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DESIGN PROCESS AND CONSCIOUS PROBLEM SOLVING THROUGH COMPUTER AIDED DESIGN EDUCATION

Nenad PAVEL and Mikael OMLID
Oslo and Akershus University College of Applied Sciences

ABSTRACT
With rapidly changing technologies in product development, it is necessary for product design (PD) students to focus on inquiry-based learning in order to adapt to changes instead of simply learning form-giving and model-making skills. This paper seeks to explore how digital model making computer-aided design (CAD) skills can be learned in congruence with these new demands. A case study was chosen to exemplify how a practical training can be used as a tool for self-learning management. Students were observed in a learning situation where they use SolidWorks feature tools for the first time. As an alternative to being guided gradually, by repeating commands presented by instructor, they were encouraged to discover SolidWorks features through modeling a sketch-represented concept. This way of introducing the software features opened possibilities for conscious problem solving. This process led students not only to learn how to use the software effectively but also to understand the applicable value of this tool.
The theory of communities of practice was used to examine students' situational subjective experience in order to evaluate sources of motivation for further learning the software. The results indicate how student efficacy and motivation to learn SolidWorks can increase through tailored learning experiences. Finally, the paper reflects on societal demands and expectations for reeducation where students should self-manage their learning process in both training and productive practice.

Keywords: CAD exercise, conscious problem solving, meaningful learning.

1 PRACTICAL SKILLS AND LIFELONG LEARNING

Teaching practical PD skills through an intuitive problem-solving process is an established practice in PD education [1]. However, as the result of the fast pace of changing technologies and knowledge creation in recent years, new perspectives on learning have emerged owing to the need for lifelong learning and learning through networks [2]. Over the last twenty years, technology has reorganized how we live, how we communicate, and how we learn. Vaill emphasizes that "learning must be a way of being – an ongoing set of attitudes and actions by individuals and groups that they employ to try to keep abreast of the surprising, novel, messy, obtrusive, recurring events…[3]." Because technology develops rapidly, almost half of the skills that students acquire in higher education, today will be obsolete by the time they are employed [4]. According to Friedman, as design education cannot prepare students for the novel technologies of the future that are difficult to predict, it is important that design students develop their competence through inquiry-based learning. Therefore, design education today should place greater emphasis on the design process and conscious problem solving instead of form giving, drawing, and model making [5]. As Swanson claims, "the design students of today will be the inventors of the design field of tomorrow" [6]. Because of these conditions, the goal of educating future designers is to support their abilities in reflective thinking, problem solving, and lifelong learning in order to ensure they can effectively adapt to coming changes and challenges [4].
There is a need to address the fast-changing knowledge and rapidly evolving design profession in relation to learning practical design skills as design education is trying to minimize costs and depart from traditional small-group tutoring [7].

1.1 Digital modeling as a practical model-making skill

One of the practical design skills, digital modeling, has been widely adopted by design practitioners and schools. It has become common because of its ease of adoption and low costs, but it has also been widely criticized because it involves departing from physical experimentation and obstructs divergent design processes with its parametric structure [8]. In recent years, the digital modeling tools have evolved and diversified to various fields adapting to different workflows in order to support creative practitioners producing everything from media to virtual prototypes; such tools have also been adjusted to different phases in the design process [9]. Digital modeling is a process in which a CAD system is used to assist in defining the geometry and visual appearance of design [10]. Digital modelling is generally utilized during the convergent phase of a design process where designers make final decisions through incremental changes by editing and modifying geometry. It enables three-dimensional manipulation of objects in ways not possible with physical tools; it also allows designers to work with more precision and in greater detail. One of the main characteristics of CAD systems that appeals to designers is that they offer the possibility to make photorealistic renderings quickly [11]. Experienced design practitioners are adopting this tool in their workflow, learning the new ways to use it over time through experimentation; as a result, the role of CAD in the design process and in various types of software is changing very fast [9]. However, the downside of CAD systems is that most of the software used by designers is not necessarily compatible with a design workflow and is used and learned by design students completely separate from the design process, which can result in lack of interest or a difficulty to adopt it [12].

1.2 Teaching CAD systems in the context of design practice

In practice, CAD is taught in different scenarios. It can be taught by software distributors who organize courses as a course in design study curriculum. It could also simply be left to students to implement it in problem-based learning design projects. In these projects, design students independently discover how CAD can be implemented in the design process. Even though strategic use and teaching of CAD is discussed and strategies are proposed [13], it has not become common practice in design education. The way the future designers are introduced to CAD can affect the way they structure their workflow [14]. This can have implications for how design students manage future design problems that are not possible to predict.

