and Production Processes

D. CAx-related deliverables

Digital resources allow for multiple possibilities in the study of the dissection process of the disposable camera, the images shown below exemplify those activities usually at the reach of reverse engineering enthusiasts

D.1 CAD Diagrams

Figure 7.9 below shows a sample CAD diagram of an early generation of a disposable camera including its parts list, students can use this drawing as reference to produce a similar one

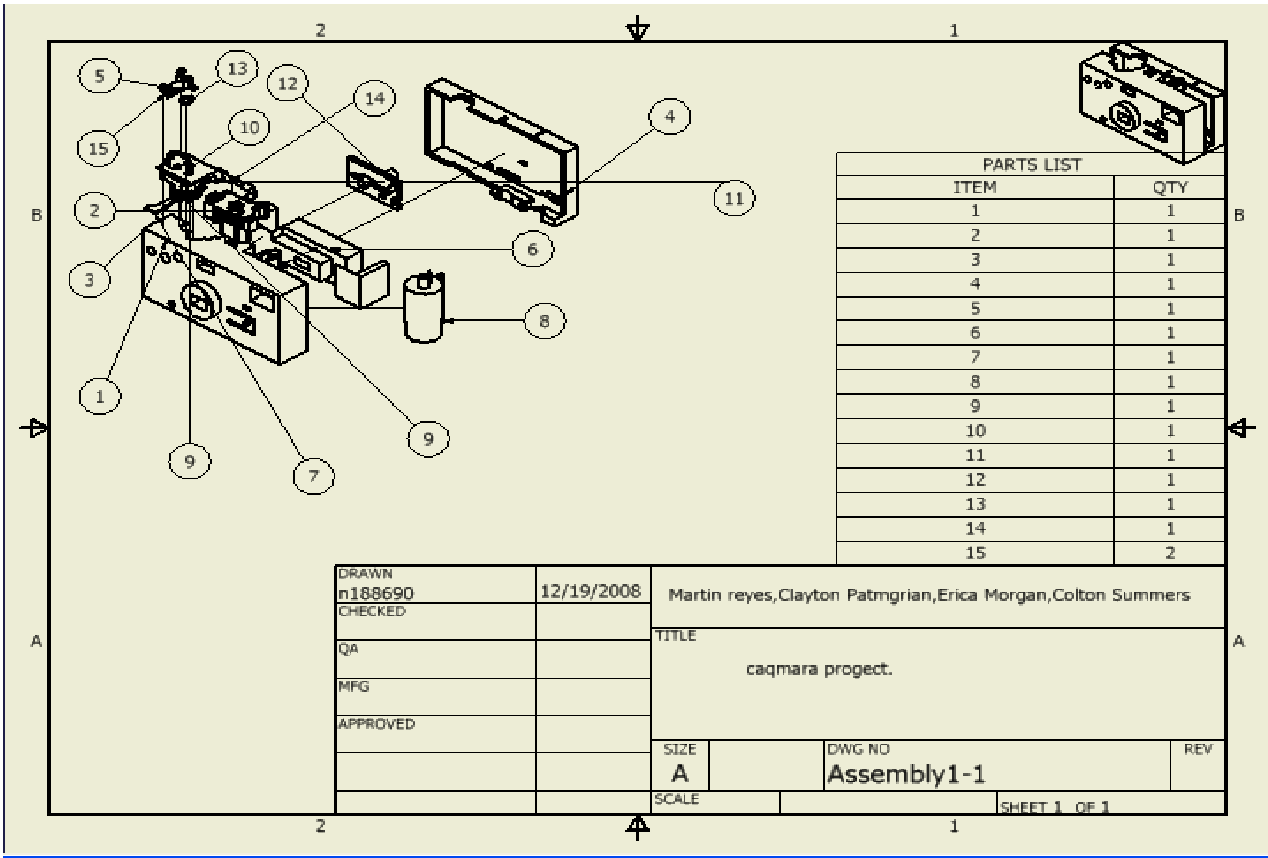


Figure 7.9 Sample CAD Diagram of a Disposable Camera, Source: [CIESE. 2008]

D.2 Assembly diagram:

Figure 7.10 shown next is an example of an assembly drawing of an early generation of a disposable camera, if read in tandem with Table 7.7 above further information about it the drawing will be obtained; students of course, can create their own diagram and use this one as reference only.

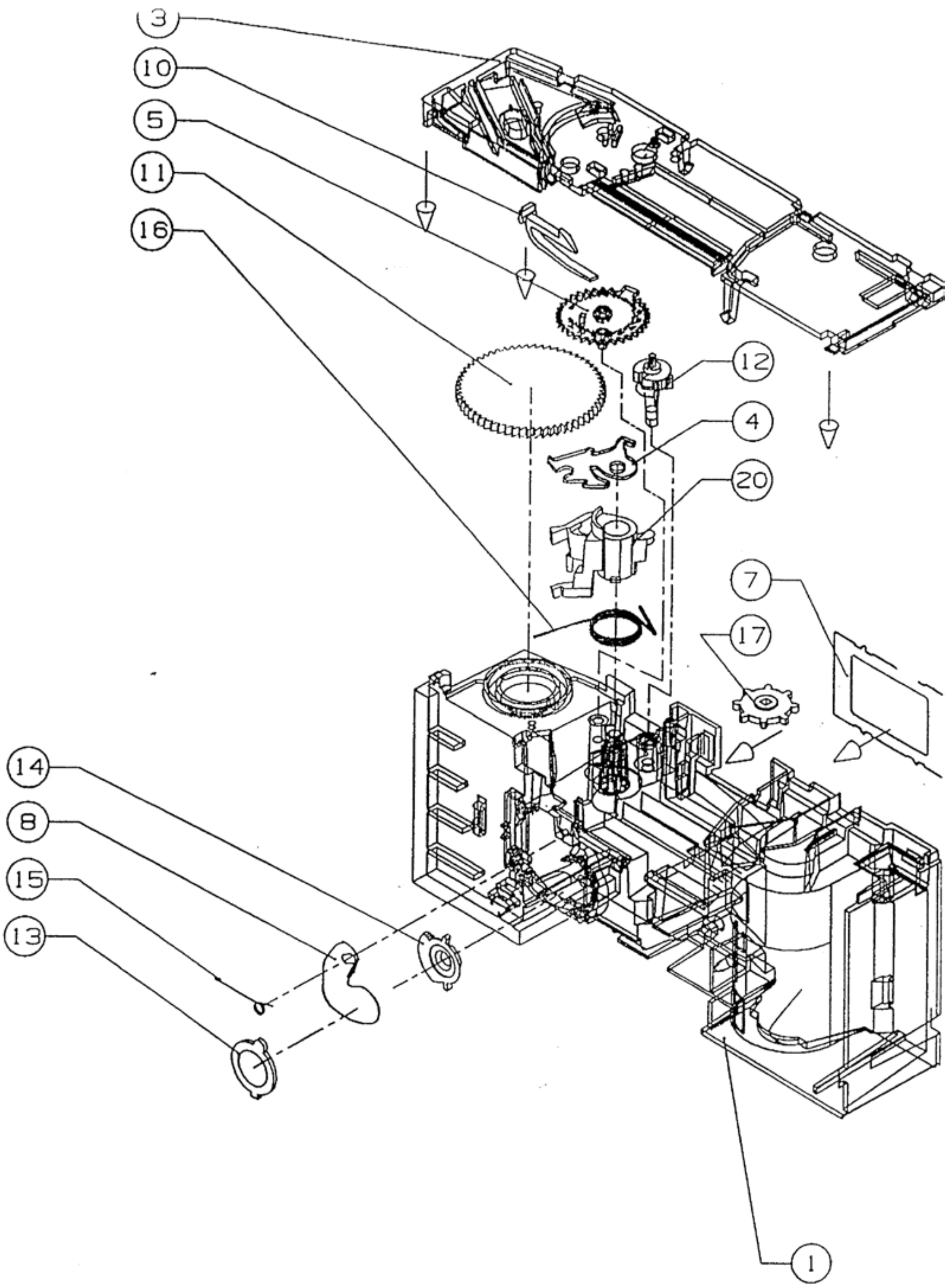


Figure 7.10 Assembly Drawing of an Early Generation of Kodak's Disposable Cameras, Source: [Simpson. 2009]

D.3 3D CAD Models

Sample CAD models of individual parts of the Kodak Waterproof camera were published by [Kutz. 2007] and are shown in Figure 7.11 for reference, for more complex devices or by request from the professor, full subassemblies could be drafted instead as shown in Fig 7.12 further below

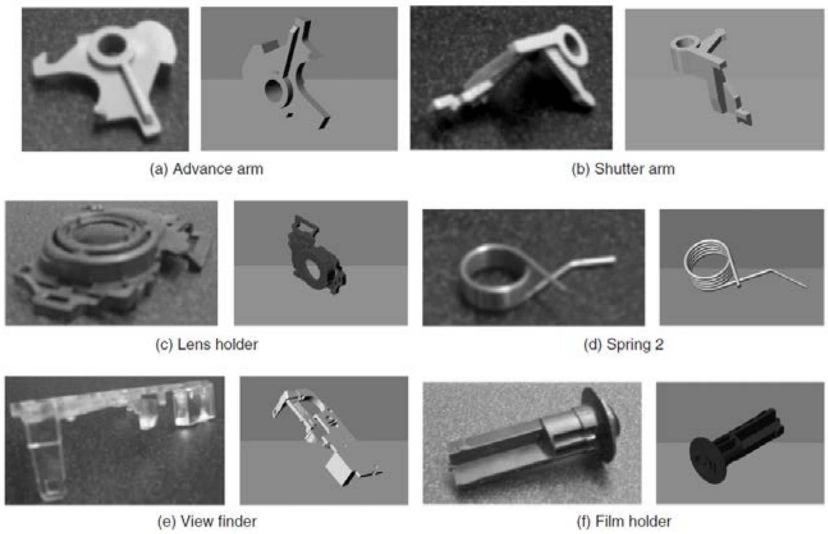


Figure 7.11 Sample CAD models of components in a Kodak Waterproof camera, Source: [Kutz. 2007]

D.4 3D CAD model of a full assembly of a Kodak Waterproof camera

A sample CAD model of the internal housing of a Kodak waterproof camera was published by [Kutz. 2007] and is shown in Figure 7.12 here as reference for the creation of one's own examples.

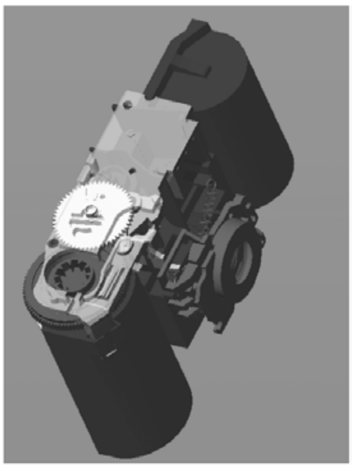


Figure 7.12 Assembly Drawing of the Internal Housing of a Kodak Waterproof Camera, [Kutz. 2007]

D.5 3D Scanning and Digitization Samples

Figures 7.13 and 7.14 below show a published example by Author [Kutz. 2007] that illustrates the 3D digitization process for the front outer shell and front housing inside the shell of a Kodak Waterproof camera; the figures include two views of raw data from an isometric scan (a & b), the merged and partially cleaned-up data (c), and the actual component that were scanned (d). The author reports that these scans were produced using a Minolta Vivid 910 3D Scanner and GeoMagic Studio 6 software to merge and edit the data, few institution will have such resources at hand but if available, EREA can serve as an opportunity to introduce or practice the skills needed to operate the scanner

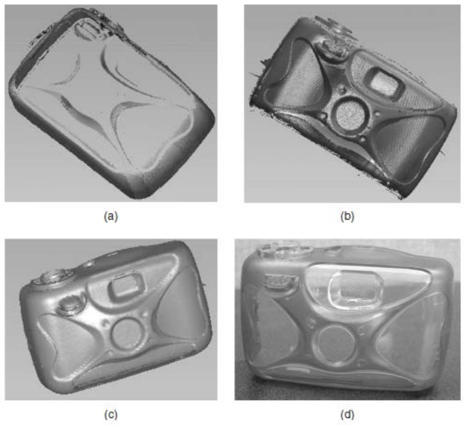


Figure 7.13 Digitization of Front Outer Shell (a) Raw scan—top, (b) Raw scan—side, (c) Merged images, and (d) Actual component, Source: [Kutz. 2007]

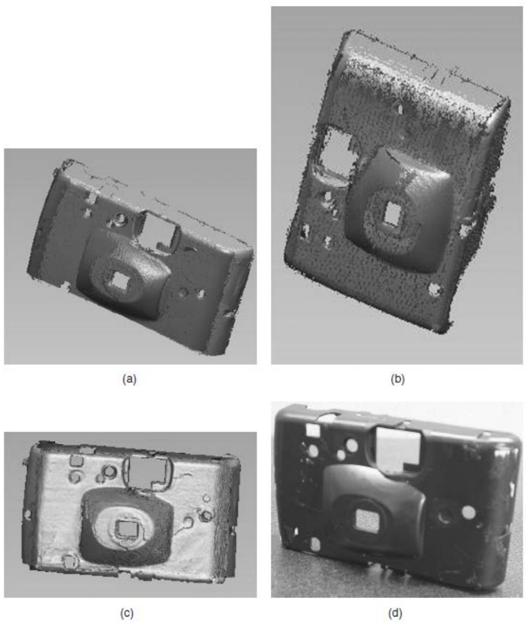


Figure 7.14 Digitization of Front Housing inside outer Shell: (a) Raw scan—top, (b) Raw scan—side, (c) Merged images, and (d) Actual component, Source: [Kutz. 2007]

E. Assessment of Fastening / Assembly means in the camera

It was noticed that in the Kodak Flash camera (and in the whole Kodak lineup for that matter) components slide into position and only snap fasteners (snap on / snap off) are used to hold the camera together, and although the objective of this is to simplify the assembly process and minimize the number of parts used, the disassembly of products with snap fasteners is not as simple as the assembly since fasteners may be damaged if not done carefully

F. Salvaging of camera film for further use

Because information about the internal construction of Kodak disposable cameras found at the previous data collection stage indicated that the film cartridge in it comes originally unwound, it was understood that if the camera was disassembled without first activating the shutter button through the whole roll to wind the film back into its canister then incoming light would damage it rendering it unusable. Cameras from the laboratory are kept like new and are used for next semester students so we couldn't just operate it and use the film taking random pictures so the professor hinted at a possible solution that we had the responsibility to develop which consisted in operating the camera in a dark environment in order to salvage the film for further uses, several options were possible, the simplest and definite one was to cover the lens with a small piece of black electrical tape to avoid exposing the film and then use the shutter and film advance wheel until "0" (zero) appeared, thus we shot the whole film and tried not rewind all the film back into the canister but to leave approximately 1" sticking out thus salvaging the film for future uses and making the analysis of the camera of a non destructive nature

7.2.7 Stage VII: Product Analysis

7.2.7.1 Methodology

Most of the resources available for this stage were spent in analysing the product's overall features; its operation, architecture, functional and technical characteristics, and its ecological impact, the mix of tasks, questions and tests to attempt was determined based on the available information from past stages and on the technical dexterity of the team members, in the end though, a team meeting to assess all of the information collected so far was conducted where the professor provided the technical input and personal experience to help us glue everything together and thus move on to the next stage of the methodology.

7.2.7.2 Suggested Pedagogy

Although a varied number of tests; questions and analyses are suitable for this stage, only those that provide the best balance between the quality of information they provide against the amount of resources employed should be attempted; it is the role of the professor at this stage then, to help students select what exercises are done and to what depth based on available resources and their technical proficiency; for the analysis of the disposable Kodak Flash camera the areas of electromechanics (functions, architecture) and ecodesign (materials, production methods, cost impacts) can be chosen for investigation since they are suitable for both methodological work and self discovery; once students are done with their work though, the professor must help glue everything together so students end up with numerical results that support further investigation into the subject system

7.2.7.3 Sample Deliverables

A. Product Overview

The Kodak Flash used in this example is a single use camera manufactured by Eastman Kodak Co. It is comprised of 23 distinct parts with the majority being made of ABS Plastic via injection moulding; it is assembled from simple parts such as a circuit board; halogen flash, battery, a moulded plastic housing, plastic gears, and film. Table 7.9 below shows a quick overview of its main characteristics (complementing information for the Kodak Waterproof model for the reader using it as subject system is also included)

Item	Description
Name of Artifact	Kodak Flash camera
Description of Product	One Time Use; Low Cost, Convenient Camera
Manufacturer	Eastman Kodak Company
Built in	Mexico
Assembled in	Mexico
Cost	11.99 USD / 17,75 EUR
Number of Parts	Camera with flash (22), Waterproof Camera (23),Camera With Flash and Zoom (38)
Main Tool Required for Disassembly	Flathead Screwdriver
Film Exposures	27

Film Speed	ISO 800
Waterproof characteristics	50 Feet / 15 Meters (Only the water & sport model)
Sources of Energy	Mechanical Energy; 1.5 volts AA Battery (For cameras featuring a flash)
Current Status of the Product	Still in Production
Type of Materials	Mostly plastic; Few Metal Parts, Circuit Board (Models featuring a flash) and a photographic film

Table 7.9 Overview of the Kodak Flash camera, After: [Castellani. 2006] & [CIBER-U. 2012]

A.1 Kodak Camera's UNSPSC Codes

Table 7.10 shows all UNSPSC Codes that apply to the disposable camera. The United Nations Standard Products and Services Code (UNSPSC) is a taxonomy of products and services for use in eCommerce that provides and efficient, accurate and flexible classification system for achieving company-wide visibility of spend analysis, as well as, enabling procurement to deliver on cost-effectiveness demands and allowing full exploitation of electronic commerce capabilities. The UNSPSC for a given item is a five-level hierarchy coded as an 8-digit number meaning that it is composed of five two-digit identifiers, which together categorize the item into a five-level hierarchy. The five levels of the classification are "Segment", "Family", "Class", "Commodity", and "Business Function" (Business Function is optional). Further information can be found in [UNSPSC. 2013]

Applicable UNSPSC Code	Description
31241500	Lenses and prisms
31241501	Lenses
45120000	Photographic or filming or video equipment
45121500	Cameras
45121503	Disposable cameras
45121600	Camera accessories

45121603	Camera lens
45121604	Camera shutters
45131501	Color film
73151701	Water proofing material treatment services

Table 7.10 Kodak Camera's Applicable UNSPSC Codes, Source [Castellani. 2006]

A.2 Kodak Camera's SUMO Entries

Table 7.11 below summarises the SUMO codes applicable for the study and understanding of the Kodak's disposable camera. The Suggested Upper Merged Ontology or SUMO is an upper ontology intended as a foundation ontology for a variety of computer information processing systems. An ontology is similar to a dictionary or glossary, but with greater detail and structure that enables computers to process its content. It consists of a set of concepts, axioms, and relationships that describe a domain of interest.

