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MODELS, METHODOLOGY AND FINDING FOCUS: DEALING WITH THE CHALLENGES OF PhD RESEARCH

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1. Introduction

For the past thirteen years, a summer school has been organised annually for research students of engineering design [Andreasen and Blessing, 2003]. This paper discusses the summer school from a student perspective. In particular, course materials concerning the use of models and methodology to guide the student are reviewed, based on our experiences as summer school participants.
The course is organised by Prof. Dr.-Ing. Lucienne Blessing, Prof. Mogens Andreasen, Prof. Dorian Marjanovic, Dr. Ralf-Stefan Lossack and Prof. Dr.-Ing. Christian Weber. The main purpose is creating strong researchers by providing insight into design theories, an overview of design research methods, discussions and commentary on research topics and an opportunity to establish new collaborations [Andreasen, 2002].
The course is not intended to act as an alternative to effective supervision but rather as a supplementary aid to students. Indeed, the survival of the course, since 1990, is evidence of supervisor satisfaction. The training provided by the course, especially in the area of methodology, is beyond the scope of most, if not all, research groups. The need for such training is demonstrated by the poor quality of some research papers from a methodology viewpoint. In addition, many engineering design research students have little experience of engineering, design or research. The training obtained at summer school goes some towards addressing this issue. It also helps to establish a commonality of views across the field.
Summer school is aimed at PhD students who have completed 30-40% of their planned research duration. It consists of two parts, each lasting one week and separated by a two-month interval. Core activities include presentations, group exercises, model building and lectures as described below. Further information on the course is available at [Andreasen and Blessing, 2003, Andreasen, 2002].

1.1 Course activities

As preparation for the first week, twenty students put together a five-minute presentation of their research topics, objectives and outline plans. The instructors critiqued these presentations, providing useful suggestions about feasibility, practicality, relevance to industry and the need to focus on a specific problem. Questions such as *what do we know about designing*? And *what is actually influenced by our design?* were discussed.
Students were asked to develop 'bubble' and reference models (as discussed in Section 3) showing the scope of their proposed research projects and to identify their social and scientific goals. The models also facilitated the presentation of the PhD topics and encouraged discussion. Further, the models were used to build up and consolidate research goals, research questions and hypotheses and to identify

overlaps with other search fields. Finally, the necessity of focusing on a specific research topic and identifying the industrial relevance of the research was illustrated by the models.
As part of a group exercise, the participants designed a game intended to illustrate the nature of engineering design. This inspired questions such as *what do we know about design research?* and *where do we get insights about design research?* Students were asked to formulate research questions during a second group exercise based on a video description of a design process. The exercises helped participants to exchange and develop ideas and identify common problems. During these exercises, and in the following discussions, the difficulties of PhD research were brought to light. Among the key concerns were time constraints and problems in formulating research questions.
Following a two-month interval, in which the participants reviewed the material distributed in the first part of the course, the students presented posters describing their research. The posters contained an *impact model* showing the contribution of the research to the design community. The instructors critically assessed the posters, commenting on issues that required attention. The posters were also criticised and discussed by the other students regarding content and presentation. The content of the posters and presentations, as well as the comments made by the instructors, were analysed with a view towards identifying problems and clarifying the focus.
Pairs of students were asked to build up a research plan. These plans were presented and critically discussed by the teachers and students. Students tried to answer questions such as *why is your research scientific*? or *how do you make sure that you reach the desired results?* The preparation of the research plan, and discussions aimed at answering these questions, supported the formulation of appropriate research goals and hypotheses and outlined a path to the expected results.

1.2 Lectures

Lectures in the first week concerned design models and design theories [Andreasen and Hein, 2002, Lossack, 2002, Blessing, 2003, Marjanovic, 2003], as such information is indispensable when establishing a suitable foundation for research work. Also theories of other domains, such as information processing, human computer interaction, social behaviour theories, communication theories, cognition, learning, ergonomics, systems theory etc. were presented. The lectures also contained much information about design in general and relevant case studies. Other lecture topics were the design process and the structure of technical systems. During the lectures and in the associated discussions, much information was exchanged between instructors and students and among students. This information concerned the design community, relevant conferences and journals, the evolution of design research, domains in design and existing literature, and was highly beneficial. Lectures in the second part of the course concerned design theories and computer support [Weber, 2003], models and design research methodology [Blessing and Chakrabarti, 2002] and computer support and the transfer of academic work to industry.
Interruptions occurred frequently during lectures with a view to obtaining clarification or challenging a particular view-point. Such interruptions often came from the instructors. In many respects, this was reassuring - it reinforced the view that research in design is a complex area and that there is still a lot of work to be done. There is a danger that students may come away from such courses with an arrogant view that they know everything relevant to design. The teaching approach adopted strived to avoid this problem.

