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ASSESSMENT OF DESIGN COMPETENCIES BY A FIVE LEVEL MODEL OF EXPERTISE

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ABSTRACT
In recent years, enabling competencies has become more and more relevant in design education and design practice. Various problem-orientated and project-based learning approaches allow students to develop their key competencies. However, difficulties in assessing these compentencies are rarely discussed. This paper presents a case study that analyses the appropriateness of a five level model of expertise to assess design competencies. The study includes a combination of document analysis and open interviews with undergraduate mechanical engineering students. The document analysis is based on engineering detail drawings that were designed by students within their exam on mechanical design. The following aspects of expertise are analyzed: (1) treatment of knowledge (without reference to context or in context), (2) recognition of relevance (not present or present), (3) assessment of context (analytic or holistic) and (4) making of decision (rational or intuitive). By application of this evaluation scheme central results of the study are presented and discussed.

Keywords: Assessment, competencies, expertise, experience

1 INTRODUCTION

Nowadays products and processes are changing constantly. The consideration of stakeholder needs and technological progress, of life cycle management and interdisciplinary project work entails that modern product development processes are highly cross-linked socio-technical systems. This increasing complexity generates new challenges for design engineers developing processes and products. In consequence, there are high expectations on design education. Aside from factual knowledge and basic qualifications, professional experience is highly ranked among labour markets. The present challenge of design education is to put educational approaches into practice that both enable the required competencies and support the efficient assessment of these competencies.

The case study presented in this paper analyses the appropriateness of a five level model of expertise to assess design competencies. The applied model goes back on the brothers Stuart and Hubert Dreyfus and their research works in the field of artificial intelligence [1, 2]. The Dreyfus Model differentiates between novices, advanced beginners, competent, proficient and experts. These levels of expertise are assigned to an evaluation schema considering four central aspects of expertise [3]: (1) treatment of knowledge (without reference to context or in context), (2) recognition of relevance (not present or present), (3) assessment of context (analytic or holistic) and (4) making of decision (rational or intuitive). In order to evaluate the appropriateness of the Dreyfus Model to assess design competencies in engineering design, a combination of document analysis and open interviews with mechanical engineering students is applied. In addition further aspects regarding the way design experience is gained are considered.

The paper proceeds as follows. Section 2 gives a brief overview of the concept of competence and different approaches of its assessment. Section 3 points out the differences between novice and expert performance in design. Furthermore the Dreyfus Model is introduced. In section 4 the research objects and research methods are presented. The results of the case study are presented and discussed in section 5. In this context an adapted evaluation scheme is introduced. Section 6 concludes.

2 CLASSIFICATION OF COMPETENCIES

2.1 Concept of Competence

The concept of competence is essential in design education. Within the education research community, there are various definitions of competence, addressing different point of views. Rychen and Salganik [4] avoid defining a one-sentence definition of competence, but reflect the concept in a multidimensional way. In order to characterize competencies, they identified the following dimensions:

- Recognizing and analyzing patterns, establishing analogies between experienced situations and new ones (coping with complexity).
- Perceiving situations, discriminating between relevant and irrelevant features (perceptive dimension).
- Choosing appropriate means in order to reach given ends, appreciating various possibilities offered, making judgments and applying them (normative dimension).
- Developing social-orientation, trusting other people, listening and understanding others' positions (cooperative dimension).
- Making sense of what happens in life to oneself and others, seeing and describing the world and one's real and desirable place in it (narrative dimension).

In recent years, enabling of competencies has become more and more relevant [5]. New educational approaches have been successfully established. Nowadays, various problem-orientated and project-based learing approaches seek to allow students developing their competencies in all dimensions presented above. However, difficulties appearing in assessment of these compentencies are rarely discussed.

2.2 Assessment of Competencies

Gray [6] proposes that effective learning assessment has to focus on the intended outcomes for students, that is, the knowledge, skills and attitudes that students are expected to master as a result of their educational experiences.

Design education assessment is often aligned to Bloom's Taxonomy [7], which represents six levels of educational objectives in form of a cumulative hierarchy (cp. Figure 1). Nevertheless there are several modern approaches reflecting the assessment of competencies in the context of factual, conceptual, procedural and metacognitive knowledge [8] as well as in the context of cognition, observation and interpretation [9]. Based on these approaches, actual research projects consider the development of suitable methods and techniques for the assessment of competencies. Recent results are technology-based assessment (TBA) or computer-adaptive testing (CAT) [10].