SUMO and its domain ontologies form the largest formal public ontology in existence today and they are being used for research and applications in search, linguistics and reasoning. SUMO is free and owned by the IEEE, for further information on the topic please check [Pease. 2011]

SUMO Entry	Description
Class	Camera
Class	Photographic Film
Class	Lens
Class	Radiating Light
Axiom	1857149431
Axiom	420166000
Axiom	1698756505

Table 7.11 Kodak Camera's Sumo Entries, Source: [Castellani. 2006]

A.3 Kodak Camera's NIST Functional Basis Elements

In engineering design, functional basis is a design language consisting of a set of functions (a description of an operation to be performed by a device or artifact, expressed as the active verb of the sub-function) and a set of flows (a change in material, energy or signal with respect to time. Expressed as the object of the sub-function, a flow is the recipient of the function's operation) that are used to form a sub-function which can be understood as a description of part of a product's overall task (product function), stated in verb-object form. Sub-functions are decomposed from the product function and represent the more elementary tasks of the product; for further information on the topic please check [Stone et al. 2002]. Table 7.12 below displays the main Functional Basis Element related to the Kodak's Camera

NIST Functional Basis Element		
Convert	+	Electrical Energy

Table 7.12 Kodak Camera's NIST Functional Basis Elements, Source: [Castellani. 2006]

A.4 Characteristics of the Kodak Water & Sport Model

The Kodak Water & Sport model which is another suitable option as subject system for an EREA features a scratchproof lens, a large rubber band serving as a wrist-strap, and a rugged, shockproof shell made of rubber that seals the camera, rating it as waterproof up to 50 feet. It uses an ISO 800 speed brand new film with 27 exposures and doesn't feature a flash since it is intended to be use in outdoors and in the presence of water, its average costs is US$15 dollars and compared to other cameras in the Kodak one-time use lineup its internal components are very similar; only differentiating it from the others by its outer shell which could be troublesome to pry apart since it serves as a tight, waterproof enclosure.

B. Summarised Operation

The Kodak Flash camera' thumbwheel is used to advance the film which advances a sprocket that in turn drives a cam; the cam advances the film counter and then winds the spring of the lever energy system; when the film has advanced far enough the lever system locks into place, at this point the user must press and hold the flash button until an indicator shows it is ready for firing, the lever system then is tripped when the button on the camera is depressed and this action releases the spring which opens the shutter to expose the film and illuminate the subject. For information on how other authors describe the operation of additional models in the Kodak lineup the reading of the work by [Castellani. 2006] is suggested.

C. Technical systems and architecture analyses of the disposable Kodak cameras lineup

C.1 Force flow diagram

Figure 7.15 below show a force flow analysis of the Kodak Flash camera which in complement with the information provided at this stage helps better understand the camera, its workings and its components

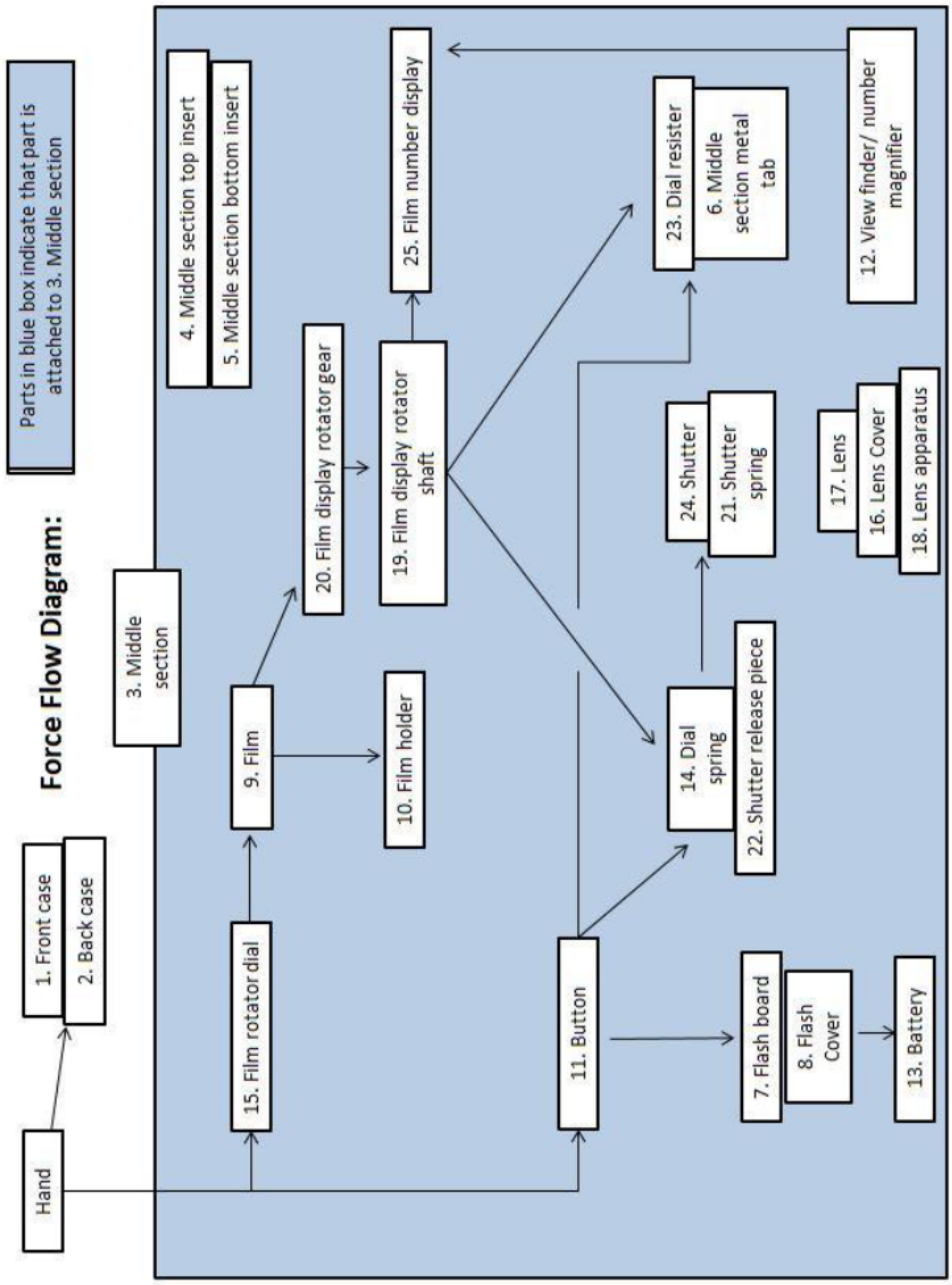


Figure 7.15 Force Flow Diagram of a Disposable Kodak Flash Camera, [Edwards et al. 2010]

C.2 Functional model

Figure 7.16 below shows a valid example of the functional model for the Kodak Flash camera, which in tandem with the rest of results from this resource should provide students with the necessary information for the creation of their own example

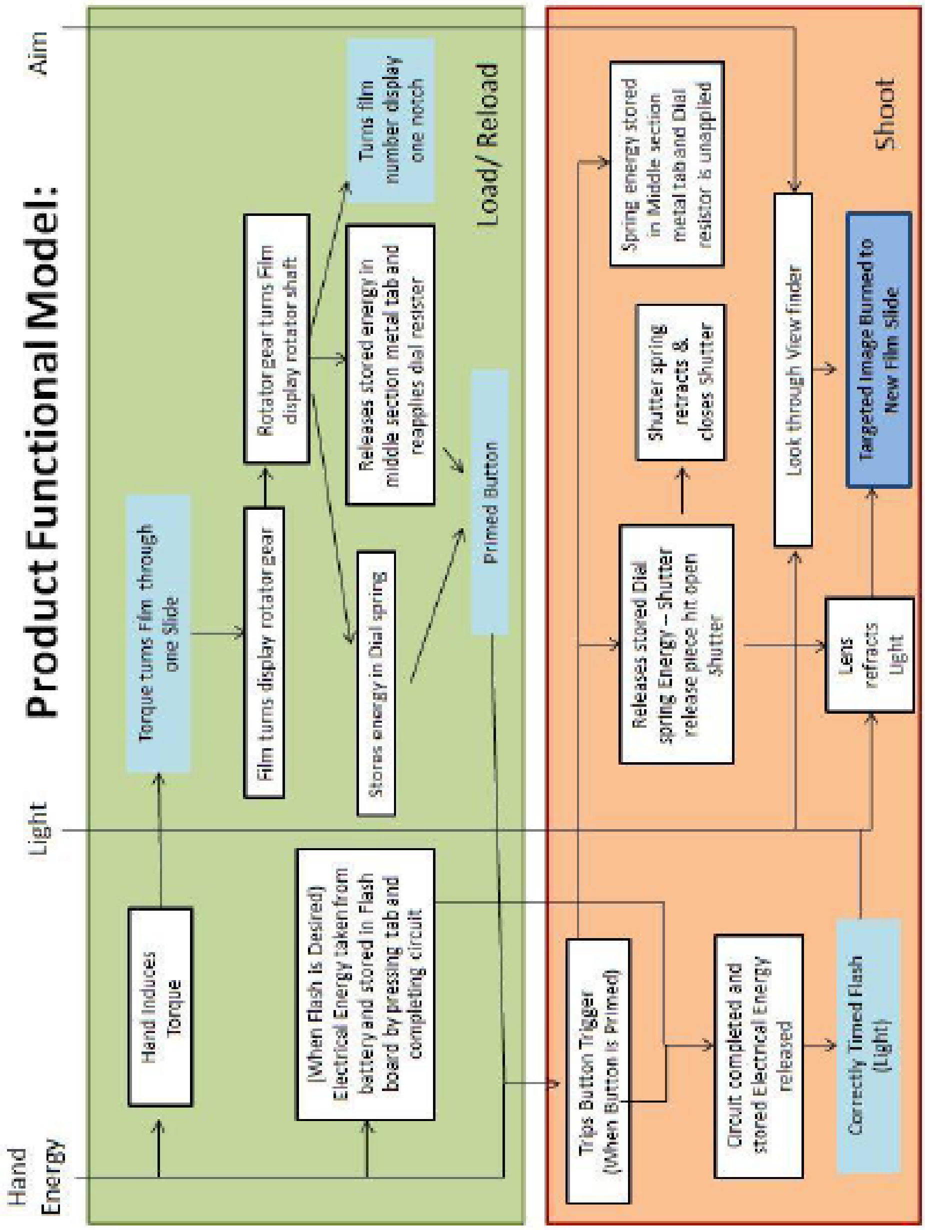
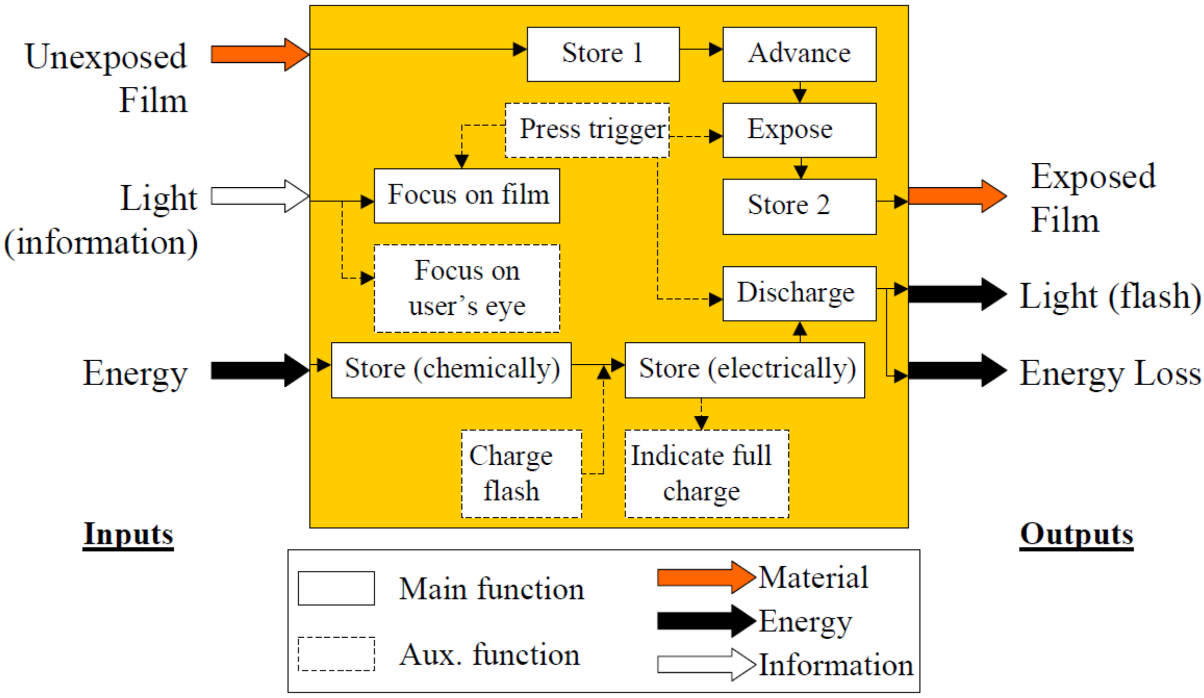


Figure 7.16 Functional Model of a Kodak Flash Camera, Source: [Edwards et al. 2010]

C.3 Function Relation Analysis:

Figure 7.17 below shows a sample function relation analysis of a disposable Kodak Flash camera with the inputs, outputs, main and auxiliary functions shown in detail that expresses the overall function for the camera's design in terms of conversion of inputs and outputs, the example here was done by authors [Comparini & Cagan. 1998] but can



be given to students as an aid in creating their own

Figure 7.17 Function Relation Analysis of a Kodak Flash Camera, Source: [Comparini & Cagan. 1998]

C.4 Design Structure Matrix:

Table 7.13 below shows an actual example of a design structure matrix of a disposable Kodak Waterproof camera and should serve as a guideline for the creation of your own matrix that represents the types of physical connections in your device (Note: The matrix is symmetric about the diagonal and so only the lower half is presented).