The intention of this article is to put the CAD learning process in perspective through the production of design practice and its meaning for learning design skills in general. There is a need to examine the role of CAD teaching in design education outside the usual tutorial setting. The article therefore discusses possibilities for design students to learn adaptively so that they can translate this way of learning to other settings. This is especially important in the context of very dynamic and changing design practices, where conscious problem solving, as opposed to intuitive problem solving, is crucial. The intention is to "increase capacity of a learner to form connections between sources of information, and thereby create useful information patterns" [2] instead of using rich experience to intuitively solve problems [15]. As CAD is replacing traditional skills as a way of generating, analyzing, and collaborating in a design process, it is important to discuss this skill in the context of problem solving. The research question is therefore as follows: How can a CAD course enhance conscious problem solving and design process?

2 THE TEACHING PERSPECTIVE

As the case study describes the classroom setting, the theory of communities of practice [16] is used to analyze the communication between students and to describe the competence-acquiring process through the exercise. The problem of competence is therefore central to this article as it is argued that generative and practical skills are not suitable for future PD competence [5]. Because self-teaching and critical reflections are important for the problem setting of this article, self-organization is discussed as the ability of a learner to define what is important for the problem-solving process [2]. The instructional side of the course was discussed through instructional theories to comprehend how to teach in order to contribute to the desired competence [17].

In order to study how CAD can be learned in congruence with the design process, the case examined here is from an introductory course to SolidWorks CAD software at Institute for Product Design, Oslo and Akershus University College of Applied Sciences [18]. The case study was needed as an exploratory tool in order to understand a real-life CAD exercise situation and its context. The case was relevant because students need to cover the basic software skills in order to be able to complete their future design courses. In order to research the social and physical setting as well as the students' behaviors and activities, participant observation [19] was used as a method to collect data for the case study. The archival studies of CAD exercise results were used to confirm the different approaches students took to solve the problem. The course manager was interviewed [20] for description of the course plan and implementation. This case study was chosen because of the bi-product of the CAD exercise; i.e., open-ended problem solving that is in line with PD methodology.

3 THE CASE OF AN INTRODUCTORY CAD COURSE

The intention of the introductory course was for students to implement CAD as part of the design process dynamics. The course was built around SolidWorks as an intervention tool such that objects are transferred from reality into the virtual world and then manipulated in order to be tested through rapid prototyping in reality. The digital tools should thus be learned in the context of design intervention rather than design creation. This course was isolated and taught separately from the rest of the subjects for the PD students, who were in the first semester of the first year of their bachelor studies.

The first part of the course emphasizes reverse engineering of an existing physical object where students had to analyze an object and its parts in advance before then measuring and remodeling it. The intention was for students to acquire instant insight about not only how well they are using software features but also how well they understand the form and construction of a given object. The intention was also that the new PD students who do not have any experience in form-giving learn to analyze and generate forms and constructions through the same set of tools.

Figure 1. The sketch on the left and the modeling outcomes on the right

The next part of this assignment was even more complex as students were given a design sketch of a bar stool (Figure 1) to interpret and then generate a virtual model out of it. This sketch was not previously tested through a CAD or physical model. The representation of the stool proportions differed from the written dimensions as the sketch was a representation of the sketcher's imagination and the dimensions were taken from the ergonomic handbook. Here the intention was for students to interpret the sketch that somebody else generated and apply their findings through a set of software features. In this exercise, they did not have any physical objects so they had to imagine it. No additional instructions or guidelines about how to analyze an object were given to students. The exercise was presented as training in the use of software features. The students were instructed to finish their virtual models to be used as production documentation, which therefore should have a large degree of detail, including materials, fasteners, and needed mechanical details. Students were also instructed to conduct analysis on the center of mass in order to evaluate the actual usability of the stool in connection to materials. As the exercise progressed the students started to notice the discrepancy between the visual representation and the written measurements on the sketch, and the following questions arose, as the course manager explains:

> "As this started to become apparent to some of the students, I stuck to the initial premise and refused to answer questions related to design aspects of the assignment. I assisted in purely technical issues related to the software, but they were on their own in regards to the design contradiction."

All of the students noticed the discrepancy between the visual representation and the given dimensions at the end, but the students who had the most experience with software features noticed the mistake first. Students started to discuss among themselves what the right thing to do was. They tried as best as they could to answer what was expected of them in the task and find the right way to interpret the sketch. Some opened discussions around ergonomics of the barstool, some constructional, and some aesthetical. Some of the students consulted the Internet to check the typical measurements for the barstool. The results were comprised of those who followed the dimensions exactly; those who ignored the dimensions and tried to recreate the visual intent of the sketch; those who tried to come to a compromise between the two; and lastly those who created both models.