2. Challenges of PhD Research in Design

During the course, it became apparent that many PhD research challenges were common to most students. One major challenge is focusing research on a topic that is relevant to industry and realistic within the constraints imposed by a PhD project. Related to this challenge is the issue of structuring the research project using an appropriate research methodology [Blessing and Chakrabarti, 2002] and managing the time frame. We contend that practical experience in either design or research is uncommon among students and that this lack of experience contributes to the above problem.
Finding practical success criteria and measuring the impact of a project on industry is also non-trivial due to the sheer range of factors which influence engineering designs. Complexity and context

dependency, for example, pose significant challenges in such diverse areas as product platform design, data-interchange, communication and education. In some senses, research challenges are more closely related to the social sciences than to engineering. Many design researchers have an engineering background and are unfamiliar with this territory.
Poorly defined terminology [Blessing, 2003] and the different meanings of terms in different languages cause an additional problem. Further difficulties appear when formulating and validating models and theories. These problems are due partially to the fact that design is a new discipline and a widespread research methodology has not yet become established.

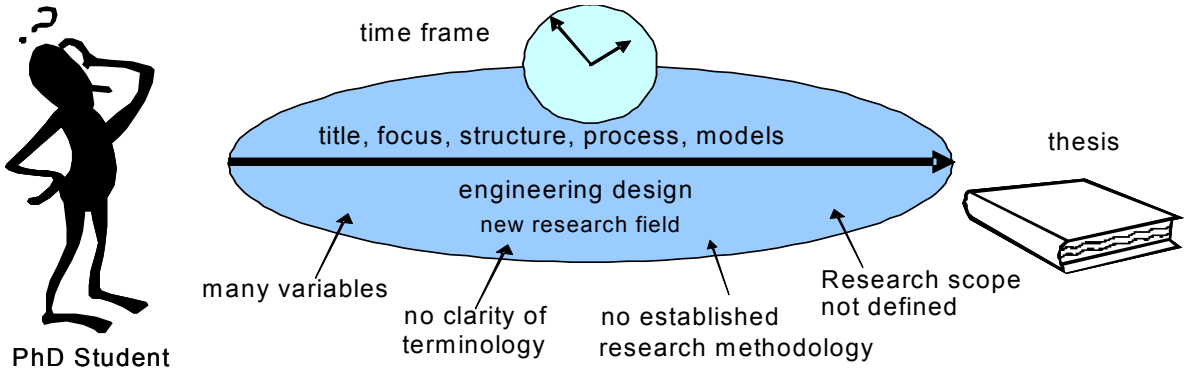

Figure 1. Challenges of PhD research

The challenges, presented in Fig. 1, were common to many summer school students and were addressed during the course. Other issues, specific to the structure of the PhD program or strongly linked to a particular research topic, are not considered here. Further, the difficulty of finding a suitable focus may not cause problems for all students, depending on the balance of freedom between the student and his/her supervisor and the source of project funding. The dangers of premature focus are also noteworthy. Failure to sufficiently explore a research area could cause students to become fixated on an irrelevant problem.
The instructors of summer school tried to support the students using a teaching approach which includes models, design theory, research methodology and general training in engineering design. They also considered the adoption and application of models and research methodology to realistic design scenarios. The instructors also provided an overview of relevant literature on engineering design. This enabled us, as students, to obtain a background understanding of a broad range of topics but also identified publications specific to each field, which in turn could be investigated further.

3. Support Mechanisms

Summer school provided several support mechanisms to address the issues described in Section 2. Our views on the usefulness of these techniques are described below. We believe that these views are a fair representation of course participants based on the feedback comments and informal discussions.