Kodak Water & Sport	Advance arm	Shutter arm	Arm retainer	Back panel	Cam	Exposure counter	Film	Film advance gear	Film advance wheel	Film advance wheel 2	Film base	Film holder	Front panel	Identification label	Lens 1	Lens 2	Lens 2 cover	Lens cover	Rubber band	Shutter	Shutter cover	Spring 1	Spring 2	Viewfinder	Washer	Waterproof back cover	Waterproof front cover
Advance arm																											
Shutter arm																											
Arm retainer	1																										
Back panel																											
Cam	1	1																									
Exposure counter																											
Film																											
Film advance gear					1		1																				
Film advance wheel	1						1																				
Film advance wheel 2									1																		
Film base	1	1	1		1	1	1																				
Film holder							1				1																
Front panel				1																							
Identification label				1									1														
Lens 1																											
Lens 2											1																
Lens 2 cover																1											
Lens cover															1												
Rubber band																											
Shutter																	1										
Shutter cover															1					1							
Spring 1											1									1							
Spring 2		1									1																
Viewfinder											1																
Washer										1																	
Waterproof back cover				1						1									1								
Waterproof front cover										1			1												1	1	

Table 7.13 Design Structure Matrix for the Kodak Water & Sport One-Time-Use Camera, Source [Kutz. 2007]

C.5 Function Structure Analysis:

Figure 7.18 below shows a function structure for the Kodak Waterproof camera which provides a form-independent representation of the product under analysis that describes how the product works at a sufficient level of abstraction and it can used as reference for the creation of your own

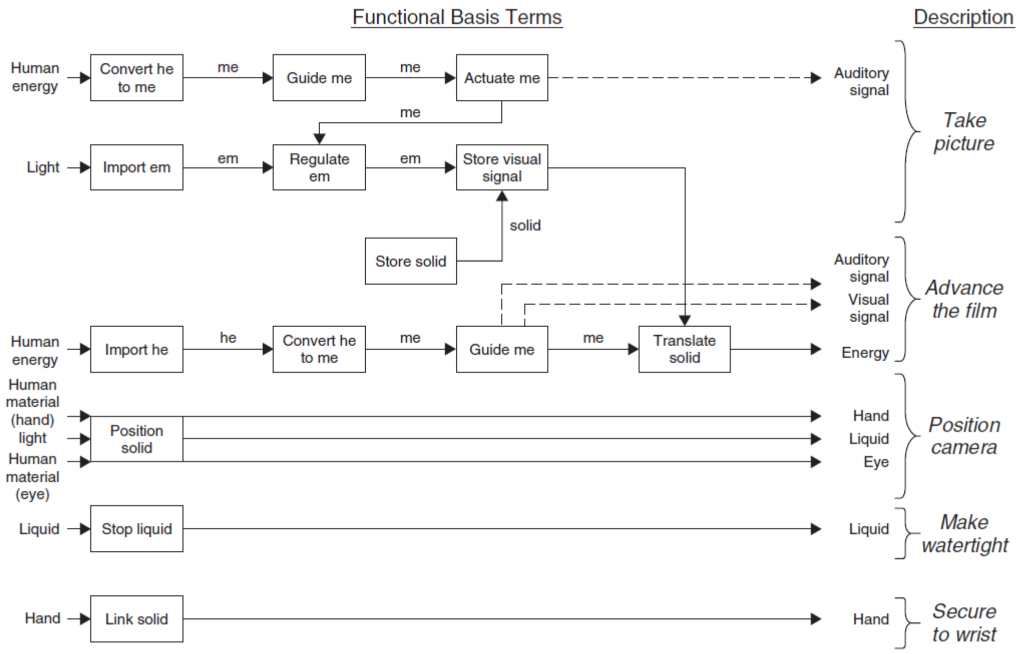


Figure 7.18 Function Structure for the Kodak Water & Sport Camera, Source: [Kutz. 2007]

C.6 Function-Component Matrix

Table 7.14 below shows a valid representation of the product architecture of a disposable Kodak waterproof camera by indicating how the different functions of the product are mapped to its physical components; the table combines both, the information obtained from the function structure analysis and the components listed in the camera's BOM, and should be used as a reference for the creation of your own

KODAK Water & Sport	Arm retainer	Advance arm	Shutter arm	Waterproof front cover	Cam	Exposure counter	Film advance gear	Spring 2	Battery	Back panel	Film	Film advance wheel	Film base	Film holder	Front panel	Viewfinder	Lens 1	Lens 2	Lens 2 cover	Shutter	Shutter cover	Spring 1	Film advance wheel 2	Rubber band	Waterproof back cover	Washer	Identification label
Actuate me		1	1					1												1	1	1					
Convert he to me				1																			1				
Guide me	1				1	1						1		1													
Import em																1	1	1									
Import he				1																			1				
Position solid				1											1										1		
Regulate em																	1	1	1	1							
Store solid											1		1														
Store visual										1	1				1												1
Translate solid							1																1				
Link solid																								1			
Stop liquid				1																					1	1	

Table 7.14 Function-Component Matrix for the Kodak Water & Sport One-Time-Use Camera, Source: [Kutz. 2007]

C.7 Product Commonality Index for the Family Of Kodak Disposable Cameras

The dissection of disposable cameras has been used already at a graduate level course of product family design by authors [Simpson & Thevenot. 2007] to improve a students' understanding of platform commonality. If several different models of the same brand lineup are available, students can be asked to compute their commonality index by dissecting all cameras, laying out all of the parts side by side and then discussing the similarities and differences among the components in them, Table 7.15 below shows a sample calculation of a Product Commonality Index for a family of Kodak disposable cameras and should serve as a reference for the creation of your own example

Parts	Water & Sport		Max Flash		Max Outdoor		FunSaver 35		ni	1/ni^2	Size & geometry f1	Material & Manufacturing f2	Fastening & assembly f3	ni*f1*f2*f3
Back Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	0.750	1.500
Battery		0	1	1		0	1	1	2	0.250	1.000	1.000	1.000	2.000
Cam	1	1	2	1	2	1	3	1	4	0.063	0.500	0.500	1.000	1.000
Exposure Counter Wheel	1	1	2	1	3	1	4	1	4	0.063	0.250	1.000	1.000	1.000
Film	1	1	1	1	1	1	1	1	4	0.063	1.000	1.000	1.000	4.000
Film Axle	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000
Flash Assembly		0	1	1		0	2	1	2	0.250	0.500	0.500	1.000	0.500
Flash Cover		0	1	1	0	1	1	1	3	0.111	1.000	1.000	1.000	3.000
Frame	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	1.000	2.000
Front Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	0.750	1.500
High Energy Lever 1	1	1	2	1	3	1	4	1	4	0.063	0.750	0.500	0.750	1.125
High Energy Lever 2	1	1	2	1	2	1	3	1	4	0.063	0.750	0.500	1.000	1.500
High Energy Lever Spring	1	1	1	1	1	1	2	1	4	0.063	0.750	1.000	1.000	3.000
Lens	1	1	2	1	2	1	2	1	4	0.063	0.750	1.000	1.000	3.000
Lens Holder		0	1	1	1	1	2	1	3	0.111	0.667	0.667	1.000	1.333
Metal Clip	1	1	1	1	1	1		0	3	0.111	1.000	1.000	1.000	3.000
Picture Frame	1	1	2	1	3	1	4	1	4	0.063	0.500	1.000	1.000	2.000
Shutter	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000
Shutter Cover	1	1	2	1	3	1	4	1	4	0.063	0.500	0.750	1.000	1.500
Shutter Spring	1	1		0	1	1	1	1	3	0.111	1.000	1.000	1.000	3.000
Sprocket	1	1	2	1	1	1	3	1	4	0.063	0.750	0.750	1.000	2.250
Thumb Wheel	1	1	2	1	2	1	3	1	4	0.063	0.500	0.500	1.000	1.000
Top Cover		0	1	1	1	1	2	1	3	0.111	0.500	0.667	1.000	1.000
Viewfinder	1	1	2	1	2	1	3	1	4	0.063	0.500	1.000	1.000	2.000

Sum ni*f1i*fi2i*f3i	46.208
Sum 1/ni^2	2.118
Number of non-differentiating parts P	24
Number of products N	4
PCI	**47.0**

Table 7.15 Sample Calculations of Product Commonality Index for a Family of Kodak Disposable Cameras, Source: [Simpson. 2013]

C.8 Morphological analysis of a disposable Kodak Flash camera

In preparation for the Redesign Suggestions stage, the morphological analysis of the subject system and the population of its associated chart is suggested, Figure 7.19 below for example is a partially completed chart that shows how the camera's design is decomposed into sub-functions and how they are mapped to their potential means and/or components; a populated morphological chart then, serves as a tool for generating and capturing multiple design possibilities and one is shown here as reference for the creation of your own example

Sub-Functions		Means				
		A	B	C	D	E
1	Initiate Process	button	lever	voice	timer	switch
2	Focus Image	lens	glass	hole	mirror	prism
3	Record Image	film	paper	disk	tape	slide

⋮ ⋮ ⋮

Possible Design Concepts = 5 x 5 x 5 = 125

Figure 7.19 Partially Completed Morphological Chart for a Disposable Kodak Camera, Source: [Dalrymple et al. 2011]

C.9 Analysis of behavioural elements of the Kodak Flash camera

The major elements are: Energy storage; linear motion and motion conversion (e.g. The camera uses multiple forms of energy to work; chemical energy from the battery is transformed to electrical one when the capacitor is charged to illuminate the flash, but also the user of the camera supplies mechanical energy by pushing buttons, flipping switches, and winding knobs)

C.10 Analysis of Multifunctional Parts and Assemblies

- Function sharing can reduce the number of product components which in turn may also reduce the environmental impact of it; in the lineup of Kodak disposable cameras the viewfinders are an example of structural components with multiple purposes, in the current Kodak Flash model for instance, it also magnifies the number on the remaining picture count wheel

- The camera’s front cover is another example of a part with multiple functions since it protects the printed circuit board; it holds the lens and the lens carrier in place, and it contains the button to recharge the flash.
- The camera’s film cover for example, in the latest models of Kodak disposable cameras has been integrated into the main frame of the camera thus reducing the number of parts and their associated manufacturing, assembly and disassembly steps.
- Finally, the circuit board also has several functions; it charges and triggers the flash, it indicates when the flash is fully charged, it holds the flash, and it holds the battery

D. Detection of Recycling Indicators in Disposable Cameras’ Main Frame

While analysing the insides of the disposable camera, certain marks were discovered in its main frame (which houses the film, the advance mechanism, the circuit board and the battery); after deliberating about their purpose (but later confirming it via published research) they turned out to be indicators of the camera’s recyclability since the main frame is reused and the manufacturer keeps track of how many times it is used by marking it after each cycle, so, it is reused up to ten times before it gets ground up and recycled c.f. [Comparini & Cagan. 1998] thus ensuring the quality of reused parts

D.1 Detection of Manufacturing Date Stamps

Author [Kutz. 2007] describes another interesting feature of Kodak’s disposable camera parts and components in that, a date stamp, indicating when the part was made can be found on many of the large, plastic camera components, such feature is circled and seen in Figure 7.20 below:

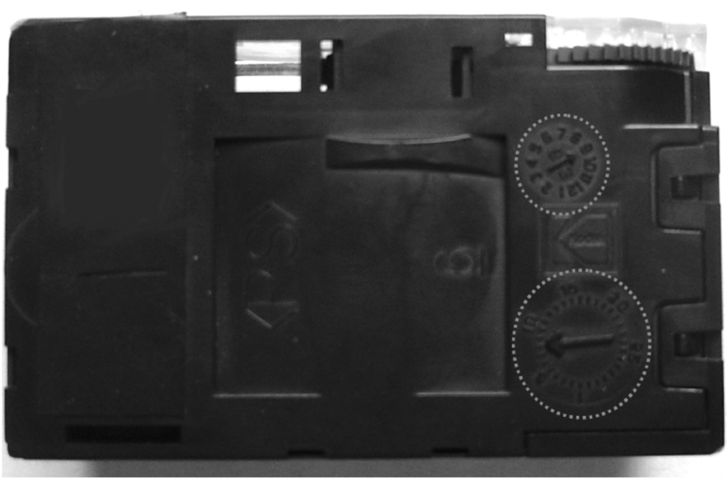


Figure 7.20 Manufacturing Date Stamp on a Camera’s Rear Housing, Source: [Kutz. 2007]

This date stamp, -as author Kutz describes-, often takes the form of a clock with an arrow pointing to the month in one (top circle) and day of the month in the other (bottom circle). The author explains that this form of a date stamp is easy to change in the mould itself before parts are made and helps Kodak keep track of when particular parts are made (e.g. What percentage of new and recycled material was used in a given batch of plastic on a particular day), thus providing useful information for the recycling process given that the time between when a camera is made and when it is returned to the photo finisher is highly variable.

D.2 Numbering of Internal Pieces of Kodak Disposable Cameras

In relation to the abovementioned marks, each major internal piece of Kodak disposable cameras is numerated and has a standardized code stamped on it indicating the material from which it is manufactured; this aids the assembling process of the camera at the manufacturing line but it is actually intended to help sort the materials for an eventual recycling

D.3 Assurance of Quality of Reused Camera Parts

According to authors [Comparini & Cagan. 1998] just as in the above mentioned cases other camera components are reused a limited number of times too; the printed circuit board (PCB) for example is reused up to seven times and it is tested after every cycle, whereas the batteries which still contain more than half of their charge c.f. [Simpson. 2009] are donated to various charities (Refer also to Figure 7.4 for additional information on this)

D.4 Safety Measures Against the Refurbishing, Remanufacturing or Recycling of Disposable Kodak Cameras by Unapproved Entities

Author [Kutz. 2007] has reported in this regard, that initially some photo finishers were recycling the cameras directly, without returning them to Kodak, but without the proper inspection and testing, the quality of the photographs could degrade very quickly if the cameras were simply reused time and again; because of this Kodak designed a special film canister of a specific shape that they only produce for their one-time-use cameras to prevent this unauthorized recycling since the film canister cannot be bought separately from the camera itself and cannot be used in traditional film cameras (thus the importance of salvaging the film in this educational activity). Figure 7.21 below shows how a unique saw-tooth pattern on top of the film canisters is used in all Kodak disposable cameras and how it mates perfectly to the underside of the film advance wheel seen in the same figure. The recommendation of salvaging this film as suggested in this EREA then, is only of value to students

Figure 7.21 Special Film Canister for one-time-use Cameras, Source: [Kutz. 2007]

E. Design Assessment of the Disposable Kodak Flash Camera

E.1 Design philosophy and criteria

After integrating the data collected about the subject system with our own experiences testing and analysing it, it was agreed by the team that the main criteria and design philosophy of the Kodak Flash camera are: Low cost; mass production, easy use, international marketability, easy film removal, light and moisture resistant packaging, and durability (see also Table 7.19 for complementing views on this).

E.2 Design constraints

Authors [Sidler-Kellog & Jenison. 1997] have published their findings in this regard in Table 7.19 "Typical Findings after Reverse Engineering a Disposable Camera" shown further below, and from there it was agreed by our team that the major design constraints that determine the current configuration of the Kodak Flash camera are indeed the availability of an automatic flash; the focus-free lens, and its low cost.

F. Life-Cycle Inventory Analysis

Figure 7.22 below shows an example of how to evaluate the environmental effects of the raw materials of a disposable camera and the waste released back into the environment, it was created by authors [Comparini & Cagan. 1998] and it is shown here as a reference for the creation of your own. From the figure then, it can be noted that the energy consumption during manufacturing is much higher than during product use, thus for the redesign of the product, one can suggest that integrating two or more camera parts into a single one can help reduce the amount of energy consumed, or even that, by eliminating the printed paper instructions and stamping them into the camera, one type of material would be eliminated with its corresponding processes and wastes (e.g. Bleach; ink, printing, cutting, etc.)

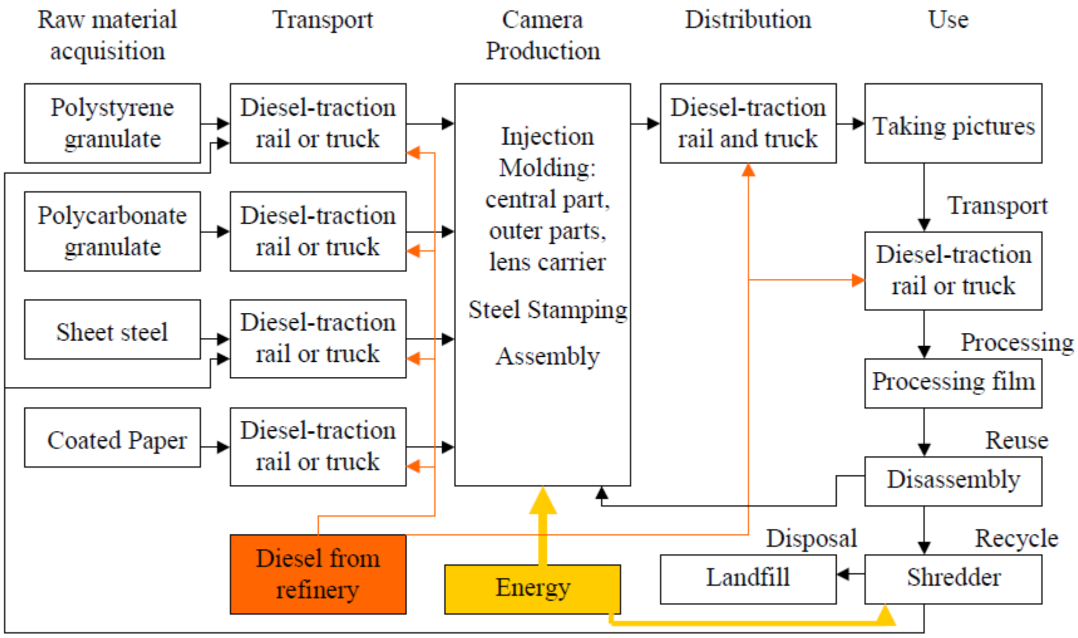


Figure 7.22 Stages of Life-Cycle Inventory Analysis of a Kodak Single Use Camera, Source: [Comparini & Cagan. 1998]

G. Consolidation of the assessment of the industrial design aspects of the Kodak Flash camera

G.1 Perception of product quality

Through data collection and eventual confirmation through the inspection of the part once it was disassembled, it was corroborated that the polycarbonate viewfinder and the camera lens are not reused more than once in disposable cameras and the material is ground up and recycled since these parts have a direct impact on the product's performance and the customer's perception of product quality c.f. [Comparini & Cagan. 1998]

H. Assessment on the materials chosen for the subject system

An analysis of the mix of materials selected for the Kodak Flash camera in combination with the available information on how important the recycling programme is for the manufacturers lead us to believe that such materials have been selected for the properties of strength; texture, durability and producibility, and thus as mentioned already up to 90% of the camera components can be reused or recycled

7.2.8 Stage VIII: Product Reassembly

7.2.8.1 Methodology

The two major tasks to fulfil at this stage are on the one hand; to reassemble the disposable camera having already defeated any anti-tampering measures that could have rendered it unusable, and on the other, to document the whole process so future readers of this work get detailed information on the full disassembly/reassembly sequence of the subject system. For reassembling the disposable camera then, special care was taken not to damage its photographic film via an undesired exposure to light thus being able to bring it back to its original state; for the documenting of the reassembly process, the instructions and supporting diagrams previously sketched at the Product Disassembly stage were finally completed and checked for inclusion in the final activity report.

