INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
2 & 3 SEPTEMBER 2010, NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY, TRONDHEIM, NORWAY

THE DESIGN RESEARCH METHODOLOGY AS A FRAMEWORK FOR THE DEVELOPMENT OF A TOOL FOR ENGINEERING DESIGN EDUCATION

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ABSTRACT
Some educators believe that engineering design students in these times are less prepared to do well in engineering, since they lack the experience and intuition that develops from "hands-on" activities from adolescent years. At the same time, other educators declare that “To teach and study engineering design can be difficult sometimes, especially when transforming theoretical knowledge into practice” [1], these two arguments can be logically related and support the need to provide high quality hands-on experiences to students. Kolb’s model of learning states that concrete and practical experience can be obtained through product dissection activities [2], also known as D/A/A activities (disassemble, analyze, assemble) or more generally as reverse engineering since these activities help reduce the gap between theory and practice in experimental learning environments. To address this issue the author is developing as part of his doctoral research a guiding manual 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, methodologies, test materials and feedback mechanisms. This project will require the documentation of the theoretical background behind hands-on activities in education and the technical and methodological knowledge needed to conduct reverse engineering exercises so the project’s hypotheses can be tested and the research questions answered. Throughout this paper, the descriptions and definitions from authors Blessing and Chakrabarti’s book on a design research methodology [3] are presented, along with the comments and experiences obtained while using their framework for the conduction of this research project.

Keywords: DRM, engineering design education, reverse engineering, product dissection

1 INTRODUCTION

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 and Chakrabarti called DRM has been chosen as the supporting framework for this research project since its methods are intended to support a more rigorous research approach by helping to plan and implement design research. If used flexibly as the authors suggest, 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 (PS-II), 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 increasing the understanding of design and the factors that influence its success by investigating the phenomenon of design to inform the development of support, where the term support is used to cover the possible means, aids and measures that can be used to improve the current situation and that enable the evaluation of the core contribution of the researcher (a guiding manual for this paper). The PS stage aims at developing support in a systematic way, taking into account the results of DS-I. And finally, the DS-II stage focuses on evaluating the usability and applicability of the actual support and its usefulness.

2 RESEARCH TOPIC

The analysis of existing consumer products referred to as " Reverse Engineering" in this paper, is a means to provide students with hands-on activities during their engineering design studies and is concerned with the attempt to discover the technological and non technological principles of a device, object or system through an analysis of its structure, function and operation, taking it apart and analyzing its workings in detail to try to recapture the abstract and functional specifications envisioned by the original designers during the Product Design Specification (PDS) stage. A major goal of it is to help students of an engineering design curriculum to understand and compare against their own conclusions the design rationale and trade-offs the original designers faced to go from multiple solutions to the solution boundaries embedded in a final product as a way to asses a product's fulfilment of customer requirements and its eventual market success or failure. Reverse engineering activities in an engineering design education context thus should be considered a derivative modern effort that is pedagogically oriented and benefits from modern media technologies not available before to provide engineering design students with practical hands-on experiences that help them understand and catch up with the ever changing design and manufacturing technologies relevant to an engineering design curriculum.

3 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:

1. "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" [4]
2. "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" [5]
3. "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" [6]

A clear definition of engineering design education helps position the educational nature of this research project and clarifies its areas of expected contribution.

3.1 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 several authors. E.g. Archer [7] identified "Design pedagogy" as one of the ten fields of design science.