3.1 Models

The bubble model is essentially a mind-map with the core research theme at the centre surrounded by other research areas which are strongly related to the core topic. A simplified bubble model, based on a PhD in communication support, is shown in Fig. 2. Despite the simplicity of the model, it clearly illustrated the intended scope of the PhD project. It also sparked discussions on the size and maturity of different research fields and enabled students to identify dependencies on research fields which also belong to, or border on, their research topic. In many cases, it shows that the project scope is extremely broad and ambitious for the approved time-frame. Thus, the model-building process increased focus and illuminated problems.

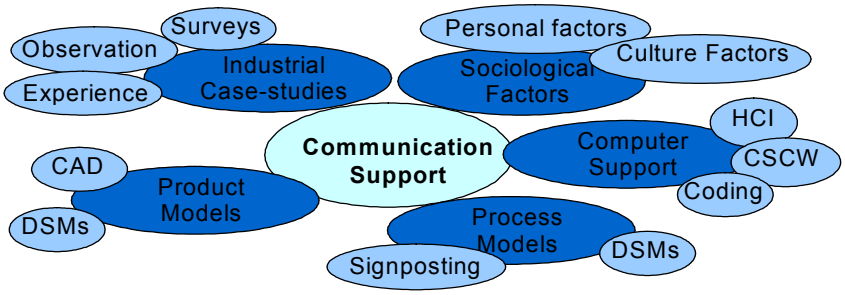

Figure 2. Bubble Model

The bubble model also helps when structuring and representing research and when explain this research to others. It captures the cause-effect relationship between the student's researches and helps him/her obtain a better understanding of logical connections between different aspects of their own research. Hence, the model helps students understand and formulate their research topics and to identify key issues.

In addition to the bubble model, reference and impact models were also used to identify the industrial value of a given PhD project, by showing the connection between successful project outcome and enhanced industrial performance. The core value of these models is that they cause students to (re)consider the questions *is my research useful?* and, if so, *how is it useful?* This, in turn, helps students to re-evaluate their work and to identify simple changes which can improve their research.

3.2 Research methodology

The Design Research Methodology (DRM) proposed by Blessing and Chakrabarti, (Fig. 3) formed the backbone of the course. The lectures and associated discussions on methodology are aimed at helping students to methodically structure their research into key phases consisting of success-criteria establishment, prescriptive and descriptive studies. This, in turn, highlights the time-constraints relevant for each phase and thus the importance of time-management in completing the project on schedule. The lectures provided the students with a much wider view of the scope and interpretation of the DRM methodology than can be obtained from literature.

The methodology caters for a wide range of different types of research by allowing the researcher to determine which phases are given the most attention and indeed how many of the research phases are covered throughout the research project. However, the establishment of success criteria, which focuses attention on the problem of measurement, is obligatory. In addition to establishing suitable success criteria, deriving measurable criteria from the success criteria is a complex task. Several students proposed changes to planned investigations in order to deal specifically with this issue.

The lectures on methodology and the exercise of building up a research plan, complete with hypothesis and research questions, aim students to learn working scientifically. Besides learning how to formulate a hypothesis, the meaning and function of the hypothesis is also stressed during the course. This enables the students to discuss critically different research hypotheses.

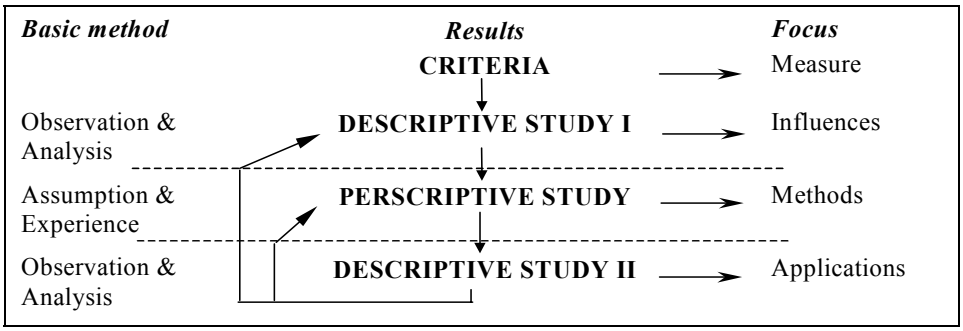

Figure 3. The DRM Design Research Methodology [Blessing et al. 2003]

3.3 General Observations

Several observations of the summer school did not fit directly into the categories of models or methodology. These are discussed in the following section and concern the discussions, theoretical foundation, overview and teaching approach.