7.2.8.2 Suggested Pedagogy

The major task of professors at this stage is to support students in the reassembly process of their subject system, both by checking on the methodological aspects of the task itself, and by providing the technical input required to defeat or avoid any anti tampering measures that could impede the return of the subject system to its original state. Other minor situations that could show up where professors would need to lend their support include for example, dealing with remedial actions for lost or damaged product parts, or helping students to draw at the end of the stage, meaningful conclusions from detected differences between the disassembling and reassembling of a consumer product.

7.2.8.3 Sample Deliverables

A. Reassembly instructions

Table 7.16 below describes a step-by-step process for reassembling the Kodak Flash camera used as the main subject in this example; and although most of it was written at the Product Disassembly stage, it is only during the actual reassembly where it can be confirmed and refined for the benefit of the reader, it can be noted for example, that it is not the exact reverse process of disassembly (however, it is very close) this is typical of a full disassembly/reassembly sequence and it's mainly due to changes of state in the product components. For additional information, read the process in tandem with Table 7.5 for a quick cross reference between camera parts and listed instructions

Step	Description
1	Start by taking Part number (22) which is the internal frame and place it flat on the table with the respective front facing up
2	Replace the metal spacer Part number (19) by returning it to the post in which it resides on. Making sure that it lays at a tangent to the hole made for the lens.
3	Now that the metal spacer is on, take the lens base unit (Part number 20) and put it on the frame. Attaching this piece involves the lining up of the locking mechanisms and just slightly pushing so they come together.
4	Now that the lens base is on, there is now the post for the little copper resistance spring (Part 6). It is reattached to the post in the lower right corner or the lens base and to the post in the section slightly above the left corner.
5	Now that the front is for the most part done rotate the camera so the respective top is facing up.
6	Re-insert the resistant spring (Part number 18) it has the hole inserted around the large post in the right hand corner.
7	Since the camera is sitting upright you can now put the film advance gear back into the back side of the camera. It goes into the slot that is right about the opening for the viewing area. This Part number (16) just slides into the slot.
8	Now replace the rotating shaft (Part 15) being careful when you put it back through the designated hole you must also make sure that it lines up with the hole in the gear that was replaced in the step prior to this.
9	Now put the film advancer locking mechanism (Part14) back onto the same shaft that the resistance spring is located on. Making sure that the rounded end when you are finished is in contact with the recoil shaft (Part 21), (the more finished side will be the top of the part).
10	Now replace the film advancer gear (Part 13) it is returned to its position on the shaft that also contains Parts (21, 18).
11	Now replace the picture remaining counter (Part 12) by lining up the hole on the bottom

	with the top of the revolving shaft and slightly pressing down.
12	Now that all of the mechanical / interface parts have been replaced that are in the upper right hand corner, we now replace the gear protector/picture capture button (Part 11). (It just slides over the top and when the locking mechanisms meet with the appropriate spaces just push down a little and it will be locked back into place.)
13	With the camera still in its upright position replace the viewing lens by lining up the lens and pushing it down in its appropriate spot, (the lens is made so that it only fits one way) once it is fit in, it will not be held in place by friction
14	Now rotate the camera so that the respective back is once again on the table with the lens base facing upward
15	Now replace the lens (Part 10) by lining it up with the round hole that is in the lens base and setting it on it with the curved portion facing upward
16	Now that the lens is on the base take the lens fastener (Part 9) and line it up with the holes around the lens with the respective fasteners that come out of the piece. Insert the fasteners into the depressions and turn the piece slightly in the direction that it will let you, so that you may lock the lens down to the camera
17	Now for the hard part take the circuit board / flash (Part 7) holding it in the position with the flash facing up, insert the long metal section right below the lens holder and wiggle the piece until it becomes flush with the lens base. You might have to insert it at a slight angle and then when you are pushing slowly decrease that angle until it is flat with respect to the frame. (The flash should sit in the upper right hand corner facing you when the camera is in this position).
18	Now that the front of the camera has been reconstructed place the front cover (Part 5) over the frame and rotate the camera so that the front cover is now facing the table and the back unfinished portion is now facing upward
19	Now reinsert the battery (Part 4) to the two prongs that have now been replaced, now that the circuit board/flash has been replaced the battery should set with the positive end on the two pronged side and the negative end on the one pronged side.
20	Now replace the film cartridge (Part 3) which sets on the right hand side in its little slot. The canister goes in with the protruding piece up and the respective bottom down, it just sets in place there.
21	Now replace the unexposed film spool (Part 2). It goes into place with the larger end up and the smaller end down so that it may rotate in the slot that the internal frame has provided for it. The pieces will not fit the other way so if you put them in wrong you will

	know
22	Now it is time to replace the back cover (Part 1), line the back cover up with the front cover, there will be several locking mechanisms around the outer edge. Once they are lined up just push. They will lock and the front (Part 5) and back cover (Part 1) will be locked together.

Table 7.16 Reassembly Process of a Disposable Kodak Flash Camera, Source: [CIBER-U. 2012]

A.1 Assembly hierarchy of a disposable Kodak Flash camera

Figure 7.23 below shows an assembly hierarchy for the subject system in this example which can be useful not only to aid the reassembly process but also for understanding the different camera subsystems and just as the deliverable above its drafting started at the Product Disassembly stage but it was only here where it could be verified and presented

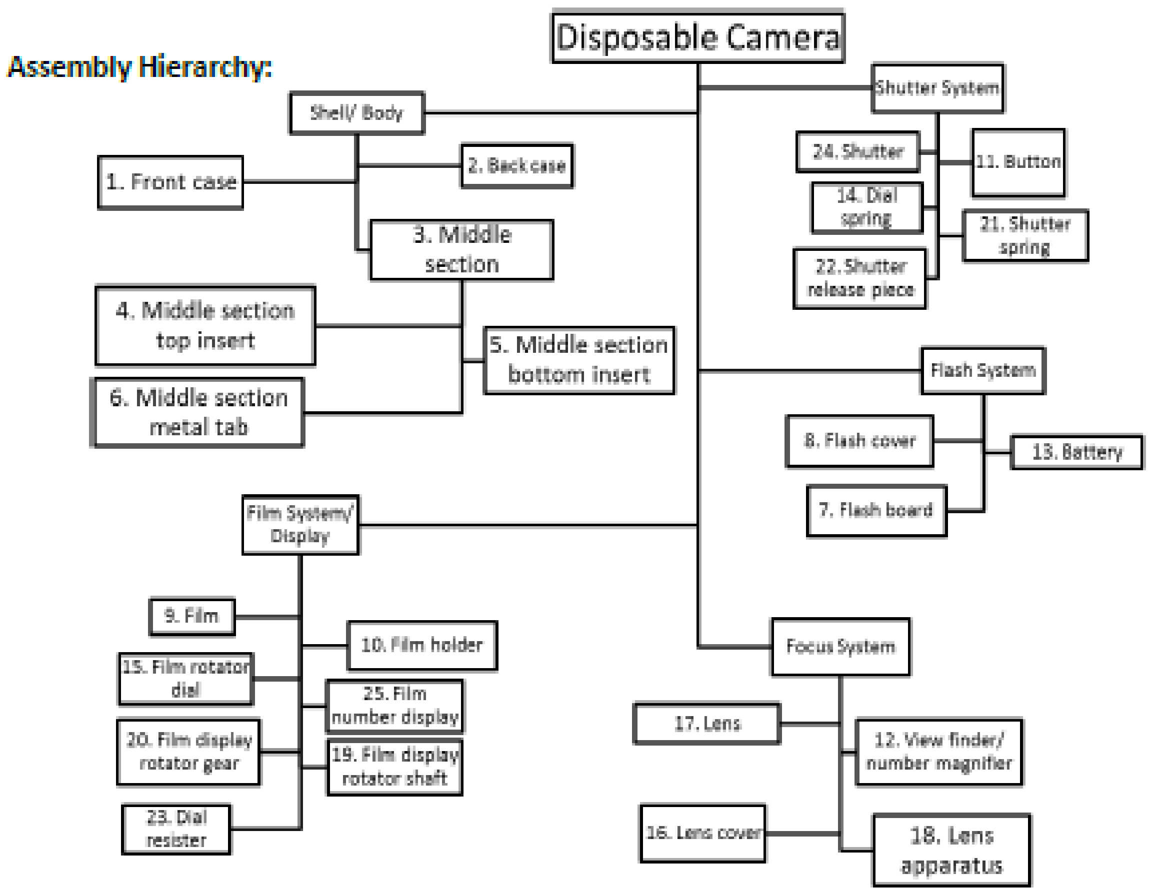


Figure 7.23 Sample Assembly Hierarchy for a Kodak Flash Camera, Source: [Edwards et al. 2010]

A.2 Provisions for a non destructive assembly / reassembly sequence

As explained already in Section 7.2.6.3 – F, the photographic film was first wound back into its cartridge so it wasn't damaged by light entering during the disassembly of the camera; to put the unexposed film spool back into place for the reassembly sequence and in order to reduce the possibility of light damage the three last steps in the reassembly sequence shown above in Table 7.16 could be done in a pitch black environment; some universities still have photographic darkrooms where this could be done, or else the simplest choice would be to use a photographic changing bag such as the one seen in Figure 7.24 that are light proof, have elastic sleeves for handling, and can be usually acquired for US$15-90 depending on quality, they are commonly used in film photography to rescue jammed or partly exposed film so it can be safely removed from the camera; by taking this precautions, the reverse engineering analysis of the disposable Kodak Flash camera can be considered non-destructive, and it closely simulates competitive analyses done on industry where engineers go to similar troubles not to destroy the elements under inspection

Figure 7.24 Sample Photographic Changing Bag, Photocredits: [Freestyle. 2013]

7.2.9 Stage IX: Product Performance Test II

7.2.9.1 Methodology

Once the product has been reassembled, it has to be operated via the same battery of activities suggested at the Product Performance Test I stage, if the product works satisfactorily, the results must be compared and reported, for inclusion in the final activity report; if on the contrary, the product does not operate as expected, it has to be examined and a solution must be sought, which usually entails the disassembly, reparation and reassembly of the subject system until a desired result is reached. The Kodak Flash camera for this example worked as intended at the first try and so the work area, tools and measuring devices were cleaned and returned to the laboratory technician to end with the work to be done at the university laboratory as agreed in the timetable and work schedule from the Task Clarification stage

7.2.9.2 Suggested Pedagogy

Unless a new testing device becomes available; unexpected information about the product arises, or a destructive analysis of the subject system was inevitable, the battery of tests to conduct is the same as in the Product Testing I stage and so similar recommendations apply. If any of the previously mentioned conditions show up though, the analyses to the subject system will have to be adapted to warrant the continuation of the stages of the methodology. In any case, professors should see that students report at least the following three items at the end of this stage, namely: Any detected differences between the results from Product Performance Test stage I and II (with potential explanations to this); any attempt to adjust; repair or improve the performance of the disposable camera, their understanding of the subject system to detect problems in it. After this, the final task for the professor will be to ensure that students actually clean the workplace and return the set of tools and measuring devices in full working order back to the laboratory technician to continue at a different venue with the rest of the methodology

7.2.9.3. Sample Deliverables

A. Assessment of Product Operation and Capabilities

Because plenty of information about the internal construction of the camera was at our reach during the past stage of the methodology a successful reassembling was actually achieved; thus, during the tests required for this current stage, we could confirm that the operation and capabilities of the product remained the same with all dials, knobs and buttons feeling and working the same; indeed, the camera handed from last semester students was in full working order and throughout our EREA no part was deformed, damaged or lost so no real need for a thorough maintenance (e.g. Lubricating, cleaning, etc.) or repairing of it was necessary either.

At the end of the stage though, it was agreed that the definite way to prove that the reassembled camera worked as intended was to actually take pictures with it and develop the film to see the quality of the resulting pictures, however, this was not possible because the cameras belong to the university and they have to be returned to the laboratory warehouse for use by future students, still, and because of their reduced cost one of the teams in the course agreed to purchasing a disposable camera with their own money and set out to disassemble, reassemble and take pictures with it to have them later developed, their actions actually ended up satisfactorily and got crisp and clear images from their camera.

7.2.10 Stage X: Knowledge Synthesis

7.2.10.1 Methodology

In Section 2.3 a full explanation was provided on how students build knowledge throughout an EREA, in this section though an account is given of what was done for this particular example where a wealth of information was available to students since the very beginning. Indeed, much of what students usually present only until reaching this stage (e.g. Lists, summaries, compilations, etc.) has already been shown as intermediate results at the previous stages of the methodology, a fact due to the exemplary nature of this specific case but with the added benefit of its comprehensiveness which makes it suitable for use as a reference on what to expect from students undergoing an EREA.

The most relevant work done at this stage then, dealt with the integration of all past information, the reaching of some conclusions summarizing the understanding of the subject system, and the documenting of them in a way that provided a meaningful explanation of the subject system to future readers of this work. Individual activities from this stage then, that are worth highlighting include:

- Reviewing all past information about the Kodak Flash camera and complementing it with intermediate findings from past stages not to leave any significant loose end behind before moving on to the next stage of the methodology
- Consolidating the assessment of the design of the subject system specially in the areas of assembly, lifecycle and generational changes
- Reflecting on the socioeconomical aspects of the camera (mostly represented by the analysis of its ecological considerations)
- Speculating on the still ununderstood aspects of the camera

The stage itself then, ended both when no further information could be added to the report in progress, and when the understanding of the subject system was considered satisfactory enough as to start suggesting improvement modifications to it

7.2.10.2 Suggested Pedagogy

The resources for the conduction of this stage represented by the suggested stage methodology in Section 5.4.10, the proposed pedagogy mentioned in Section 6.5.2.9, and the actual examples shown here provide a variety of perspectives on how to help students reach the main goal of this stage which is construct knowledge both from the numerical data resulting from past tests of the methodology and from the actual exchange of ideas in discussing them, the major tasks for professors at this stage then, is to guide students in the cognitive exercises (e.g. Brainstorms) that help them turn numerical data into information and information into knowledge that can either provide independent confirmation to previously published results or be presented for future confirmation by independent testers; for this specific case where a wealth of information about the subjects system was available to students since the very beginning, the major challenge as a professor was to help students benefit from past findings while still helping encouraging them to come up with their own conclusions that could or could not confirm past, published results.

7.2.10.3 Sample Deliverables

A. Consolidation of the Assessment of the Disposable Kodak Flash Camera's Design

A.1 Design Efficiency

In a low cost product such as this one it is of paramount importance to accomplish its function in an efficient manner, unlike regular film cameras for example in the Kodak lineup of disposable cameras the film is unwound from the film canister and prewound into a roll in the camera; this means that if the camera is opened without advancing through all the pictures the film will be exposed and damaged, this design decision however, allows the film to rewind into the canister as pictures are taken thus eliminating the need for a separate film rewind mechanism in the camera therefore reducing costs, complexity and materials

A.2 Ecodesign features of disposable cameras overall

By comparing information and designs from previous generations of disposable cameras it can be seen from a design perspective how they have evolved to improve their ecological impact (e.g. Easier disassembly; higher part reuse, better quality) , in this regards author [Dalrymple 2009] states that as a result of DfE principles Fujifilm disposable cameras (and Kodak ones for that matter) follow a cradle-to-cradle production type through the use of remanufacturing and are every time lighter and more compact using the least number of parts possible; their parts are standardized and can be used in multiple models, they are easy to assemble and disassemble since they do not use screws or adhesives, and a single material is used for a variety of parts since it aids the recycling of non reusable parts

A.3 Generational Changes in Kodak Disposable Cameras to Improve Recyclability and Disassembly

It is interesting to observe the changes that single use cameras have undergone since they were first manufactured in 1988 in order to improve their recyclability and facilitate their disassembly. Much in line with the findings from our team; author [Kutz. 2007] for example has pointed out how the components of the camera mechanism have remained largely unchanged since they were first introduced; one of such examples for instance, can be seen after comparing an exploded view of the internal chassis of the original Kodak FunSaver camera model shown below in Figure 7.25 against the mechanism of the Kodak Water & Sport camera that is available in the market twenty seven years later, seen in Figure 7.26:

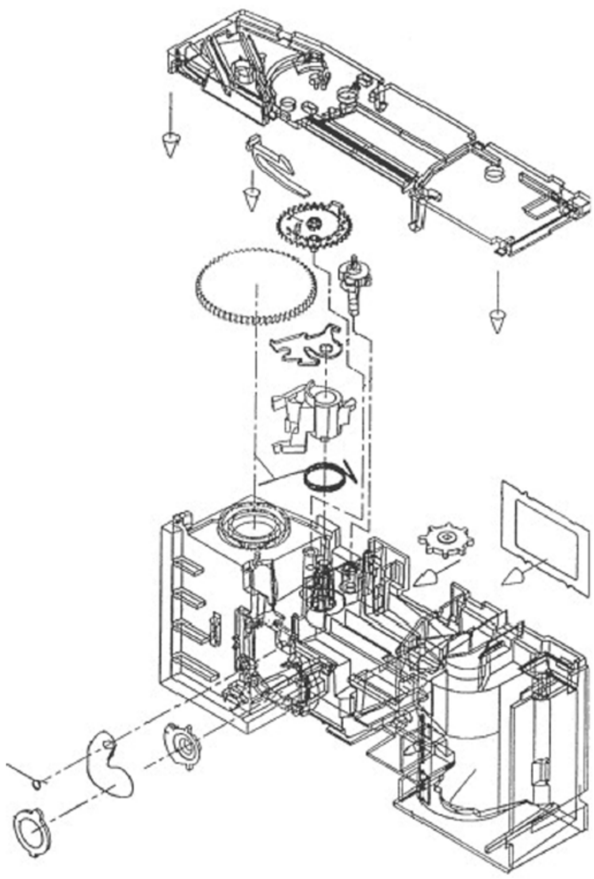


Figure 7.25 Exploded View of the Chassis of an Original Kodak's FunSaver one-time-use Camera, Source: [Kutz. 2007]

Figure 7.26 with the comparable mechanism of the Kodak Water & Sport model is shown below:

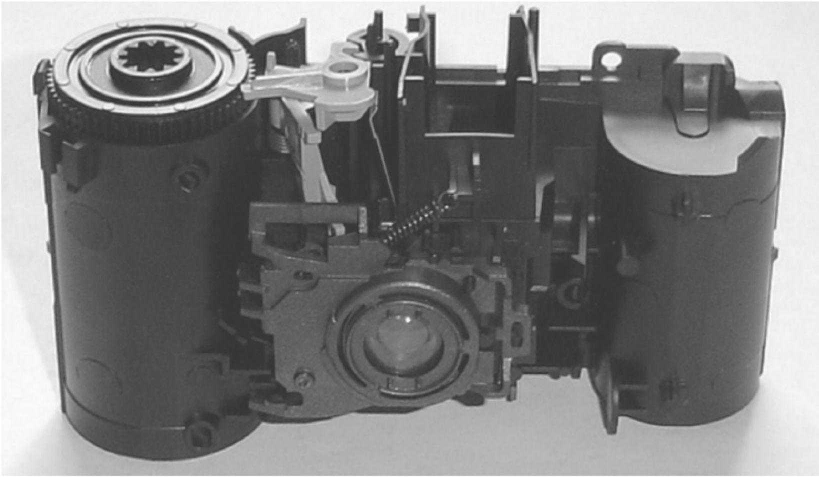


Figure 7.26 Camera Mechanism in the Kodak Water & Sport one-time-use Camera, Source: [Kutz. 2007]

One camera part that has had noticeable changes over time though is the camera's top cover and viewfinder which has evolved from an original monolithic single piece, as seen in Figure 7.25 to a smaller piece and eventually into two separate pieces as can be seen in Figures 7.27 and 7.28 below. Author [Kutz. 2007] comments that as this part has evolved, the percentage of clear transparent plastic used in the view finder has decreased as well, enabling Kodak to recycle a higher percentage of plastic.