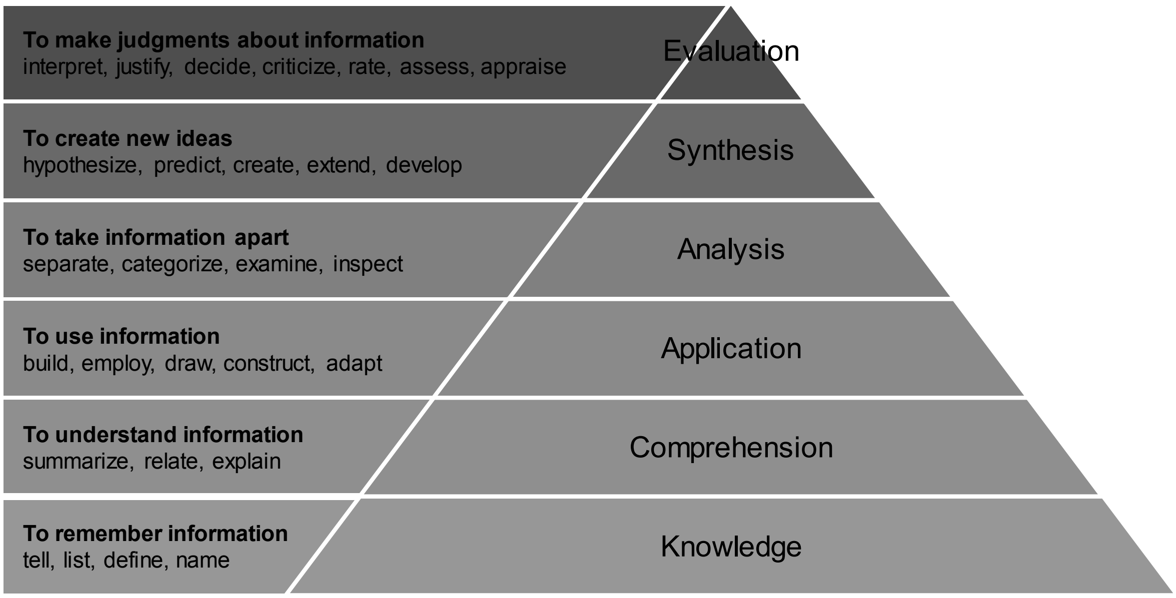

Figure 1. Bloom's Taxonomy (cp. [5])

3 CLASSIFICATION OF EXPERIENCE AND EXPERTISE

3.1 Novices and experts in design

Cross [11] describes that education is not only about the development of knowledge, but also about developing ways of thinking and acting. He further explains that education in design has well-established practices that are assumed to help the progression from a novice learner to an expert performer, but also that there is still rather limited understanding of the differences between novice an expert performance in design and how to help students move from one to the other.

Several studies analyzed the differences between how novice and experienced designers approach design tasks (cp. [12]). A selection of current results entails:

- Short-term memory is limited by the number of chunks; experienced designers are able to recall more information than inexperienced ones.
- Novice designers tend to reason backwards and to use a deductive approach. Experienced designers tend to reason forwards and to alternate between forward and backward reasoning. Thus they can solve more complex problems.
- Studies with experienced and novice designers show that cognitive activity and productivity of the expert is nearly three times higher than that of the novice designer.
- Novice designer are often uncertain about their own decisions. This may explain, why they often need to evaluate, what they do (trial and error).
- Novice designer spend time to understand how the design functions and they express difficulty in the task they undertake as they had not done it before.
- Experienced designers consider issues and context of the current design task; they are aware of reasons or limitations, often refer to past designs and make intuitive decisions.

The listed aspects show that experienced designers possess qualitatively and quantitatively more skills and competencies than novice designer. These insights systematically support the development of future design education and especially improve the assessment of competencies. In this context the strict separation in novice and expert designer seems to be insufficient. In order to support the process of students becoming more experienced, a multi-level approach is required.