3.3.1 Discussions

Students had the chance to discuss their research topics in-depth with the course instructors. In [Andreasen, 2002], it is noted that advice from the course leaders may conflict with advice from supervisors but that such conflicts have not been reported. We are also unaware of any such conflicts. However, we note that opportunities for intense discussions, concerning a PhD topic, with highly respected academics are rare, and contend that the value of such conversations strongly outweighs any potential drawbacks.

Complementary to student-instructor discussions were the discussions that took place between students with similar research interests. As a result, we learned how to critically assess research and to defend criticism. Further, the opportunity to present and discuss research in English was beneficial for those with a different mother tongue. The discussion aspects of the course were useful from a networking point of view and have led to new collaborations (such as writing this paper).

3.3.2 Theoretical foundation

Lectures on both design and design theories and methods were also helpful. A good understanding of these issues is useful when trying to develop a solid foundation and adapt an appropriate strategy for research. Such understanding also helps relate a specific topic to the more fundamental concepts of design, to differentiate between main and sub problems and to identify key opportunities for further investigation. As a result, a strong theoretical background helps students become more self-confident about research topics and about the manner in which to proceed with projects.

3.3.3 Overview

During summer school, students got a broader overview of research areas in engineering design through discussions about each other's projects. The different areas covered included product innovation strategies, product platform assessment, automatic assembly processes, specification driven design, communication support, distributed collaborative design, context dependency of design, functional product design, industrial acceptance of design methods, design as a social process, learning theories and design education, requirement elicitation and clarification, target costing, environmentally conscientious design, product information sharing, strategic product design in SMEs, packaging and design of mechatronic products. We became aware of the key research problems within the different areas and the current approaches to tackling these problems, as well as the leading academics working in each field. The course also provided us with insights into links between our own research and other topics which initially appeared unconnected.

The overall contribution of the summer school is shown graphically in Fig. 4.

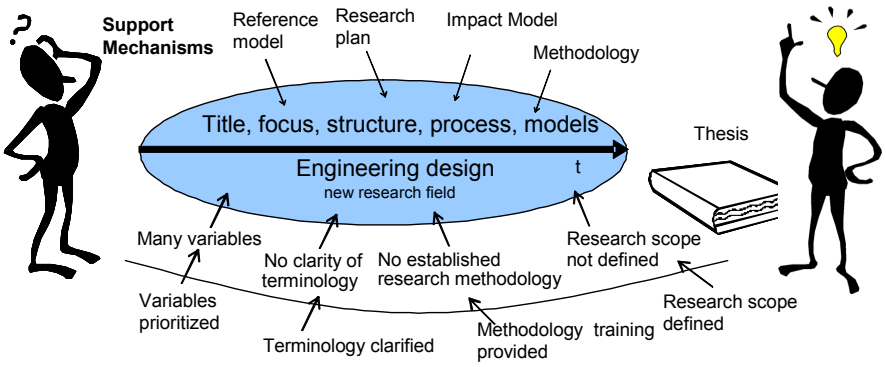

Figure 4. Support Mechanisms

4. Conclusions

The summer school on engineering design research helped us, as students, to identify key research questions and to focus our research topics through the use of models, methodology, design theory and group exercises. Based on discussions with other course participants, it became apparent that many students of engineering design encounter similar challenges during their research. One common difficulty is focusing on a topic which was realistic for the proposed time-frame. Other challenges include establishing suitable success criteria and defining appropriate metrics to measure success.

We cannot claim that these challenges were completely solved for every student during summer school. However, the course provided support techniques and methods that are invaluable in dealing with these issues and establishing a clear focus. The use of bubble, reference and impact models to clarify the scope and industrial contribution of the research, as well as the design research methodology to structure and plan the PhD thesis, formed the core of the course materials. Lectures on design theory, advice from course leaders and the overview gained from general discussions were also invaluable.

All in all, Summer School was an excellent experience. It provided several insights into the complex discipline of research in engineering design within an environment conducive to learning. We firmly believe that the course will strongly influence and improve our own research and that of the other students over the coming years.

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Course leaders

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