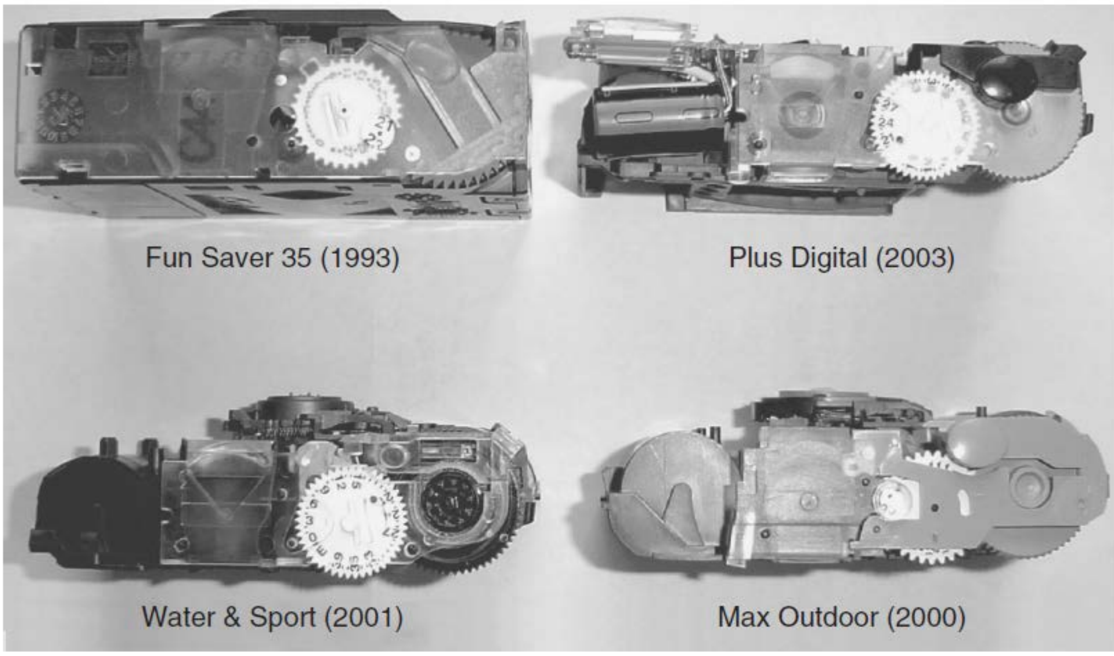


Figure 7.27 Top view of Finder on four of Kodak's one-time-use Cameras, Source: [Kutz. 2007]

Figure 7.28 below shows the evolution of the viewfinder piece in Kodak one-time-use cameras:

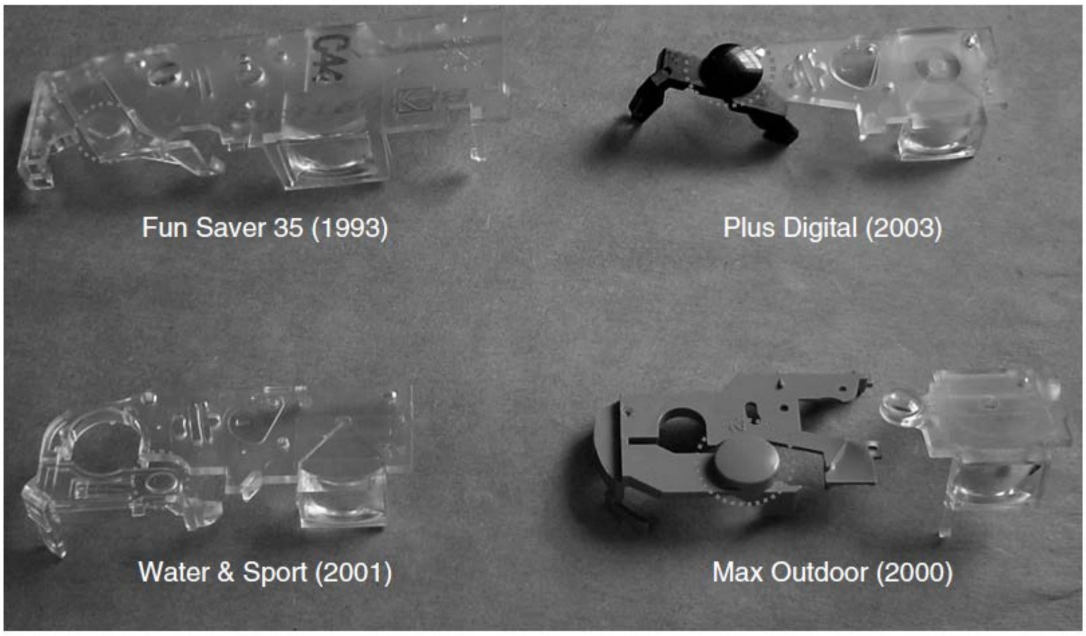


Figure 7.28 Close-up of Viewfinder in four of Kodak's one-time-use Cameras, Source: [Kutz. 2007]

The author also explains that the clear view finder uses raw (virgin) material to ensure the highest possible quality, while the shutter actuation button, can now be made from recycled plastic; finally author [Kutz. 2007] also emphasizes that while it may appear that evolution took a step backward in the current Water & Sport camera, he has found that this model tends to lag behind the other models in the disposable Kodak camera lineup by about one generation, and that in fact, there is usually a strong resemblance between the camera enclosed within the outer waterproof shell, and the outdoor (nonflash) model of the previous generation of single use cameras.

A.4 Implications of a Destructive Disassembly of Disposable Kodak Cameras

When cameras are disassembled by photo finishers to be sent back to Kodak Co. for recycling, a careless process would actually break their snap fasteners; however, authors [Comparini & Cagan. 1998] state that both the camera's front and rear covers (where the snap fasteners are) are actually ground up and recycled, so in fact it doesn't matter (to the film developer) if they are broken during the disassembly process (Note: it only matters to students using them as subject systems and having to return them in working order back to their professors)

A.5 Satisfaction of Constraints against Design Criteria

Keeping costs low in a disposable camera; which is one of its main design criteria, takes a toll on the final design of the product, one of such examples can be seen in how optional features taken for granted in traditional, low cost, film cameras such as large viewfinders, grip surfaces or lens protection mechanisms are missing in the lineup of disposable cameras (see also Table 7.19 for a complementing views on this).

B. Lifecycle Stages of Kodak's Single-Use Cameras

Table 7.17 below summarises the lifecycle stages of the Kodak lineup of disposable cameras, it was compiled after information published by [Simpson. 2009] and helps position and contextualize new findings and ideas in the study of disposable cameras

Stage	Description
1	Camera is manufactured and loaded with unexposed film which is pre-wound from the cartridge into a roll in the camera.
2	Consumer purchases and uses camera, winding film back into the cartridge one frame at a time as photographs are taken.
3	Consumer returns entire camera to a photo-finisher for processing
4	Photofinisher removes the battery and film cartridge and develops the pictures
	Camera body is returned to the manufacturer (Kodak Co.) for reuse and recycling.
	Manufacturer pays photofinisher a small fee for each camera returned as incentive to recycle. C.f. [Kutz. 2007]
	Battery is reused by other industries since it still has over half of its useful life remaining. (Refer also to Table 7.18 for additional information on this)
5	Manufacturer removes lenses and external enclosures for regrind with to raw materials.
	Internal camera body and mechanism

	assembly is inspected and re-used, and new film, a battery, lenses and outer covers are added to make a "new" single use camera ready for sale.

Table 7.17 Lifecycle Stages of Kodak's Single-Use Cameras, [Simpson. 2009]

C. Recycling and Reuse Rundown of Components in Kodak Disposable Cameras

From information published by [Simpson. 2009] and derived from the rest of resources available up to this point; Table 7.18 was created to summarize the "Closed-Loop" recycling program by Kodak and show how every piece of the camera is reused; it should be noted though that since no process is 100% effective, the parts of the camera that don't pass inspection are reported to be simply ground up and fed into the raw material stream for moulding into new cameras

Component	Reuse
Covers	The polystyrene covers of the Kodak cameras (both flash and waterproof) are ground up and recycled into covers for new cameras
	The paperboard outer shell of cameras is made of recycled material
	Polycarbonate elements in the cameras are ground up and sold to make non-photographic products
Label	The graphic label is ground up during the recycling of the outer covers
Film	After removing the film for processing, the photofinisher has the option of returning the camera to Kodak for recycling and reuse
	Since retailers and photofinishers play a key role in this recycling process, they are reimbursed for each camera returned and shipping costs
Lens	To ensure optical purity, the camera receives a new lens each time it is recycled

	Used lenses are ground up and sold to outside companies as raw materials for other products
Camera Mechanism	The chassis, basic camera mechanism and electronic flash systems are tested, inspected and reused
Viewfinder	The viewfinder is re-ground and recycled into new internal camera parts
Battery (For camera models featuring a flash)	When sending the camera back for recycling, photofinishers can choose to keep the batteries for reuse or sale to another industry; however, authors [Comparini & Cagan. 1998] state that if the batteries are returned to Kodak co. they are in turn donated to various charities since (as author [Kutz. 2007]) points out they typically have more than half of their useful life still left

Table 7.18 Kodak's Single-Use Cameras Component Recycling and Reuse, After: [Simpson. 2009]

7.2.11 Stage XI: Redesign Suggestions

7.2.11.1 Methodology

At this point in the methodology, students have already summed up their understanding of the subject system; and thus based on their own experiences operating the product and on their actual needs as potential customers of disposable cameras, a clearer point of view to start suggesting improvement changes has been reached; for this specific example then, an initial assessment activity to know how much was actually known about the Kodak Flash camera in terms of opportunities for improvement was done, immediately followed by a professor-led session of formal ideation methods (e.g. Brainstorming , checklists, fishbone, etc.) to suggest value adding changes to the subject systems, it will be noted from the deliverables shown further below though that no prototypes or working models of the improvement concepts were requested by the professor in charge mainly due to the resources available for this activity, however all resulting findings from this stage were integrated to the report in progress in order to be presented later in the methodology

7.2.11.2 Suggested Pedagogy

To successfully reach the goals of this stage the professor in charge has to provide two different types of advice, one of them is related to the organization of formal sessions of ideation methods where students will meet and come up with original and innovative suggestions of their own on what they consider to be improvements over their product under analysis, whereas the other type has to do with the technical input necessary to screen, modify and expand resulting ideas so students end up with improvement suggestions that are actually plausible and correct from an engineering design perspective ; still a balance has to be reached where student's suggestions may be slightly off in a technical or even feasible sense but where they still start building up trust in them and in their design through the arrival to their own conclusions and the justification of them

7.2.11.3 Sample Deliverables

A. Consolidation of the understanding of potential areas for improvement

Because of the information available about the subject system and our own understanding of it, it was agreed that the major areas for improvement of the Kodak Flash camera (and disposable cameras overall) relate to their: Affordability (e.g. Better cost effectiveness overall); ecofriendliness (e.g. Recyclability), efficiency, user friendliness and reliability. Other authors such as Sidler-Kellog and Jenison for example, have also published their understanding of what disposable cameras do which in turn serves as a lead for the suggestion of design improvements, Table 7.19 below then, summarises some of that understanding and is shown here for comparison to your own conclusions

Item	Description
Design philosophy	The camera has been designed to be easy to use, compact and inexpensive
Primary needs to meet	-Providing a means for taking photos if a camera was forgotten at home -Providing a camera for consumers who cannot afford the expense of owning one
Design criteria	-Low cost -Mass production

	-Easy use -International marketability -Easy film removal -Attractive packaging that is light and moisture resistant
Design constraints	-Availability of an automatic flash -Focus-free lens -Physical dimensions -Low cost (also usually identified as a criteria)
Satisfaction of design constraints vs criteria	-To keep costs low many optional features such as picture dating or an automatic timer are necessarily excluded -The low cost mechanism that controls the shutter and the way in which it has been integrated with the flash where a battery charges a capacitor which subsequently discharges, resulting in a bright flash

Table 7.19 Typical Findings after Reverse Engineering a Disposable Camera, After [Sidler-Kellog & Jenison. 1997]

B. Typical improvement suggestions for Kodak disposable cameras

Single-use cameras have been manufactured by Kodak for almost thirty years, a period of time where they (and other manufacturers such as Fujifilm) have been refining their design and associated processes, cutting down costs in a lot of ways thus making the finding of potential improvements for the camera a difficult, but not impossible task. Structurally and operationally speaking; Kodak for example, has already eliminated fasteners, switched to cheap plastic materials, come up with a very simple design and therefore simple production methods; the design suggestions in Table 7.20 below though, are typically brought forward by students during an EREA, similar proposals have been documented by [Sidler-Kellog & Jenison. 1997], [CIBER-U. 2012] and others elsewhere and are presented here for comparison against your own:

Feature	Improvement Suggestion

Battery	Since the battery used in the camera is a standard AA size manufactured by Kodak itself, it could be subcontracted to a battery manufacturer supplying them at a lower cost or perhaps, it could be possible to manufacture a smaller specialized battery for disposable cameras, reducing size, weight and possibly cost
	Alternatively , a rechargeable battery could be used for a better reuse of components
Chassis	If the centre chassis part of the camera were manufactured from stamped sheet metal instead of injection moulded ABS plastic it would get thinner, lighter, shorter and above all cheaper, thus removing both, product weight and cost, making it a more attractive product to the consumer.
Construction	Because most pieces are made of a cheap plastic, the pieces are easily warped during reassembly and product performance is easily altered, this may affect the manufacturer's reusing policies and negatively impact their profits
Ergonomics	Square corners of the camera are uncomfortable to hold so rounding the edges of it is suggested
	Provisions for lefthanded users with simple changes to the basic design such as moving the shutter button from the right corner to the centre of the camera can be also suggested
Film	More than 27 pictures per roll could be offered so that users wouldn't need to buy several cameras for long vacations; during the heyday of analogue cameras rolls with 36 exposures were actually commonplace
	Quality of single-use camera pictures are

	notoriously not as sharp as regular cameras, this could be changed by offering a sharper, higher speed film in the cameras (e.g. ISO 400), which currently is ISO 800 thus providing a less “grainy” image
	Given that film is rapidly becoming obsolete, a new specialized film produced for use in disposable cameras only is suggested; with limited research and development, a new and smaller film cartridge could be produced thus reducing the overall size and weight of the camera
Film Advance Mechanism	Benefiting from the electrical supply available in cameras featuring a flash, an automatic film advance and winding mechanism is suggested
Film Advance Wheel	The film advance wheel is difficult to grasp and advance properly so an enlargement of it is proposed
Flash Unit	Current camera flash has a limited range of only 1m to 3m (4 to 10 ft) making pictures of large spaces difficult, manufacturers could improve this range by increasing the capacitor size in the flash circuit or at least providing a fill-flash mechanism for a better scene exposure
	The automation of the flash burst when activating the shutter speed is suggested (same button and not separate as it currently is)
Function sharing	As previously mentioned in Section 7.2.7.3 – F, energy consumption during manufacturing of the disposable camera is much higher than during its use and so by integrating two or more camera parts into a single one could help reduce the amount of energy consumed during its production

