Avoiding the potential negative influence of CAD tools on the formation of students' creativity

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Abstract: This paper examines the effects of the use of CAD tools on the development of students' creativity in the context of design education. The basis for the analysis are the results from an industry study that identified four ways in which the use of electronic design tools impacts on the creative design process in practice. The mechanisms are described as enhanced visualisation, circumscribed thinking, premature fixation and bounded ideation. Using the concept of Accidental Competency formation these four mechanisms are examined in the educational context. Accidental Competency formation allows a holistic view on the educational process to examine how factors from the broader learning environment combine with the active teaching of design and have long-term effects on the formation of students' creative abilities. These effects are analysed by means of illustrative examples that were obtained in focus groups with engineering students using critical incident techniques. The paper concludes with recommendations for design education to foster positive effects of accidental learning and equally avoid negative consequences for the development of creative design competence in engineering students.

Introduction

In today's global economy the pressure for innovative solutions and products to be developed has grown as time and cost constraints have increased. One of the skills which is increasingly seen as being important for dealing with these issues is the ability to be creative in seeking solutions to design problems (NAE, 2005).

This development is set against the background of the pervasive use of Computer Aided Design (CAD) tools, both in industry and in undergraduate engineering courses. However, there is growing evidence that the increased use of computer tools in design on the one hand and the need for more creativity on the other may not be completely compatible in industrial practice (Robertson & Radcliffe, 2006).

In the educational context authors have suggested ways of encouraging creative practices in design students (Baillie, 2002; Liu & Schonetter, 2004; Overveld, Ahn, Reymen, & Ivashkov, 2002; Richards, 1998). However, this paper contends that this only partly addresses the issue. Current ways of teaching engineering design that focus on technical proficiency in CAD tools may have the unintended consequence that creative problem solving is discouraged. In other words, as well as not being taught to be creative, are students being taught *not* to be creative?

This exploratory study used empirical data from an industry study (Robertson, Walther, & Radcliffe, 2007) to shed light on the problematic relationship between teaching CAD tools and developing creativity in students. A suitable framework for this transfer of the industry findings into the educational context is the notion of Accidental Competency formation (Walther & Radcliffe, 2006b). This concept describes how the combination of various influences relating to the practicalities of education can have unintended positive and negative effects on learning outcomes of students (Walther & Radcliffe, 2006a).

Industry case study findings - CAD and creativity

The industry study combined a participant-observation case study (Robertson & Radcliffe, 2006) with an online survey of 255 CAD practitioners from 32 different countries (Robertson & Radcliffe, 2007 in press) for triangulation of the results.

From critical incidents recorded during the immersion phase four mechanisms of how CAD use impacts on creativity in design were formulated:

- *Enhanced communication and visualization* describes how the capabilities of the CAD system allow designers to realize and communicate the products of their imagination, thus fostering the flexible development of design ideas.
- *Circumscribed thinking* occurs when the CAD tool interferes with the creative process by restricting the designer in what can be created or by encouraging the designer to over-reach the requirements of the task.
- *Premature fixation* describes the disincentive for design changes once a large amount of detail and interconnectedness is built too quickly into a CAD model. This early fixation on certain design solutions reduces the designer's flexibility in responding to creative input.
- *Bounded ideation* identifies the use of CAD under stressful conditions as adversely affecting the motivation and hence the creative potential of designers. Creative problem solving requires effort, and if there is no incentive or desire to undertake this type of thinking, it is unlikely that it will occur.

The online survey of CAD users confirmed the first three phenomena in engineering design practice (Robertson & Radcliffe, 2007 in press). Bounded ideation, however, was found to occur only infrequently. It was also found that in the early conceptual stages, skills such as sketching, communication and teamwork should take precedence over CAD - a result that agrees with the findings of several other authors (Purcell & Gero, 1998; Ullman, Wood, & Craig, 1990; Verstijnen, Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998).

Accidental Competency formation in engineering education

The notion of Accidental Competency holistically describes the formation of student competence in engineering programs: Learning activities combine with other influences from the educational environment to enhance, or equally, adversely affect students' acquisition of professional engineering competence (Walther & Radcliffe, 2006b, 2007 (in press)).