3.2 Dreyfus Model: levels of expertise

In the 1970s the brothers Stuart and Hubert Dreyfus started their research on how people attain skills. They proposed a model of skill acquisition that includes five levels of expertise: novice, advanced beginner, competent, proficient and expert [1, 2]. According to Dorst and Reymen [12] the Dreyfus model contains five levels, providing a basis to analyze the way design is learned in theory and practice:

Novices have little or no previous experience in the skill area. They simply follow strict rules and do not feel responsible for outcomes. Novices tend to see actions in isolation, thus they need close supervision or instruction.

Advanced beginners have already experienced similar problem situations. Thus, they are able to develop certain sensitivity to exceptions of strict rules. Advanced beginners see actions as a series of steps. In consequence they are able to apply guidelines, but they do not recognize the relevance of their work, i.e. all attributes and aspect are treated separately and given equal importance.

Competent persons gained considerable experience actually coping with real situations in which they note recurrent meaningful component patterns. Thus, they are able to select the relevant elements of a situation and choose a plan to achieve their objectives. Problem solving at this level involves the seeking of opportunities, and of building up expectations.

Proficient persons are characterized by a deep understanding of the discipline or the area of practice. They see situations holistically. In consequence they are able to identify the most important aspects of a problem situation. Proficient persons consider deviations from normal pattern and they are able to deal with them in a responsible way.

Experts respond to specific situation intuitively and perform the appropriate action, straightaway. Due to their deep tacit understanding across the area of practice they are able to take responsibility for going beyond existing standards and creating own interpretations. Experts achieve excellence results with relative ease.

4 CASE STUDY

4.1 Research Environment

The case study presented in this paper has been accomplished within the 2011/12 mechanical engineering course of Karlsruhe Education Model for Product Development (KaLeP) [5] the course of mechanical design is based on lecture, tutorial and project work. The mechanical design course is mandatory for mechanical engineering students. Currently the course is attended by more than 1500 students. Despite this number of participants, project work was introduced and observed as a successful means to enable students not only to develop competence regarding mechanical elements but also to learn how to cooperate and to coordinate in a design team. The lecture focuses on theoretical contents, while tutorials concentrate on application of the given theory in specific cases. For the project work, students form teams of five members in order to fulfil a small, but complex design task with project character. This accompanying design project is coached by faculty stuff and student helpers. Students receive individual feedback regarding performance and competence development to be able to evaluate their state within their own learning process. After four semesters the students have to pass a two-part exam: (1) a theoretical part over two hours, which includes theoretical exercises and (2) a practical part over three hours, which includes a creative engineering design task considering an engineering detail drawing in DIN A1 format. The design task contains a schematic diagram and a list of requirements. Object of the research presented in this paper is a selection of students that successfully passed the exam. The student's engineering detail drawings supports the research on the assessment of their competencies.

4.2 Research Method

The research method used in this work is a combination of document analysis and open interviews with the concerned students. Benefits of this method combination are that researchers do not influence the data collection with their presence and that all participants have the same conditions for this test. Before the interviews, the students do not know that they participate in this study.

After the exam, the engineering detail drawings are analyzed and evaluated regarding specific aspects of design competencies. In a next step a representative selection of drawings is made and the corresponding students are invited and interviewed. The semi-structured interview considers specific questions and allows the student to answer extensively. Based on the interviews the students' expertise is rated according to the Dreyfus Model.

The interpretation of the answers is supported by an evaluation scheme adapted from the Dreyfus Model (cp. [3]). In addition to the regular evaluation criteria of the student's drawing the following four aspects are analyzed: (1) treatment of knowledge (without reference to context or in context), (2) recognition of relevance (not present or present), (3) assessment of context (analytic or holistic) and (4) making of decision (rational or intuitive).

The primary research question considers the appropriateness of the Dreyfus Model to assess design competencies. Amongst others, central interview questions are:

- Explain the used bearing/lubrication design in your drawing.
- Explain the reasons, why you choose this type of bearing/lubrication.
- Do you think there are better solutions to design the bearing/lubrication?
- Which design aspects should be considered in general, if you have to design bearing/lubrication?

Secondary research questions consider the way of how design experience is gained and which persons participate in this process. Furthermore a self-assessment is requested.