Labelling	A Kodak disposable camera called the "Wedding package" (not available in all markets) features an outer printed cardboard where the use instructions are shown and which also decorates the camera. A possible design improvement though, would be to eliminate the need for the printed cardboard cover by stamping the instructions directly on the case of the camera
Lens	Although camera lenses are made of pure transparent plastic, they do not offer yet the best possible picture clarity; the inclusion of a higher resolution lens to increase photo sharpness is suggested
	Addition of a lens protection (e.g. Half moon barricade) to reduce the possibility of covering it with the user's fingers by accident
Materials	Minimise even more the variability of materials to increase the recyclability of the camera (e.g. Most of the structural parts of the camera are already made of polystyrene only)
Portability	Because single-use cameras are very popular with vacationers, portability is an issue, and while the camera is already small in size, a belt clip attachment could benefit hikers who wish to take photographs
	If some of the changes suggested in this table were incorporated the resulting camera components would be much smaller and slimmer, and with smaller parts the camera casing could then be shrunk to a more suitable size that would reduce weight and cost thus becoming easier to transport
Product Packaging	With the advent and widespread access to the internet, printed information about the product (e.g. Certificates of compliance or even printed

	paper instructions) can be made available online thus saving printed paper
Recycling Process	For cameras including a flash unit some sort of safety device for discharging the capacitor for the safety of servicemen disassembling the camera is suggested
Viewfinder	Addition of crop lines for a more accurate framing
	Larger size of viewfinder

Table 7.20 Common Improvement Suggestions for Kodak's Disposable Cameras, After [Sidler-Kellog & Jenison. 1997], [CIBER-U. 2012] and this Collection of Resources's own Suggestions

Most of the suggestions here help reduce the overall cost of the camera, although with some of them the cost of production would actually rise, thus reducing the manufacturer's profit; they are, however, mentioned here believing that such improvements would increase the sales of disposable cameras and thus by spending a little more on the technologies the camera offer, the perceived value of disposable cameras would increase for potential customers of them

7.2.12 Stage XII: Conclusions

7.2.12.1 Methodology

Two major tasks enable the attainment of the goals of this stage; one is the completion by students of the activity report, where past and current findings have to be integrated into a coherent document that will be both, evaluated by the professor in charge and later read by interested audiences; whereas the other major task of this stage, is to evaluate the actual attainment of the educational goals initially set for this activity both from a professors and students' perspective (the latter usually achieved through a self evaluation of their performance throughout the EREA). For the example described in this collection of resources and because of its experimental nature, students were not evaluated externally but were asked instead to evaluate themselves, on aspects related not only to their perceived learning of the technical topics relevant to the product under analysis but also on the organisational aspects dealing with the dynamics of their teamwork

7.2.12.2 Suggested Pedagogy

As a professor, two major tasks have to be done at this stage; one is to ensure that students finish preparing a thorough activity report, whereas the other is to evaluate from a professors and students' perspective the attainment of the learning objectives initially set for the EREA; for the first task, if the professor in charge has regularly checked the intermediate results from past stages of the methodology, students will have no problem in submitting a document at this point that is both coherent and approved for eventual dissemination to a variety of audiences; if on the other hand, this is the first time professors read the students' results they have to check that the students provide reasonable, thorough explanations for the whole activity and specially so from a technical and organizational perspective that describes both the workings of the subject system and the team activities that led to that understanding. For the second major task of this stage then; resources for the evaluation of students are provided in Section 6.5.3 of this document, but still, it should be mentioned that for this specific example, and because of the exploratory nature of it, students were only required to evaluate themselves individually and then be evaluated by their teammates through a 360 degree assessment, from both results and from the professor's accumulated knowledge about them, students can be evaluated and assigned a proper grade for the EREA

7.2.12.3 Sample Deliverables

A. Activity Conclusions

Throughout this activity we implemented the reverse engineering methodology proposed in this collection of resources, while evaluating at the same time, its usefulness as an aid in the learning and understanding of concepts of engineering design. To achieve the goals set for the EREA then, a number of analytical tools, testing devices and computerised resources where used throughout the activity in complementing and accumulative ways that helped us reach a conclusive understanding about the product under analysis.

For example, in regard to the hands-on nature of the EREA, it can be said that all stages of the Kolb model were visited and that a different learning experience overall was had where the learning of theory was complemented with its practical counterpart. Concerning the technical principles behind the product though, we were told that the thorough knowledge of the subject system is not a goal in itself but rather an excuse to go through the proposed methodology and thus develop our design-related abilities, however, it still should be stated that the disposable Kodak Flash camera provided an opportunity to experience typical analyses and situations in the area of engineering design which ultimately allowed us to learn not only the ins and outs of our career but also how it interrelates with other areas of knowledge.

Respecting the actual tasks and analyses done to the subject system, it can be said that the reverse engineering methodology made us combine not only the information obtained from outside sources about the operation and manufacturing of the subject system (e.g. Acquired via thorough bibliographical investigations) but also our own experiences in testing and analysing the Kodak camera (one example of this, relates to how customer needs about the subject system were established not only by researching and interviewing people about them but also by self-experiencing the camera in order to complement them and refine them). Indeed, the experiences gained thereof gave us the confidence to suggest value adding changes to our subject system where, after analyzing our product's social factors; function, structure, materials, assembly and manufacturing process, we concluded that the Kodak Flash model is a user friendly camera (at least in comparison with previous generations of the same model) that at the same time keeps costs low, and a very high reliability of operation, which in combination with its exemplary recycling process makes it an ideal candidate for analysis for those willing to give reverse engineering a try for the first time.

Last but not least, it should be highlighted that the EREA allowed us to undergo a team experience very close to what we could find during our professional career, since we were all allocated roles, responsibilities and resources to attain a satisfactory result in a learning experience that was found motivating, refreshing and above all educational by everyone in the team

7.2.13 Stage XIII: Results Dissemination

7.2.13.1 Methodology

This stage is about reaching the right people (e.g. Evaluators, classmates, sponsors) with the right information (e.g. Tailored presentations suitable to the knowledge of the audience) and so as a student the main task is to present to the class the results from the EREA and from there, prepare derivative dissemination materials (e.g. Posters) to be displayed at relevant venues and for a variety of audiences. As a professor, on the other hand, the main responsibility for this stage falls in evaluating the students' final report; complementing their presentations with appropriate contextualization remarks, leading the actions for those student works with potential for peer-reviewed publication, and collecting the students' reactions and impressions about the EREA for the last time. Regarding the specific actions done for this example then, it can be highlighted that professors supported their students by providing them with the resources needed for their presentations (e.g. Venue, projector, etc.) and helped them organize and moderate Q&A sessions where each others' work could be constructively criticised and improved

7.2.13.2 Suggested Pedagogy

For evaluating; supporting and refining the dissemination works by students at this stage it is advised to make them aware of their target audiences first and then helping them the tailor the results to present and the kind of presentations to give according to the target audience; given that any of the students' exhibitions will carry the potential to become an opportunity for further development and collaborations (e.g. Paid internships with sponsors, paper co-authorships, etc.) it is important as a professor to help students get in touch with the right audiences and thus any existing network of contacts should be made use of in order to increase the reach of their works; should there be any students' results with the potential for peer reviewed publication the professor must provide the necessary advice so students elaborate on the results from their EREA to reach their full potential. Concerning the specific actions done for this stage then, no student publications were actually achieved, however, their results were shown to students of different university departments and visiting professors at the time, where students had an additional chance to receive feedback from their work

7.2.13.3 Sample Deliverables

A. Dissemination posters and presentations

Dissemination works by students can take different forms (e.g. Display boards; multimedia, oral presentations, webpages, etc.) because they are largely dependent on the target audience and on the allowed format of the presentation, they are however all constituted from the findings and results obtained from their respective EREA (just like the examples shown throughout this resource) with only slight variations on the depth and way in which they are presented depending on the situation at hand. Figure 7.29 below for example shows snippets of actual posters and presentations done by the author of this collection of resources to present at a variety of venues the details of this collection of resources in general, and of EREA in particular, and are shown here to help spark ideas for the eventual creation of your own dissemination works.

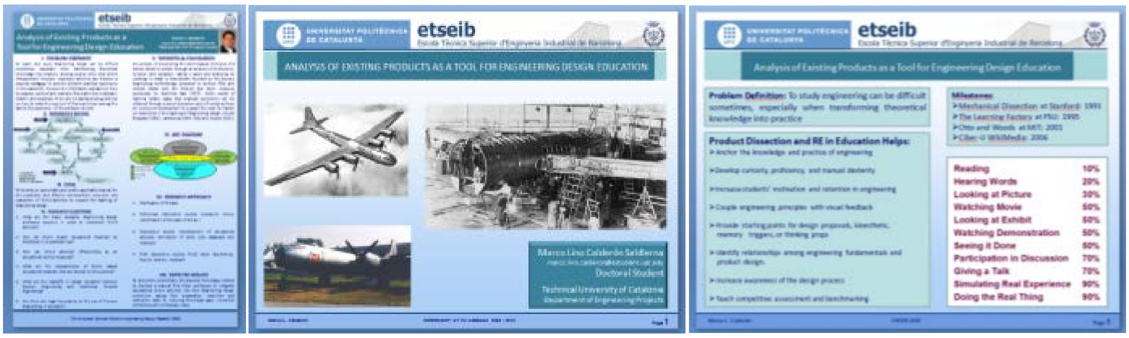


Figure 7.29 Sample Dissemination Posters and PowerPoint Presentations to Discuss the Details and Findings from an EREA

7.2.14 Stage XIV: Project Closure / Follow Up

7.2.14.1 Methodology

The main task for this stage is to set the up the mechanisms that will allow all knowledge gained from the EREA to remain available until it is needed again, for a student, and at a minimum, it will mean just the storing of a copy of the team's work at a reachable location, but for an ideal case, it will mean joining any type of community where similar topics are discussed and where contributions can be eventually made. For a professor on the other hand, this stage entails not only analyzing all feedback collected from the EREA up to this point so that a minimum baseline from which to keep improving on future projects is set, but also, it will mean actually publishing whatever relevant data can be presented to the appropriate audiences and thus keep contributing to the existing body of knowledge on the field. Concerning the actual actions for the example presented here then, it is worth highlighting that for all the participant students this stage effectively meant the end of the EREA, but for the involved professors new experiences and case studies were generated from it for potential inclusion in future peer reviewed publications

7.2.14.2 Suggested Pedagogy

At this point of the methodology it is important to ask students to reflect on how the knowledge gained from their EREA can benefit themselves (e.g. As future opportunities on related fields) and others (e.g. By disseminating relevant findings); also and in order to help them keep in touch with the latest developments in the area Resource 9 and its comprising sections for example, has been included in this collection of resources to serve them as one of the possible entry points to the variety of existing resources for the study of reverse engineering. For new professors on the field of reverse engineering though, the reading of the doctoral thesis and peer reviewed papers form which this collection of resources originates is recommended to better contextualize how reverse engineering can from its industrial origins be tailored to support the teaching of engineering design and the creation of new educational case studies on the topic

7.2.14.3 Sample Deliverables

A. Sample peer reviewed papers on EREA

One of the possible ways to preserve the findings about EREA is to publish any relevant results from the study and testing of them, the author of this collection of resources for example has presented at peer reviewed conferences details about EREA and about their application in the teaching of engineering design, the list of papers shown below for instance, are part of the dissemination efforts in progress to contribute to the existing body of knowledge on the field, and are available for reading to anyone interested in them, namely:

- Product Visualization Praxis and its Integration to Academic Curricula, [Calderon. 2008]
- Analysis of Existing Products as a Tool for Engineering Design Education, [Calderon. 2009]
- Application of Reverse Engineering Activities in the Teaching of Engineering Design, [Calderon. 2010a]
- A Comparison of Competences Required in Reverse Engineering Exercises Versus Conventional Engineering Exercises and its Relationship to IPMA's Competence Baseline, [Calderon. 2010b]
- The Design Research Methodology as a Framework for the Development of a Tool for Engineering Design Education, [Calderon. 2010c]

7. 3 Resource Conclusions

In a guided example such as the one presented in this resource it can be seen how the stages of an EREA call for the integration of varied perspectives for every single activity included in them; indeed it is not only about placing importance on the technical foundations for the development of a given task but also on the cognitive processes that are set in action and that ensure a proper learning experience for the students, in this sense the guidance and judgement of the professor in charge can determine how much students will learn from an EREA; for example, and as seen throughout this resource, a wealth of analytic tools exist that provide information about a product under inspection, but it is the decision of the professor in charge to tell students only which of them to develop and why, in a way that allows the continuation of the EREA without leaving any significant knowledge gaps behind; since the information presented here, including the methodology, pedagogy and examples, is all based on past, published research on the topic and complemented with original findings from this research, the guided example presented in this resource should be considered a self-explanatory backbone for the understanding of the basic elements of EREA, and after the reader's own contextualization, it should help enthusiasts of reverse engineering not only to make the most out of EREA but also to serve as a baseline for the eventual creation of further educational materials.

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RESOURCE 8: CONCLUSIONS AND FINAL REMARKS

8.1 Resource Introduction

Although published studies stated that hands-on activities such as educational reverse engineering ones could become a popular pedagogy to provide students with practical experience in the classroom [Lamancusa et al. 1996], there are still nowadays many areas left to explore in the topic; for example, further studies on suitable pedagogies which allow for the right balance between teachers' guidance and students' freedom are still required to make the most out of these activities; and it is not only the pedagogical aspects of them that need to be improved, other challenges in the implementation and expansion of such activities also exist, in initial exploratory studies conducted as part of this research project -to name but another example- some educators manifested a reticence to complement the teaching of the design process with reverse engineering activities and the varied reasons given for it ranged from personal to organizational ones, the contents of this resource then, intend to present an overview of what EREA currently are and what they could still become.

8.2 Present of Reverse Engineering Activities in Education

From the research leading to the creation of this collection of resources, which included the analysis of all available data and the drawing of conclusions from field results and experiences collected throughout the duration of the project, it could be concluded about the use of EREA as an educational tool, that they:

- Are just another tool for the teaching of engineering design, they don't try to abolish other approaches and as such they are a complement rather that a substitute of traditional engineering design projects, or any other existing teaching tool.
- Are fun: Because students have the opportunity to disassemble and see the insides of everyday products, thus engaging in a novel and appealing challenge that can help them stay motivated and interested.
- Are dynamic: Because in to order to complete a successful activity; a simultaneous collection, integration, and contextualisation of knowledge from different areas has to be done which demands from students an increased sense of awareness and a display of resourcefulness.
- Provide a realistic opportunity for practice: EREA provide opportunities for repetition and reinforcement of key information where students can make mistakes and learn from them and also from the feedback provided by their instructor, besides, the

infrastructure and rules inherent to an educational environment provide students with a safe environment to fail and try again, thus encouraging them to test new ideas and behaviours.

- Make learning concrete: EREA are realistic, complex experiences that allow students to link information to action, and to reinforce engineering concepts through hands-on experiences which could later help them use concrete learning in real life situations.
- Help learning to permeate: EREA have the potential to enhance students' learning by providing them with an opportunity to bring whatever has been learnt theoretically, into a practical environment where all information can be challenged; analyzed, discussed and interpreted to come up with a realistic explanation of what has happened during the design process of the product under analysis and during its actual operation
- Help students work as team: EREA are a group activity where specific roles and responsibilities are set; and as such, students can mix their abilities and ideas with those of their team members thereby helping reinforce learning and interaction in the team; should noticeable differences in experience; knowledge and status among team members arise during and EREA, the opportunity to safely repeat the activity until a desired state is attained contributes to level the knowledge about the product under analysis of all team members.
- Let the instructors observe the learning process: Professors and teaching assistants can observe the students while they perform the hands-on tasks and discuss about what they see and how they relate it to theory; educators then, can provide feedback and guidance whenever needed while team members take active responsibility for the learning that occurs during the activity.
- Foster cooperation with industry partners: Existing industrial requirements could be handed to students to help find a suitable solution, (e.g. By proposing and designing improved derivative products from the one under analysis)
- Are mostly technology oriented: EREA are just another tool available to support the teaching of engineering design and as such they will cover just a set of the total possible, expected competences of an engineering design student, indeed and as seen in Table 4.10, and Resource 4 overall, EREA best suit learning objectives related to the technical aspects of engineering design and shouldn't be considered the main choice to teach or exercise "soft skills" with them.
- Have an added value that lies in giving students early in their studies, the opportunity to acquire and develop, through interesting and engaging activities, some of the abilities required to lead a successful career in engineering design.

8.3 Future of Reverse Engineering Activities in Education

In complement to the abovementioned conclusions; and given that the actual introduction and development of EREA in the field of engineering design can still be considered a relatively recent one, several lines of new research were identified throughout the duration of this project, and the most promising ones are mentioned in Table 8.1 below to help the interested reader get an overview of potential, future developments in the area.