The concept of Accidental Competency formation is based on empirical data that was collected as part of an ongoing study into the nature of competence formation in engineering students (Walther & Radcliffe, 2006b). In ten focus groups with a total number of 40 participants from Australia, Germany and the US specific accounts of Accidental Competency acquisition were obtained. To elicit these accounts the semi-structured focus group procedure (Walther & Radcliffe, 2007) employed critical incident techniques (McClelland, 1973; McClelland, 1998; Spencer & Spencer, 1993). The focus groups were conducted with graduate engineers and engineering students who had taken part in a range of formal placement programs. This was to ensure that the participants were sufficiently close to their educational experience as to be able to recall detailed incidents. Yet, the participants' industry experience ensured the validity of the competence concepts for professional engineering practice. The focus groups were digitally recorded, transcribed and subsequently analysed with the qualitative data analysis tool NVivo 7. The analysis of the selected illustrative quotes presented here, focuses on how the effects of CAD on creativity that were observed in industry, impact on the development of creativity in design education. This specifically includes how factors from the broader educational context act to aggravate possible negative effects and create unfavourable long-term behaviours or working habits.

Critical incident 1 – the realities of design

"With my design, I drew everything butted up against each other. They were all flush, everything fitted perfectly. I had 45-degree angles, which blew everything out of the water when you do manufacturing. But, down there in the work shop they needed everything one or two mil longer so everything fits together. That's something with CAD, I mean, everyone says it's great to have 3D models, but try and make it - whole different story." (Strephon, fourth year Mechanical Engineering student)

This quote illustrates how two of the effects of the use of CAD identified in the industry study play a role in design education to influence the students' development of creativity.

Effects of the Use of CAD

Firstly, the student describes how he assumed the same precision that CAD offers in the design process for the subsequent stages of the product development process. In this particular case this might be in part due to missing learning content to cover the principles of manufacturing and assembly with the inaccuracies or necessary tolerances involved. On a deeper level the quote shows that this assumption also derives from the CAD system's capabilities to visualise the design. From the visual impression of the model produced the student assumes that "everything fitted perfectly". This misleading sense of precision of a CAD model is a negative side-effect of "enhanced visualisation and communication", which was identified in the industry case study as being an advantage for creative problem solving.

The second effect referred to in the above quote relates to the CAD system's improved capability to create geometry, which interfered in the design process and caused the student to overreach the design requirements. Without immediate necessity and mainly because the CAD system facilitated the operation, he designed the parts to non-rectangular shape. This, however, conflicted with the realities of manufacturing in the particular company. This is an interesting example of circumscribed thinking, where the functions of the CAD program have interfered with the design process by influencing what was created.

The two examples show that both enhanced modelling and visualisation capabilities of the CAD system can create a false sense of reality to the CAD model. The user is left with the impression that 'the CAD model is the design' rather than an abstract representation of a possible future design which will then be given to a manufacturer who will have to interpret it and produce something that approximates it.

Educational Impact

From the context focus group transcript it was evident that in the educational context this false sense of reality of a CAD model was compounded by several other factors. A main influence is the espoused belief in education that CAD models are the *non plus ultra* in design and visual representation of design ideas. The student reports that this view was prevalent in his design education where "everyone says, it's great to have 3D models" (Strephon), thus re-enforcing the misconception that 'the CAD model is the design'. The second factor that hampers the student's comprehensive understanding of design to include the realities of manufacturing and assembly is the teaching of university courses in disciplinary isolation. In other parts of the transcript the respondent recounts that CAD design was taught in separation from other courses that are concerned with the later stages of the product life cycle. Based on a similar experience another respondent remarked that "*no courses deal with the design from drawing to manufacture; and manufacture is very big."* (Conrad, fourth year Mechanical Engineering student).

These examples show how the effects of CAD on creativity that were observed in the industry case study combine with other influences in education to cause long-term effects beyond an immediate application of CAD in professional practice. The educational premise that advocates the adoption of CAD combines with the tool's characteristics of enhanced visualisation to create an impression for the students that design is fundamentally about using CAD tools. Rather than coming to an understanding that design is a flexible creative process, they might see achieving technical competence in CAD as having primary importance in design.

Critical incident 2 – Design as an iterative process

"With my test rig I had to set up, I could do a few things in CAD and take it to the boiler maker, but the first thing I drew up in CAD was a nice little picture. He said 'Take it away and draw roughly what you want me to do on a bit of paper, describe it to me, and I will do it for you'. He caught on nothing but really sketching the stuff. He had been welding this stuff for thirty years. He would say: 'I'll make it work. Is there anything critical that can't be changed? I'll make everything fit around." (Adam, fourth year Mechanical Engineering student)

This illustrative quote shows how enhanced visualisation and the effect of premature fixation were experienced in the educational context and ultimately influenced the development of the student's creative abilities.

Effects of the Use of CAD

Firstly the quote shows that the improved ability of CAD system to realise, and then communicate the products of the designer's creative imagination caused the student to rely solely on CAD models to communicate his design ideas. The student recounted a situation during an industry placement where he assumed that the CAD model would be sufficient to communicate the design idea to an employee in the company's workshop. While the creativity-enhancing capability of CAD to clearly visualise the model as a detailed, three-dimensional object may seem like an advantage particularly for the purposes of design for manufacturing, the respondent describes it as unsuitable in his experience in practice. For communicating the design idea in the context of a piece production, a sketch was seen as more appropriate in combination with a verbal description of the design and function.