Table 1. Archer's ten fields of design

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

Education and a pedagogy for the teaching of engineering design 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 "[8], Additionally, Fulcher and Hills considered research and education as part of the "third primary cluster" in their descriptive taxonomy of design research topics [9]. but it is perhaps in Horváth's order of engineering design research where the design education domain is more clearly seen, 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, it forms a hierarchical structure which under the context of purpose delimits the fields of knowledge and the areas of attention in research, it includes source, channel and sink categories of knowledge and research of engineering design, where in every

category, research domains, trajectories, and approaches are identified along with the semantic relationships of domains, trajectories and approaches. The research in the domain of design education decomposes to the study of design teaching and learning processes, methods, and tools, development and experience with various design learning programs and exercising product design and realization by co-located or dislocated collaborative groups. This determines that the results from this paper fall mostly into the design education area leaving the decidedly technical aspects of the reverse engineering activities under study in this project in a low profile since the primary focus of this paper is to present the rational that led to this project and how the results can be implemented by interested engineering design professors.

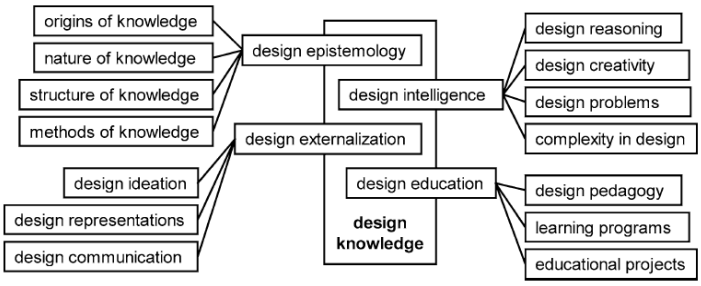

Figure 1. Research in design knowledge [10]

4 OBJECTIVES AND BENEFITS OF USING DRM

Design is a complex multidisciplinary activity and DRM (a Design Research Methodology) is used as the supporting framework for this research project as it aims to provide a set of supporting methods and guidelines to be used as a framework for doing design research and it suits a variety of fields usually found in research projects. The two overall objectives of design research are formulating and validating models and theories about the phenomenon of design as well as developing and validating knowledge, methods and tools founded on these models and theories with the aim to improve design. The specific objectives of the DRM methodology are:

- 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.

4.1 Research project goal

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 considering specific learning objectives, fundamentals, methodologies, tools, test materials and feedback mechanisms, easing the learning curve for the preparation, execution and evaluation tasks by reducing knowledge gaps, unwanted complexity and unnecessary steps.

5 DELIVERABLES FOLLOWING THE METHODOLOGICAL FRAMEWORK

DRM consists of four stages: Research Clarification, DS I, Prescriptive Study (PS) and Descriptive Study II the next figure shows the links between these stages, the basic means used in each stage and the main outcomes. The bold arrows between the stages illustrate the main process flow, the light arrows the many iterations.

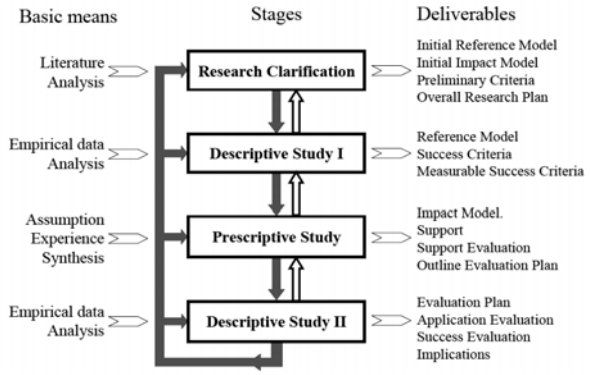

Figure 2. DRM Framework: Stages, basic means and deliverables [11]

As shown in figure 2 the DRM Framework sets deliverables for every stage, the collection and organization of the information leading to the deliverables themselves are presented here in graphical and tabular form and constitute the results themselves for this paper.