Category	Research Line	Description
Product Engineering	Cycle time compression	How reverse engineering in product development can further shorten lead times to market a new product
	Effectiveness of technical obfuscation measures	Development of obfuscation measures to avoid reverse engineering of sensible designs
	Reverse engineering of processes rather than products	Development of analyses to help uncover a whole manufacturing process and its practical limits, rather than just uncovering a manufacturing process that is already optimised for a specific product
Software	Virtual (product) dissection	Virtual reality-based dissection for real time interaction between students and the object of study (but reconciling the fact that the physical object is being taken away from the student again for the sake of convenience and mass reaching)
	Creation / Expansion of digitized product teardowns	The capturing and digital publishing of product teardown reports to be accessible to interested people all over
Education	Integration of reverse engineering activities with new technologies	Streamlining of the reverse engineering method considering the integration of existing and future technologies. (e.g. The current integration of computational techniques in the analysis, tracking and support of a reverse engineering project is still limited)
	Curriculum	To study the mechanisms that could help instructors of

	development	educational reverse engineering to add the value from their industrial experience and research accomplishments into their teaching curriculum. To research on how to reuse the findings and conclusions at a class level from one semester to the next, etc.
	Capturing of embedded knowledge and transference to new designs	Exploration into research opportunities from the statement by author [Kutz. 2007] in the sense that "an important challenge both to those doing reverse engineering and to those attempting to apply its lessons is how to capture the embedded knowledge in such a way that it can be both readily identified and applied to new design contexts."
	Educational experiences beyond purely technical topics	Exploration into research opportunities from the statement by author [Kang. 2011] in the sense that "Integrating the global, economic, environmental, and societal issues in engineering design education is a promising new direction for courses that incorporate product dissection activities"
	Delivery of real life-like experiences in the classroom	Measures to avoid the reverse engineering experience to be taught by non-practitioners or by non experienced professors (this research itself focuses on that line)
	Product performance prediction	To understand and evaluate a product's performance based only on available data about it without resorting to a dissection or testing of the actual, physical product.
	Design for X	Reverse engineering activities enhance the awareness of materials and manufacturing processes used in consumer products, thus the inclusion of Design for Disassembly (DFD) and other relevant DfX areas into a reverse engineering methodology should be explored
	Software assisted product teardowns	The reverse engineering method presented in this research follows a rather algorithmic, brute force approach, as such, it is prone to a software implementation of computer assisted reverse engineering tools that can serve students as an interactive guide in the realization; planning, structuring and contextualization of a reverse engineering exercise
	Product families and platforms	Author [Kang. 2011] for example, has suggested to update his own "product dissection methodology for dissecting a group of products, and for an after-dissection analysis of the

		product family and product platform", further research opportunities in this topic then, should be also available for the interested reader
Dissemination	Creation and dissemination of study materials	Development of physical hands-on kits; textbooks, resources and reference materials not only for students but also for, independent, self-paced learners; the same materials could be further translated to languages which are currently lacking. (e.g. Spanish)
Engineering Design Practice	Codes and standards of engineering design practice	The results obtained through a reverse engineering analysis help to learn from the mistakes and successes of others, this experience should not be lost and could be used to assist in the continuous development of codes and standards of engineering design practice
	Experience and design decisions	After author [Kuffner & Ullman. 1991] studies uncovered that up to 90% of the design decisions made to come up with a finished product could be derived by unrelated designers by experience alone, it would be interesting to see how different this percentage is for people with different levels of experience in the area of product design (e.g. From students to senior designers), and how experience would play a role in reverse engineering analysis.
History of Science and Technology	Analysis of ancient mechanisms	It concerns the study and reproduction of the manufacturing processes of ancient objects in order to gain some insight on the knowledge, resources, and available technologies at the time. This line of research can also be about contributing to the understanding of the use of ancient objects. (e.g. The research conducted on the Antikythera mechanism [AMRP. 2012])
Commercial Ventures	Business start-ups	There is a market for professionally made hands-on kits to promote learning; educators gaining experience with reverse engineering activities could later start a company to develop hands-on experiences for use at home, institutions or distant educational settings.
Intellectual Property	Settlement of patent disputes	Analysis of existing hardware at the mechanism or even semiconductor level can help determine whether proprietary technologies have been used by competing companies; educational reverse engineering activities could at least

		provide students with an initial experience in the integration of hardware analysis and patent law and could serve as a possible line of collaboration in the area of intellectual property.
Manufacturing	Uncovering of manufacturing processes involving non reversible reactions	Although materials and manufacturing analyses are an integral part of educational reverse engineering activities, manufacturing and materials' processes that include irreversible reactions (e.g. Plastic deformations, chemical interactions, etc.) are beyond the reach of typical engineering design practitioners and call for the collaboration of multiple specialists; the reverse engineering of such processes rather than that of specific products, opens up another potential line for future research (cf. "Investigation of the Brewing Process: An Introduction to Reverse Process Engineering and Design in the Freshman Clinic at Rowan University" by [Farrell et al. 1999]

Table 8.1 Potential Research Lines in Educational Reverse Engineering

While some other potential lines of research also exist, the abovementioned ones represent the state of the art in the field at the time of releasing of this collection of resources.

8.3.1 Other Authors' Views on the Future of Educational Reverse Engineering and Similar Activities

Of relevance to this document are the words by editor Myer Kutz who has provided an interest view on what he expects reverse engineering to achieve as an educational practice , he states for example that the practice of reverse engineering principles will "facilitate the education of a new generation of students on knowledge areas critical to their survival and success as engineers such as functional modelling; competitive product design, information technology, globalization, and product platforming within an enterprise". What's more, he states that, "the proliferation of reverse engineering principles and practice has even further-reaching implications" (since) "the sustained development of engineering principles, technologies, and tools will continue to shape and influence product development processes in globally competitive markets" (and) "similarly, the teaching of these principles, technologies, and tools will help prepare a wide range of engineering students to enter the workforce with a more effective understanding of how to efficiently develop consumer-driven; cost-effective, and environmentally friendly products in a distributed, technology-mediated environment.", [Kutz. 2007]. The information presented in this resource and in the collection of resources overall about the documented benefits of reverse engineering activities aim indeed to support author Kutz's views.

8.4 Resource Conclusions

All in all, there is no better or worst approach to the teaching of engineering design; EREA must be understood as just another tool to support its teaching and in consequence they will only favour a limited set of the total expected, and desired competences of an engineering design student; however, there will always be a need to improve engineering education and thus, new approaches such as EREA will have to be explored; tested and expanded, continuing studies about reverse engineering then, can be reasonably expected, and considered healthy for the development of the area.

The information provided here regarding the reasonable expectations from an EREA should help educators plan their introduction at the time and purpose that better fit their teaching needs; reverse engineering activities indeed, can work in very different settings, but the greater the differences in levels of technical support, training, resource materials and facilities the greater the attention instructors need to pay in ensuring that reverse engineering activities work at expected at their academic institutions. Conveniently, the advice given in this collection of resources considers all realistic scenarios for their implementation and thus the core learning effect in students and the results brought about by them should remain valid irrespective of the amount of resources available at the time of their implementation.

The study of the design principles materialized into existing products then, provides students with an opportunity to expand their sources of inspiration and information; by looking back in the history and development of consumer products, there is much to learn from the accumulated knowledge of science and technology from earlier design engineers. The results from this collection of resources though, are aimed and are of relevance to academic environments only, if any inference or association were to be made to the commercial counterparts of educational reverse engineering activities, different considerations about individuals; groups, technologies and organizational aspects would need to be made which were always outside the scope of this project.

Finally, it is expected that the challenges in the familiarisation, and the eventual implementation of EREA into existing engineering design curricula are correctly addressed in this document, in such a way that the reader can actually benefit from previously published best practices on the area, as well as from the original results presented here. Your impressions and feedback nonetheless, will be paramount in helping revise this collection of resources until the right balance that ensures that the learning setting; the curriculum content, the teaching method, and the evaluation mechanisms support students in their attainment of the learning goals expected from an EREA.

RESOURCE 9: MISCELLANEOUS RESOURCES FOR THE STUDY OF EDUCATIONAL REVERSE ENGINEERING

9.1 Resource Introduction

The study of EREA nowadays; benefits from the amount of relevant, yet dispersed information available across a varied number of fields, this resource thus, aims to bring together those relevant pieces of information that will allow the reader to understand the background behind the theory and practice of EREA and that can support the eventual creation of new reverse engineering-based instructional materials.

9.2 How to Look for Information about Educational Reverse Engineering

Specific information about educational reverse engineering can be tricky to get, thus it must be searched with very clear ideas and keywords in mind; the reason for this is that "Reverse Engineering" is a common name (cf. Table 1.1) shared among other contexts that are somewhat unrelated to the main one in this document, and for which there is much more information available; most of the results returned by search engines (if using one) when introducing the terms "reverse" + "engineering" will be either from the software engineering area or from the context of the machinery used in the extraction of geometrical features; thus in order to get the results desired, one must provide a search engine at least the following terms to have a high rate of relevant results, namely: "reverse" + "engineering" + "product" + "disassembly". With the use of the right keywords and by looking at reputable databases such as those associated to the resources shown in Tables 9.4; 9.6, 9.8, 9.10 and 9.12 shown below, one can retrieve useful results. Moreover, Tables 9.4 to 9.8 themselves aim to categorize and summarize the main sources of information currently available to the interested reader for the study of educational reverse engineering activities.

9.3 Resources for the Understanding of EREA

9.3.1 Ideal Examples of what Educational Reverse Engineering can Become

9.3.1.1. The Study of the Antikythera Mechanism

The way the Antikythera mechanism is being analysed from several domains of knowledge in order to come up with a reconstructed vision of what the device is and how it works mimics what an ideal case of an educational reverse engineering activity could be, where students are resourceful, integrate existing knowledge and collect new information to come up with their best approximation to explaining what a device does and why, Table 9.1 below includes information about current research on the mechanism for the interested reader

Name of the Resource	Associated Webpage	Description / Notes
The Antikythera Mechanism Research Project	http://www.antikythera-mechanism.gr/	A quintessential example of academic reverse engineering

Table 9.1 Resources for the Study of the Antikythera Mechanism

9.3.1.2 Video Dissection and Analysis of an iPad Device by Product Design Engineers

Table 9.2 below links to a discussion showing EREA's core elements, which are dissecting a product; analysing it, conjecturing about the design decisions made, and actually coming up with new suggestions for improvement of the existing product

Name of the Resource	Associated Webpage	Description / Notes
iPad Teardown: An Engineering Design Perspective	http://vimeo.com/14596673	A 23 minute long dissection and analysis of a 2010 Apple Inc.'s iPad® by the product design engineers at LUNAR (http://www.lunar.com)

Table 9.2 Video Dissection and Analysis of an iPad Device

9.3.2 Relevant Authors on the History and Development of EREA

Table 9.3 below lists several contributors to the development of reverse engineering in education, it is by no means a comprehensive roster and it might unintentionally leave relevant people out; so it only reflects the author's opinion on who should be mentioned as a major driver (both directly and indirectly) in the development and dissemination of reverse engineering in education.

Author	Related Institution(s)	Notes	Sample Work

Agogino, Alice M.	University of California at Berkeley	Pioneer in the use of mechanical dissection in education	http://www.me.berkeley.edu/faculty/agogino/
Barker, Phil	Heriot-Watt University, UK	Supporter in the creation of case studies and disassembly activities	http://www.icbl.hw.ac.uk/~philb/
Brereton, Margot.F	Stanford University	Researcher on how students connect engineering fundamentals to hardware design	http://www-cdr.stanford.edu/intuition/Brereton_Margot.html
Cecarelli, Marco	University of Cassino, Italy	Researcher and author of books on the history of mechanisms where reverse engineering analysis of them is necessary	http://webuser.unicas.it/weblarm/ceccarelli.htm and http://www.springer.com/engineering?SGWID=3-175-404-173698703-7481
Dalrymple, Odesma Onika	Purdue University, USA	Researcher on the pedagogical value of dissection activities	https://engineering.purdue.edu/ENE/HomepageFeatures/Spotlights/Researchingreverseengineering2
ElMaraghy. Waguih	University of Windsor, Canada	Supporter of educational Reverse Engineering in Canada	http://www.uwindsor.ca/engineering/imsc/WElMaraghy
Durfee, W.	University of Minnesota, USA	Creator of a short guide on Mechanical dissection	http://www.me.umn.edu/courses/me2011/handouts/dissection_guide.html
Gerard Jounghyun Kim	University of Southern California, USA	Researcher on reverse engineering topics	http://dxp.korea.ac.kr/~gjkim/

Grand, Joe	Grand Idea Studio, Inc.	An enthusiast who has spent two decades finding security flaws in hardware devices and educating engineers on how to increase the security of their designs.	http://www.grandideastudio.com
Günter Ropohl	Universität Frankfurt am Main, Germany	Supporter of the Socio technical understanding of products, one of the goals of educational reverse engineering	http://www.ropohl.de/
Kemper E. Lewis; Castellani. Michael, Simpson W. Timothy, Stone B. Robert, Wood William H. and Regli, William	John Wiley & Sons, Inc.	Researchers and co-authors of Chapter 4 " Fundamentals and Applications of Reverse Engineering" of the book "Environmentally Conscious Mechanical Design"	http://onlinelibrary.wiley.com/book/10.1002/9780470168202
Kremer, Gül	Pennsylvania State University, USA	Researcher and disseminator of product dissection activities	http://gicl.cs.drexel.edu/wiki-data/images/3/39/ASEE.Workshop.Slides.pdf
Kutz, Myer	Myer Kutz Associates, Inc	Editor of the book "Environmentally Conscious Mechanical Design" which contains a chapter on reverse engineering	http://onlinelibrary.wiley.com/book/10.1002/9780470168202
Lamancusa, John S.	Pennsylvania State University	Pioneer in the use of Product dissection in education	http://www.mne.psu.edu/Directories/Faculty/Lamancusa-J.html
Leifer, Larry J.	Stanford University	Supporter of the use of mechanical dissection in education	http://soe.stanford.edu/research/layout.php?sunetid=leifer

Lewis, Kemper	SUNY at Buffalo, USA	Researcher and disseminator of product dissection activities	http://gicl.cs.drexel.edu/wiki-data/images/3/39/ASEE.Workshop.Slides.pdf
McLaren, Andrew	The Higher Education Academy, UK	Disseminator of mechanical dissection as an approach to the teaching of design	http://www.engsc.ac.uk/downloads/scholarart/design.pdf
Ogot, Madara	Pennsylvania State University, USA and Maseno University, Kenya	Researcher and published author on the topic of engineering design and product dissection	http://maseno.ac.ke/index/index.php?option=com_myjspace&view=see&pagename=maradaogot
Otto, Kevin N.	Massachusetts institute of Technology	Pioneer and co-author of a foundational book on Reverse Engineering	http://www.kevinotto.com/wb/index.php
Pamela Samuelson	University of California at Berkeley	Expert on the law and economics of reverse engineering	http://people.ischool.berkeley.edu/~pam/papers.html
Sato, Yoshihiko	Pioneer of the “Tear Down” process in automotive clinics	A researcher that in 1972 was assigned to the Cost Planning Department of Isuzu Motors Japan where he developed the "Tear Down" process as a way to enhance value engineering studies.	http://www.valuefoundation.org/fellows/sato.htm
Sheppard, Sheri D.	Stanford University	Pioneer in the use of mechanical dissection in education	http://soe.stanford.edu/research/layout.php?sunetid=sheppard
Simpson, Tim	Pennsylvania State University, USA	Researcher and disseminator of product dissection	http://gicl.cs.drexel.edu/wiki-data/images/3/39/

		activities	ASEE.Workshop.Slides.pdf
Wood, L. Kristin	University of Texas at Austin	Pioneer and co- author of a foundational book on Reverse Engineering	http://www.me.utexas.edu/~madlab/~wood/ and http://www.me.utexas.edu/directory/faculty/wood/kristin/73/

Table 9.3 Relevant People in the Development of EREA

9.3.3 Published Academic Resources for the Study of EREA

9.3.3.1. Conferences Dealing With EREA-related Topics

Table 9.4 Shown next lists representative conferences where topics about reverse engineering activities of an educational nature have been discussed so far

Name	Homepage	Main Geographical Focus
ASME's International Design Engineering Technical Conferences (IDETC)	http://www.asmeconferences.org/IDETC09/index.cfm, http://www.asee.org/conferences-and-events/conferences/future-conferences	North American
CIRP Design Conference	http://www.cirp.net/index.php?option=com_jcalpro&Itemid=27&extmode=cat&cat_id=3	Global
Engineering and Product Design Education	http://iepde.org/epde12/conference_aim.html	Global
Frontiers in Education Conference	http://fie-conference.org/	North American
International Conference on Engineering Design	http://iced13.sql.co.kr/main.htm	Global
International Conference on Engineering Education	http://www.icee2012.fi/	Global
International Conference on	http://cpdm.iisc.ernet.in/icord'11/venue.html	Asian

Research into Design		
International Congress on Project Engineering	http://www.aeipro.com/index.php/xvi-congreso.html	Ibero-American
International Design Conference	http://www.designconference.org/	Global

Table 9.4 Peer-reviewed Conferences where Topics about Educational Reverse Engineering are usually Covered

9.3.3.2 Published Dissertations on EREA-related Topics

Five theses dealing with educational reverse engineering topics by authors [Jounghyun. 1994]; [Kodak. 2008], [Leek & Larsson. 2007], [Dalrymple. 2009] and [Kang. 2011] have been identified so far and are listed in Table 9.5 below; they all confirm what has been published on peer reviewed papers on the topic already, but what is most important from these theses though, is that the validity and success of such activities, to bring practical experience to the classroom is supported by credible evidence now. This collection of resources and the dissertation from which it stems then, do not try to prove the validity of reverse engineering by repeating once again previous experiments by other authors (though independent confirmation is always important) instead this document is devoted to the promotion of such activities and the justification of why they are useful and how