- Where did you get this idea from? From the professor in the lecture, from the responsible PhD student in the tutorial, from the supervising PhD student in the workshops, from master students or other sources like internet or fellow students?
- Who did you ask, if you have a specific question to a design problem?
- Do you trust certain persons more than others, if the design experience of others is needed?
- From whom have you learned the most design experience?
- Estimate your experience level with designing bearing and lubrication on a scale of 1 to 5 (1 = I have no idea, 5 = I am an expert)?

5 RESULTS

5.1 Primary Results

Within the scope of the case study the Dreyfus Models have been successfully applied to support the assessment of design competencies. The model helped to reveal the student's individual motives, which led to the design solution represented by the engineering drawing. In the interviews the students explained and justified their motives by application of their competencies. In this context the following evaluation scheme was used to analyze the interviews (cp. table 1). It decisively supported the classification into the five levels of expertise.

Table 1. Adapted evaluation scheme

<table>
<tr><th>Level of design expertise</th><th>How design knowledge is disposed?</th><th>Detection of the relevance for the design task?</th><th>How design problems are solved?</th><th>How decisions are made, when designing?</th></tr>
<tr><td>Novice</td><td>Without context</td><td rowspan="2">None</td><td rowspan="3">Analytically</td><td rowspan="4">Rational</td></tr>
<tr><td>Advanced beginner</td><td rowspan="4">In context</td></tr>
<tr><td>Competent</td><td rowspan="3">Present</td></tr>
<tr><td>Proficient</td><td rowspan="2">Holistically</td></tr>
<tr><td>Expert</td><td>Intuitive</td></tr>
</table>

In the following the application of evaluation scheme is briefly presented and illustrated by examples of the case study.

- How design knowledge is disposed? All interviewed students gained design knowledge, but novices are not able to apply their knowledge in a specific context. An example: All interviewed students have known that lubrication can be generally realized by oil or by grease. In contrast to more experienced student, novice students could not explain, in which cases they have to use oil lubrication and in which cases they have to use grease lubrication.
- Can the relevance for a specific design task be detected? Giving a specific design task, novices and advanced beginners could not estimate the relevance of their design. Thus, it is important to teach them rules. An example: Some interviewees answered that their design only includes a certain type of lubrication because they always used this type in the project work, where it has always been a right solution.
- How design problems are solved? Most interviewees solved the given design task analytically, i.e. they design the mechanical elements e.g. shafts, housing and bearings independently from each other. However, proficient designers and experts should be able to adjust all sub-designs in order to achieve an optimal result. They are able to solve design problems holistically.
- How decisions are made, when designing? Except experts all designers consciously think about their actions and their decision when designing. Due to their experience experts are able to make decision intuitively, i.e. based on their emotions rather than on facts or evidence. As expected none of the interviewed students has been classified as an expert.

5.2 Secondary Results

In the case that students had specific questions to a design problem, they asked a supervisor master student (40%) or a supervisor PhD student (40%); 20% of the interviewee answered that it makes no difference, who they ask, because they always test the answers for plausibility. When design experience of other persons is needed, all students refer to people they know personally; almost half of them have fear of asking silly questions. 64% gained a lot of design experience in the project work; 18% gained experience in the lecture and 18% gained experience in personal environment (e.g. through autonomous studies). Students assigned to the lower levels of expertise made a good estimation of the own level. All students assigned to higher levels of expertise have not been aware of it.

6 CONCLUSION

This paper introduced an educational approach for assessment of design competencies by a five level model of expertise. The theoretical background of the concept of competencies and their assessment in mechanical design education are introduced. The differences between how novice and experienced designers have been illustrated. A five level model of expertise, the so called Dreyfus model of skill acquisition has been explained. Within a case study this model has been used to assess design competencies by mechanical engineering students.

The case study results that the Dreyfus model is appropriate to support the assessment of design competencies. The evaluation scheme of the model must be adapted to the context of product development. Regarding aspects of experience transfer it was found that students gained experience by different sources from their environment (lectures, tutors, fellow students, internet, etc.). They favour people who know personally and they always test the experience of others for plausibility, if the experience of others is needed.

The adapted Dreyfus model can be used to assess the progress in the development of design competencies. It helps lectures and tutors to define a desired level of competence and supports the purposeful competence development by understanding the learning needs. The model can be used to determine when a person is ready to teach others.

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