6 PRELIMINARY RESULTS

6.1 Reference model

The Design Research Methodology (DRM) requires the visualization of the current existing conditions to better analyse the situation and come up with a suggested support tool that can improve the situation. At this initial stage and according to experience; assumptions, literature search and own studies it has been identified that the ultimate success criteria for this research project is a high level of integration of a reverse engineering pedagogy in engineering design education, but measurable success criteria that can be identified and analysed in this research project will focus on the engineering design professor's level of eagerness to include reverse engineering activities in their curriculum and the level of favourable perception of these reverse engineering activities, where the key factor to be addressed through the support tool (the guiding manual) is the level of awareness of engineering design professor about the existence of pedagogies involving reverse engineering as a tool to teach engineering design. The left side of figure 5 graphically shows the current understanding of the research problem through a network of influencing factors and the relationships between them.

6.2 Research Questions

The research questions that initially sparked the interest in this project are shown on the left side of figure 3 and they address the concerns expressed by potential adopters of reverse engineering activities in exploratory discussion previously held before the beginning of this project.

6.3 Hypotheses

The right side of figure 3 shows the hypotheses the project aims to test which will help to evaluate if the proposed solution is indeed suitable for the problem detected.

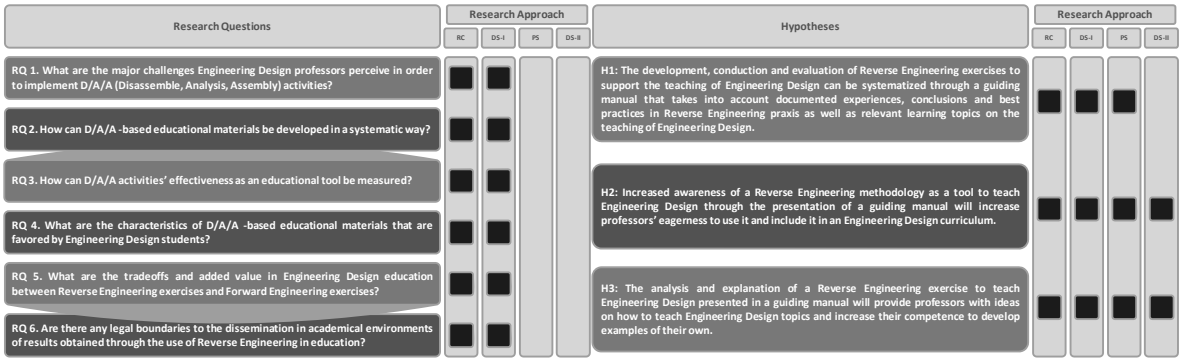

Figure 3. Research questions and hypothesis against impacted stages

From figure 3 it can be seen that every step of the DRM methodology is comprised of different studies and deliverables and not all of them might be required for all the questions and hypotheses. The

research questions for example are considered only for the first two stages of the DRM methodology, this means that once the research questions have been fully understood and documented, the results obtained will be used for the development of the support tool. The three hypotheses will be studied one and two stages further and the support tool will be developed up to the DS-II stage as can be seen for the second and third hypotheses.

6.4 Areas of Relevance and Contribution 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 4 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 useful for the execution and completion of this project.

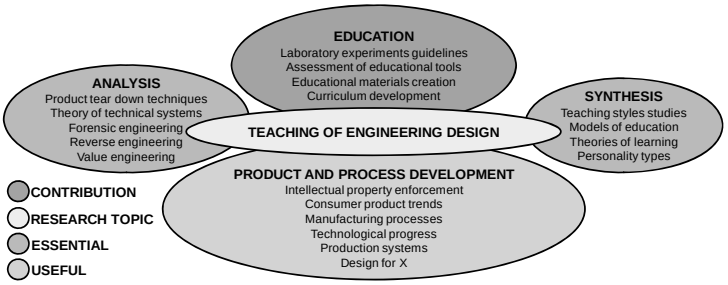

Figure 4. Diagram of areas of relevance and contribution

6.5 Impact Model

The right side of figure 5 shows the "Impact Model" deliverable which is a visual description of the desired final situation showing the expected changes to the "Reference Model" after the introduction of the support tool symbolized by the hexagon at the lower end of the picture, in this particular example after the support tool (the guiding manual) is introduced it is expected that the engineering design professors' favourable perception of reverse engineering activities will increase as well as its eagerness to include these type of activities in their teaching curricula according to their advancement into any of the five stages of teacher technology adoption described at the "Measurable Success Criteria" level which under-scores the idea that understanding and using technology well takes time [12], the impact model also considers how other external factors could also hinder the introduction of reverse engineering activities but may 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.