Author	University	Thesis Title	Link
Dalrymple, Odesma Onika	Purdue university, USA	The pedagogical value of Disassemble/Analyze/Assemble (D/A/A) activities: Assessing the potential for motivation and transfer, [Dalrymple. 2009]	http://proquest.umi.com/pqdlink?Ver=1&Exp=10-02-2015&FMT=7&DID=2038894311&RQT=309&attempt=1&cfc=1 , and http://docs.lib.purdue.edu/dissertations/AAI3402322/
Gerard Jounghyun Kim	University of Southern California, USA	A thesis proposal: Redesign by Reverse Engineering, [Jounghyun. 1994]	http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.50.8369
Cenkhan,	Massachusetts Institute of	The vulnerability of technical secrets to reverse engineering	http://hdl.handle.net/1721.1/43

Kodak	Technology, USA	: implications for company policy, [Kodak. 2008]	117
Tobias Leek; Andreas Larsson	Högskolan i Jönköping/JTH, Sweden	A reversible engineering process, [Leek & Larsson. 2007]	http://hj.diva-portal.org/smash/record.jsf?pid=diva2:4474
Kang Kang	Pennsylvania State University	Using Product Dissection To Expose Engineering Students To Cultural Issues In Product Design, [Kang. 2011]	https://etda.libraries.psu.edu/paper/12323/7719

Table 9.5 Indicative Dissertations on Educational Reverse Engineering and Associated Topics

9.3.3.3 Peer Reviewed Journals Publishing Reverse Engineering and Related Topics

Table 9.6 Shown here lists peer-reviewed journals where information about academic reverse engineering has been published so far

Journal Name	Associated Home Page	Publisher / Additional Notes
Design Studies	http://www.sciencedirect.com/science/journal/0142694X	Published by Elsevier Ltd.
European Journal of Engineering Education	http://www.informaworld.com/smpp/title~content=t713415994	Published by the Taylor & Francis Group
International Journal of Design	http://www.ijdesign.org/ojs/index.php/IJDesign/index	2nd Tier resource for information on Reverse Engineering because its focus lies mostly on the industrial design side
International Journal of Engineering Education	http://www.ijee.ie/	1st Tier source for educational reverse engineering information
International Journal of Technology and Design Education	http://www.springerlink.com/content/102912/?p=c1806c1170df411c8c94ad788eed6f90&pi=0	Managed by the Springer Science + business Media
Journal of Design Research	http://www.inderscience.com/browse/index.php?journalID=192	Managed by Inderscience Publishers

Journal of Engineering Education	http://www.asee.org/papers-and-publications/publications/jee	Published by the American Society for Engineering Education (ASEE)
Journal of Mechanical Design	http://asmedl.aip.org/dbt/dbt.jsp?KEY=JMDEDB&Volume=129&Issue=7	American Society of Mechanical Engineers 's Journal with information and resources on engineering design education
Research in Engineering Design	http://www.springerlink.com/content/0934-9839	Journal published by Springer-Verlag London Limited

Table 9.6 Academic Journals where Educational Reverse Engineering Papers have been Published

9.3.3.4 Published Book Chapters on the Study of Educational Reverse Engineering

Table 9.7 here lists books where full chapters dealing with the study of educational reverse engineering have been published already and that should be available at the engineering library of most universities.

Name of Book	Author(s)	Associated Homepage	Description / Notes
Engineering Design Graphics: Sketching, Modelling, and Visualization	Leake, James and Borgerson, Jacob	http://www.wiley.com/WileyCDA/WileyTitle/productCd-EHEP002035.html	Chapter 9 is titled " Product Dissection, Reverse Engineering, and Redesign", [Leake & Borgerson. 2012]
Environmentally Conscious Mechanical Design	Myer Kutz, Editor	http://onlinelibrary.wiley.com/book/10.1002/9780470168202	Chapter 4 "Fundamentals and Applications of Reverse Engineering" is devoted to the study of reverse engineering [Kutz. 2007]
Hacking the Cable Modem	Mr. Der Engel, TCNiSO Group	http://shop.oreilly.com/product/9781593271015.do#tab_03	A book explaining how to hack and modify a cable modem, published by No Starch Press [Der Engel. 2006]
Introductory Engineering	Abarca et al. College of	http://itll.colorado.edu/index.php/courses_workshops/g	Chapter 4 of the book is titled "Reverse

Design: A Projects-Based Approach	Engineering and Applied Science, University of Colorado at Boulder, USA	een_1400/resources/textbook/. and http://itll.colorado.edu/images/uploads/courses_workshops/geen1400/textbook/ch04reverse_engineering.pdf	Engineering" and deals with the possibilities of it in education [Abarca et al. 2000]
Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development	Daniel E. Whitney, Massachusetts Institute of technology, USA	http://www.oup.com/us/catalog/general/subject/EngineeringTechnology/MechanicalEngineering/~~/dmlldz11c2EmY2k9OTc4MDE5NTE1NzgyNg==	Chapter 13 of his book " How To Analyze Existing Products in Detail" explains how to take a product apart and figure out how it works, [Whitney. 2004]
Product Design: Techniques in Reverse Engineering and New Product Development	Kevin N. Otto & Krsitin L. Wood	http://cwx.prenhall.com/bookbind/pubbooks/otto_wood/	The primary and most comprehensive reference on educational reverse engineering topics [Otto & Wood. 2001]
Reverse Engineering: Technology of Reinvention	Wego Wang	http://www.crcpress.com/product/isbn/9781439806302	One of the latest available books on the topic, published on September 16, 2010 by CRC Press, [Wang. 2010]
Tupolev - The Man and His Aircraft	Andrei Kandalov & Paul Duffy	http://www.amazon.com/Tupolev-Man-His-Aircraft-Reference/dp/1560918993	A book that includes a description of how the American B-29 bomber was duplicated by the USSR, [Kandalov & Duffy. 1996]
Engineering Design: A Practical Guide	Ogot, Madara and Gül, Kremer.	http://books.google.es/books?id=3YhMmcAuFDAC&printsec=frontcover&hl=es#v=onepage&q&f=false	The book contains a specific section on product dissection located at: Chapter II: The Engineering Design

			Process, Section VIII: Conceptualization I: External Search, Header 8.4: Product Dissection, [Ogot & Gül. 2004]
Reverse Engineering of Rubber Products: Concepts, Tools, and Techniques	Saikat Das Gupta, Rabindra Mukhopadhyay, Krishna C. Baranwal and Anil K. Bhowmick	http://books.google.es/books?id=OaF7AAAAQBAJ&pg=PA289&lpg=PA289&dq=Reverse+Engineering+of+Rubber+Products:+Concepts,+Tools,+and+Techniques&source=bl&ots=7YtSByuh5Q&sig=iLDfqwhHTnX2foV8KbWzq34PN74&hl=es&sa=X&ei=i4EJVNHfBa_bsATMxICIBw&redir_esc=y#v=onepage&q=Reverse%20Engineering%20of%20Rubber%20Products%3A%20Concepts%2C%20Tools%2C%20and%20Techniques&f=false	A book explaining the principles and science behind rubber formulation development by reverse engineering methods by describing the tools and analytical techniques used to discover which materials and processes were used to produce a particular vulcanized rubber compound from a combination of raw rubber, chemicals, and pigments. , [Das Gupta et al. 2013]
Reverse Engineering: Mechanisms, Structures, Systems & Materials.	Messler, Robert W.	http://books.google.es/books?id=op5WAgAAQBAJ&printsec=frontcover&hl=es#v=onepage&q&f=false	A book written for a comprehensive look at reverse engineering as a legitimate learning, design, and troubleshooting tool. [Messler. 2014]
Reverse Engineering	Ingle, Kathryn A.	http://www.amazon.com/Reverse-Engineering-Katheryn-A-Ingle/dp/0070316937	The earliest reference regarding reverse engineering in education, however the book is currently out of print. [Ingle. 1994]

Table 9.7 Indicative Bibliography with Dedicated Chapters Covering Reverse Engineering Activities

9.3.4 Academic Repositories with Information for the Study of Educational Reverse Engineering

9.3.4.1 Digital Search Engines and Databases

Table 9.8 Shown below lists the relevant, electronic databases and search engines where information about EREA can be found

Name	Homepage	Additional notes
American Society for Engineering Education	http://www.asee.org/publications/jee/papers/	A 1st tier source of information on educational reverse engineering, managed by the American Society for Engineering Education
BNET/Resource Library	http://findarticles.com/?tag=untagged	A 2nd tier source where some information on the topic can be found, the website is managed by CBS Interactive
HighBeam	http://www.highbeam.com/Dynamic/Templates/BasicPageTemplate.aspx?pageID=1	A 2nd tier source of information that requires a paid subscription, managed by Cengage Learning.
IEEE Xplore Digital Library	http://ieeexplore.ieee.org/Xplore/dynhome.jsp	A 1st tier source of information on educational reverse engineering, managed by the Institute of Electrical and Electronics Engineers

Table 9.8 Specialized Search Engines and Databases with Articles on Educational Reverse Engineering

9.3.4.2 The ME 240 Course on Product Dissection

Table 9.9 below contains the information needed to access the ME 240 Product Dissection course from Pennsylvania State University in the USA, which is one the best existing resources for the study and practice of educational reverse engineering exercises

Name of the Resource	Associated webpage	Description / Notes
ME 240 - Product Dissection	http://www.mne.psu.edu/simpson/courses/me240/	A highly refined and tested full course on product dissection which includes some freely downloadable material; some of the objectives in this course include the development of the aptitude for engineering and engineering design, and the development of mental visualization skills by examination of the design and manufacture of consumer and industrial products.

Table 9.9 The ME 240 Product Dissection Course by the Pennsylvania State University in the USA

9.3.4.3 The CIBER-U Initiative

The 'Case Studies' section of the CIBER-U initiative listed here in Table 9.10 below offers a top tier source of existing examples of product dissection exercises

Name of the Resource	Associated Webpage	Description / Notes
Reverse Engineering Case Studies	http://gicl.cs.drexel.edu/wiki/Reverse_Engineering_Case_Studies, and http://gicl.cs.drexel.edu/wiki/CIBER-U	A collection of case studies on product dissection exercises from participants of the CIBER-U initiative

Table 9.10 Examples of Product Dissection Exercises by the CIBER-U Initiative

9.3.4.4 Selected Resources that Complement the Study of Educational Reverse Engineering

Table 9.11 below shows complementing resources for those interested in the study and teaching of educational reverse engineering

Name of the Resource	Associated webpage	Description / Notes
Teaching First Year Design by Mechanical Dissection	http://www.engsc.ac.uk/downloads/mechdissesction.pdf or https://www.heacademy.ac.uk/sites/default/files/teachin	The reconstruction of the design rationale behind a component's design has been successfully used already as an aid in the teaching of engineering concepts by authors such as Phil Barker from the

	g-award-teaching-first-year-design.pdf	Heriot Watt University in the UK
Disassembling and Patching Hardware	http://archive.org/details/Bunnie_Disassembling_and_Patching_Hardware	A video lecture by renowned author Andrew Huang from bunnie studios LLC, explaining how to disassemble hardware, and that can be used as an example for the development of instructional reverse engineering materials

Table 9.11 Complementary Resources for the Study of Educational Reverse Engineering

9.3.5 Resources to Support the Study of the Guided Example Presented in Resource 7

The resources listed in Table 9.12 below intend to provide additional materials for the study and understanding of the subject system used in the guided example of Resource 7 in this document

Name of the Resource	Associated Website	Notes
Single-Use Cameras	http://www.mne.psu.edu/simpson/courses/me240/me240.camera.ppt	An online Power Point presentation by author [Simpson. 2009] thoroughly detailing several aspects of disposable cameras including their history; evolution, competitors, recycling features, as well as diagrams of the initial design of disposable cameras
Design for Recyclability: Kodak's Single-Use Camera	http://www.me.psu.edu/lamancusa/ProdDiss/Camera/kodak.htm	Disposable cameras make for a great example of the integration of technologies in a simple to analyse product and plenty of resources for their study exist, this article by author [Van De Moere. 1992] provides information about the design of single use cameras and their recycling, it also helps become acquainted with their design philosophy, and provides professors with ideas on what to ask students to detect in the design of disposable cameras. (students are expected to find this article on their own though, during the Data Collection stage of

		the reverse engineering method suggested in this collection of resources)
KODAK Single Use Camera Recycling	http://www.kodak.com/eknec/PageQuerier.jhtml?pq-path=4213&pq-locale=es_US	In this webpage the Kodak company highlights the success of the recycling program of their single use cameras and states that they have recycled 1.5 billion of them since 1990 and that in fact, their rate of recycling is 84% which is up from 75% just a few years ago and is the highest rate of recycling of any consumer product in the U.S., handily beating the national recycling rates for items such as aluminium cans (52%) and plastic beverage containers (25%). cf. [Eastman Kodak Company. 2013].
Kodak Single Use Cameras	http://store.kodak.com/store/ekconsus/en_US/list/Single_Use_Cameras/categoryID.28889900	Kodak's official page of consumer products which includes the specifications of current disposable cameras
Fujifilm QuickSnap (Single-Use Cameras)	http://www.fujifilm.com/products/film_camera/quicksnap/	Fujifilm's official website for their single use line of cameras with the official specifications of current products found in the market cf. [Fujifilm Corporation. 2013]
Online videoguides at © 2015 YouTube, LLC	http://www.youtube.com/results?search_query=disposable+camera+dissection&oq=disposable+camera+dissection&gs_l=youtube.12...0.0.0.54114.0.0.0.0.0.0.0.0..0.0...0.0...1ac..11.youtube.	By using appropriate search terms such as "Disposable" + "Camera" + "Dissection" a number of videoguides can be found online

Table 9.12 Resources for the Study of the Subject System Used in the Guided Example of Resource 7

9.4 Resource Conclusions

As it can be seen from the resources provided above; relevant information for the study of educational reverse engineering is available, yet it is dispersed across diverse areas of knowledge; in order to build actually usable information from all those sources then, a binding effort that brings together the work from past researchers, and that sets the bridges that allow the exchange and applicability of results from other hands-on approaches into the reverse engineering ones must still continue.

The resources presented in this resource thus, intend to present information from varied perspectives so a comprehensive idea of educational reverse engineering that helps better understand the potentialities of it in education can be achieved. Along the same lines too, it is expected that the resources here, provide the reader with the necessary leads for the eventual creation of new instructional materials that can be better suited to their specific teaching needs.

GLOSSARY

The following is a list of terms used throughout this document next to the definitions best suited to convey the ideas presented herein and that will help the reader to arrive at a shared interpretation of their meaning and context in this document, namely:

- Ability: The power or competence to perform an observable behaviour or an activity that results in an observable product
- Capability: The ability to perform actions
- Competence: A measure of the ability to perform a specific task, action or function successfully, so if capabilities are used with success they become a competence
- Curriculum (Plural: Curricula): A collection of courses
- Engineering Design: The process of devising a system, component, or process to meet desired needs through iterative evaluation and decision-making to end up in specifications and implementations
- EREA: Educational Reverse Engineering Activity (Plural: Activities), a term introduced in this project to describe a kind of hands-on activities that assist in the teaching of engineering design
- Hands-On: It refers to the human interaction with technology that implies an active participation in a direct and practical way
- Instructional materials: The discrete physical components of a curriculum e.g. textbooks, software, kits
- Knowledge: An organized body of information (i.e. Factual or procedural) applied directly to the performance of a function and that can be considered the lowest level of a learning outcome
- Programme: A curriculum taught progressively over the full length of career studies
- Reverse Engineering: An approach to developing an understanding of the functional relationship of components; materials, manufacturing processes, and similar areas of a product, in order to develop a high level description of it, without a priori knowledge.
- Skills: The proficient competence to perform a learned psychomotor act such as a manual, verbal, or mental manipulation of data or things
- Specifications: The technical requirements for systems design.
- Subject System: The result of a development process and usually the object of the reverse engineering analysis. After: [Chikofsky & Cross. 1990]
- Syllabus: The schedule of a course

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Marco L. Calderón

Barcelona, Spain

October 2015

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All links to the resources provided below are valid at the time of issuing of this collection of resources; should web resources go offline or change addresses because of the temporary nature of data published online, several tools exist for the retrieval of old versions of webpages, more information for the interested reader can be found in pages such as "The Internet Archive" at http://archive.org/web/web.php or by selecting the "cached" version of a webpage at the Google search engine's webpage itself at https://support.google.com/websearch/answer/1687222?hl=en&ref_topic=4386094:

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BACK COVER

Educational reverse engineering activities (EREA) are a type of hands-on exercises that, among other documented benefits, bring a suitable solution to the need to provide undergraduate students with real life experiences in the classroom. The goal of this document then, is to increase the university professors' eagerness to give EREA a try, so the engineering design community in specific and the engineering education community in general can count with yet, one more tool to achieve their teaching goals. To attain this, the document in your hands provides beginning and experienced educators alike, with a collection of resources that offers relevant knowledge about educational reverse engineering in a digested and contextualized manner, not only to help the reader understand the benefits of EREA and thus make the most out of them, but also to guide the integration of said activities into their existing teaching practices. Eventually, academic institutions should benefit from exploring new approaches to engineering design education, just as much as students should benefit, from getting access to real life experiences in the safety of an educational environment.