The feedback from the students for this type of assignment was positive. The tedium of learning CAD tools and methodology was overcome by the necessity to solve the problem and utilize design processes. The CAD skills were the main focus of the exercise, but in a way that they might be used in practice, therefore avoiding the more traditional tutorial or a "click-this-enter-that" exercise.

4 CAD EXERCISE AS A MEANINGFUL LEARNING PROCESS

Wenger [16] describes competence as a direct result of a social history of active negotiation of meaning within a community of practice. The meaningful learning thus happens through participation and reification interplay that creates the memory of a community of practice. Participation relies on activities, conversations, and reflections. On the other hand, reification concerns physical and conceptual artefacts: concepts, methods, documents, links to resources, and stories. Reification literally means "making into an object." Because Wenger [16] believes learning occurs through practice, the CAD problem-solving exercise may therefore be seen as a search for meaning that is alive and renegotiable. In the context of design process, reification can be seen as generative, while participation can be seen as an exploratory part of the design process.

In the case study, the concepts of participation and reification can be seen as the students start to actively discuss what the right way to model the barstool is as they are building a digital model. In an attempt to accomplish a reification task, and in the absence of outside intervention, participation began with their need to negotiate what is the right competence for solving the problem. They returned to a reification process by applying their findings to a digital model. The case study also shows how students negotiate meaning in alignment with their "regime of competence" as they struggle to fulfill the task the way it was posed to them. The "regime of competence" is characterized as a set of criteria and expectations by which a community of practice recognizes membership [16]. Students are discovering that they need to operate as both software users and design constructors in order to be part of the community of practice. This ability to spot, grasp, and intuitively adopt new regimes of competence might be crucial in the context of rapidly changing design practice.

5 TREATING CAD AS A REIFICATION SKILL

As the rapid evolution of the design discipline is taking place, it can be assumed that practical design skills are not a priority for design education, as we cannot possibly know what the future design competences are going to be [5]. In that sense, CAD as a competence can be criticized for both the lack of potential for a divergent design phase and for the ease with which it can be outsourced to digital modelers [11]. On the other hand, traditionally, design is seen as abstract, associative thinking for problem solving that happens through a reflection-in-action process of trial and failure [21]. The theory of communities of practice [22] offers an alternative view on how design competence is evolving because it sees the production of design practices as an output of a social learning system.

Seen from this perspective, practical PD skills and activities are nothing more than reification processes needed for negotiating meaning and production of practice. They are not to be seen as the goal but rather as the agent of creating a collective history of learning. In the case study, the exercise is set up so that students have to negotiate the meaning of the problem. They are competent negotiators

of meaning [16] rather than bearers of knowledge who are able to reframe contexts [15] or define critical questions motivated by curiosity [23].
In the context of a rapidly changing design practice, Wenger would argue that students' ability to adopt new regimes of competence and their ability to negotiate the meaning of the problem through the interplay of reification and participation are both crucial.

5.1 Implications for learning CAD

The case study shows how the CAD taught in a social context can bring new qualities to PD education. In contrast to tutorials guided by a supervisor or the software itself, these CAD exercises are put in the context of collective learning. Although the response from students was very positive, there is a need for more research about how these exercises can impact the intended learning outcomes that were clearly not only software feature-oriented. Seen from the perspective of constructive alignment [17], there are some values that can be analyzed in the CAD exercise described. As the constructed object defines the exercise, it is foreseeable how much time it will take to finish it. The work is directly related to a PD activity by students, which also seems comprehendible and conductible. The task presented in the beginning is clear and feasible. Because it seems to have a closed-ended solution, the skill level seemed to match the challenge level [24]. These are all values that might increase what Biggs defines as extrinsic social achievement and intrinsic motivation [17]. As all the students delivered their exercise tasks as demanded, it can be concluded that the software learning outcomes were obtained. The fact that all the students noticed the discrepancy between the representation of the bar stool and the dimensions indicates that conscious problem solving was activated. Some students have also engaged in the design process as an intended learning outcome, as they were actively discussing and searching information in order to solve the problem and then testing that information on their model.
Biggs claims that motivation and deeper levels of understanding arise from fascination or intrinsic interest when a student already knows about and is involved in exploring the topic. He explains how good students are already oriented toward inquiry-based learning. In contrast, beginners and students who struggle have difficulties to recognize the value in learning tasks and to expect success when engaging in learning tasks. A carefully planned CAD exercise can be a potential intervention to address such difficulties, as it can spark participation through a reification process that seems defined and predictable, yet gives students a framework to ask questions. This framework is useful as it puts students in a situation to evaluate aspects of the problem and search for needed information.

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