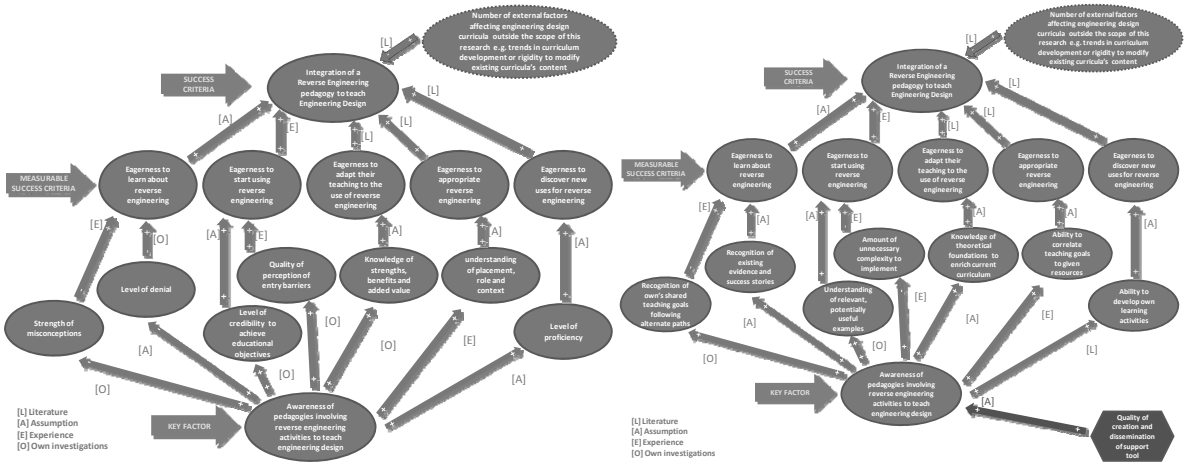

Figure 5. Reference model (existing situation) and impact model (desired situation)

7 CONCLUSIONS

This is an ongoing project with an estimated progress of 70 percent and the preliminary results are mostly linked to the foundational knowledge needed to start and understand the project itself. The next stage of the project considers the completion of the support tool which will integrate all the features mentioned before, this guiding manual will be distributed to professors who have expressed their interest in the project. And the hypothesis will be tested through the Kirkpatrick model on the professors' intention to integrate reverse engineering exercises in their teaching curricula. It is expected to complete the whole research project no later than December 2010. Research in the area of engineering design education carries a number of challenges since the integration of the technical knowledge inherent to the topic of study itself needs to be placed in the context of education and the varied fields it contains such cognitive psychology and educational strategies, however, the stepwise approach and the need to provide specific deliverables for every step of the DRM methodology helps achieve a solid ground since the beginning of the project where the ongoing work can always be referred back to the previous stages as one advances in the development of the research, while no approach can guarantee perfect results from any given project, the use of a methodology that emphasizes the documentation and scholar treatment of all of its stages helps come up with a higher change of scientifically valid results, as the DRM methodology becomes more popular among the scientific community new approaches and experiences will help enrich the understanding of the methodology itself in praxis and the transitions among its different stages, at the end of this project the use of the DRM methodology has provided a solid foundation not only for the execution of the research project but also for the clear dissemination of results and presentation of evidence with a scholarly approach.

ACKNOWLEDGEMENTS

This paper is possible thanks to the guidance and support from professors Blessing L., Andreasen M. and Weber C. of the European Summer School on Engineering Design Research, where I had the opportunity to learn first-hand about this methodology.

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