The second aspect described by the student was a form of premature fixation where the CAD program forced a high level of detail and specificity to be built into the model too early in the design process. The respondent described how the manufacturing process benefited from a certain ambiguity of a sketch and that the final shape of the product was defined in an iterative dialogue between the student as the designer and manufacturing. The workshop employee required the 'critical dimensions' which allowed him to adapt the rest of the design to facilitate manufacturing. The characteristics of the CAD system did not allow for this ambiguity. This form of premature fixation is somewhat similar to the false sense of reality of the CAD model described above. In this case the design tool communicated the design idea 'too well' so that it caused the student to assume a false sense of the finality of the design thus not taking into account the iterative nature of creative design.

Educational Impact

In the educational context the negative effects of enhanced communication and the effect of premature fixation combined with a number of influences to cause long-term student behaviour.

The student's lack of incentive or ability to use appropriate forms of communication such as sketches or verbal explanations to convey his design ideas was caused by the combination of the enhanced visualisation capabilities of CAD and the emphasis that design education puts on the value CAD models. This is particularly evident in the assessment of student work. One of the respondents described this separation between education and his professional experience as "*CAD is for the ideal world. It makes some pretty pictures and your assignment will look all impressive. But you go to the floor and they will say 'Yeah, I don't care'."* (Adam).

The effect that the student did not appreciate the iterative and sometimes ambiguous nature of the design process in practice was only in part caused by premature fixation effects. In other parts of the transcript he described the influence of a deterministic approach that is not uncommon for many engineering courses. The view in engineering education that a single correct solution can be identified for all engineering problems created the student's expectation of a single correct solution for design problems. This expectation, along with the ostensible perfection of the CAD visualisation created a false sense of finality. Another respondent described this as: *"Yeah, that's what you think, that you got* *the right answer. But it doesn't ever work [in practice], to be quite honest, there is always something that has to be changed"*. (Strephon)

From the above examples it can be concluded that the effects of CAD usage combined with other stimuli in education, not only impacted on the specific situation in practice but also caused the following two Accidental In-competencies. Firstly, the students did not develop other forms of communicating their design ideas such as sketching, which is a particularly important aspect of creativity in design (Ullman et al., 1990). Secondly, the influences prevented students from developing a conceptual understanding of the iterative and flexible nature of the creative problem solving process in engineering design. In each of these cases, we can see that it is the indirect, "accidental" processes which have formed the students' conceptions of design, rather than direct instruction.

Recommendations for Design Education

The analysis of the effects of CAD on creativity in the educational context is intended to foster a deeper and more holistic understanding of the processes that lead to students' development of design competencies. More specifically, this means that the concept of Accidental Competency formation suggests a broadened responsibility of design educators that goes beyond teaching technical proficiency in the use of CAD tools. This broader responsibility also entails the opportunity to minimize negative effects and foster positive effects of design education beyond the immediate scope of for example a CAD course.

The Accidental Competence formation examples discussed earlier suggest that the four phenomena observed in practice in industry are likely to have a more permanent impact on the formation of design competence by students. In the professional context, the described negative influence of CAD on communication might result in a practitioner not sketching an idea in a particular situation. In the educational context, however, this effect could lead to students developing an inability to utilize this particular facet of engineering communication. This demonstrates that the impact of design education goes beyond using or becoming proficient with a technical tool. It lays the foundations for the formation of students' fundamental perceptions of the nature of design and the development of personal working styles and habits.

For example, educators should avoid circumscribed thinking and encourage good design in their students by ensuring they are more aware of the realities of iterative design, manufacturing and assembly, rather than directed in their thinking by capabilities of the CAD system. They can also avoid premature fixation by making better use of other forms of visualization/communication such as sketching in the early, conceptual stages. Finally, students should emerge from design schools with the understanding that design involves much more than the part that is "computer-aided", and that it includes creative problem solving and important cognitive processes. Hopefully, this can help to avoid the situation that once caused an engineering educator to remark to freshman engineers that "if you've got any creativity in you at the start of this course, you won't have any left at the end"(Ball, 2002).

Given the above examples, it can be seen that it is not just a simple matter of developing new approaches to introducing CAD and targeted learning activities to encourage creativity in engineering courses and programs. Since there is not a simple mapping from the design of learning activities in courses and the ultimate behaviours and competencies displayed by graduates in industry we must look to the educational experience as a whole to foster students' creativity whilst achieving professional design competence.

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