Putting the Design into Computer Aided Design

There is a growing body of research suggesting that CAD does not, has not, facilitated the advances in designing that should by now be evident. The history of CAD is replete with claims that CAD improves designing and it is a common claim in the publicity of CAD vendors. However, the reality appears to be somewhat different with claims by Musta’amal, Norman and Hodgson (2008), Lawson (2002) and Walther, Robertson and Radcliffe (2007) that CAD does not in fact improve designing to anywhere near the extent that we would like to believe. This is particularly relevant in the context of Design and Technology. This paper investigates the reasons why this may be so by referring to the literature on designerly thinking (Middleton, 1999; Oxman, 1999; Newell & Simon, 1972; Schon & Wiggins, 1992; Suwa, Gero & Purcell, 1998; and Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998) and then suggests a manner by which the designing of students using CAD can be enhanced through an alternative pedagogical approach applicable to Design and Technology (D & T). The results of a trial intervention aimed at testing this pedagogical approach will be presented.

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“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 statement by Walther, Robertson and Radcliffe (2007, p 1) encapsulates a potential problem facing not only engineering education but other fields such as architecture product design and Design and Technology education. Walther et al (2007) introduce the concept of “Accidental Competency formation” based on an international study involving 32 countries and 255 CAD practitioners. They proposed four separate mechanisms by which CAD impacts on creativity; enhanced communication and visualization, circumscribed thinking, premature fixation and bounded ideation. The first three of these mechanisms were supported by the research. These mechanisms are described by Walther et al (2007) as:

“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.”

(Walther et al (2007, p. 2)

While advanced communication and visualization are normally seen as an advantage by educationalists Walther et al (2007) point out that this may give rise to a number of potential problems such as seeing the model as the product without due consideration for the manufacturing process and employing, for example, fits and tolerances that work on the model but not in the manufacture of the product. Circumscribed thinking occurs when shapes that are easily able to be employed in the CAD environment are used without considering the manufacturing implications such as assembly parts with not rectangular surfaces or free form shapes that require advanced machining capabilities. Premature fixation results from too much detail being included into the initial model making iterative change less likely to be undertaken. This may occur due to what Walther et al (2007) explain as the ‘accidental in-competencies’ developed through the use of CAD. These are the lack of development of other ways of communicating design ideas such as traditional sketching and a lack of appreciation of the iterative nature of the design process as CAD models tend to be generated in a linear fashion.

In the field of CAD in architecture Lawson (2002) highlights a number of difficulties. Lawson (2002, p. 328) points out the “there has always been a problem with design images in this process. They are not an end in themselves but often can become so” and uses examples of “impressive and convincing computer examples with poor design (p. 329) in support of this contention. Further, Lawson maintains that the design process in architecture requires the designer to keep in mind a large number of dimensions of the problem, for example the site, traffic flow, space, light, solar gain and working environment to highlight a few and that adding an additional component such as the CAD interface may lead to excessive cognitive load and a consequent reduction in the ability of the designer to consider all of the dimensions of the architectural problem. Lawson (2002) also cites examples of architectural designs being proposed on the basis of easy to produce CAD algorithms, such as ellipses and shell forms based on sections swept along parabolic paths, which are impractical both in terms of function and construction. These are examples of what may be considered ‘fake creativity’ (Lawson, 2002, p. 330). In common with the field of engineering design Walther et al, (2007) also maintains that CAD encourages linearity in design and a lack of development of other design communication mechanisms such as sketching and discussion with the client.

In the field of Design and Technology Hodgson and Fraser (2005) undertook research on the impact of CAD on school based design work. Their findings identified a number of issues some of which are in common with the findings in engineering design and architectural design highlighted above. In their 2005 survey Hodgson and Fraser found that while 62% of respondents maintained that CAD aided in visualization, particularly in terms of “size form and fit” (p. 99) however 42% of students indicated that the design was complete before it was modeled in CAD. In support of the concept of the CAD model being the object or the design Hodgson and Fraser (2005, p. 101) cite evidence that very few students (29%) were willing to sketch over CAD print outs. The authors suggest that this is because “this preservation of ‘precious’ images serves to support the notion that CAD is utilised significantly as a means to an end in its own right but not
directly to, say, modify design ideas” (P. 101). In a more recent paper Hodgson and Fraser (2006) argue that it is necessary to establish the role of CAD in the design activity of students involved in Design and Technology. They point out that CAD is being used as a means of product production through CAD/CAM and a means of producing high quality rendered images but not necessarily in designing. The student activity highlighted in the research included discussion about “how to achieve certain shapes forms and features sharing their knowledge and skills” (p. 5) but this may well be more about CAD modeling and not necessarily design. Hodgson and Fraser support this position by concluding that “CAD was enhancing pupils apparent capability by allowing them to communicate their ideas more effectively” (p. 5) and that pupils tended to communicate the output of their CAD operations not in terms of design changes but in “terms of the knowledge applied in producing the CAD model in terms of the features used” (p. 7). Hodgson and Fraser (2006) concede that there is a possibility that students do not conceive of the work done within the CAD environment as design and therefore do not document the process to accurately reflect the design process. This is supported by the practice of some pupils who have completed their designs in CAD to then go back to documenting the design process through sketches.

A more in-depth study by Musta’amal, Norman and Hodgson (2008) sought to identify creative behaviours of subjects when using CAD. This small scale study recorded creativity indicators for three subjects while undertaking a CAD design task. Only two of the subjects indicated prior to the study that they intended to use CAD as a design tool, the remainder intending to use it predominantly as a recording tool. Results of the study identified indicators in four of the seven creative behaviours; appropriateness, motivation, flexibility and sensitivity. Further analysis highlights that almost all sensitivity indicators were associated with perfecting previous ideas and all of the appropriateness indicators were associated with a ‘sensible’ design. Of particular interest were the low incidence of insightful behavior, low fluency (spontaneity, open to new ideas) and no indicators of novelty. While creative behaviours were observed, the nature of these behaviours does not seem to support a high level of creativity.

The work of Walther et al (2007), Lawson (2002) and Hodgson and Fraser (2006) in engineering design, architecture and Design and Technology thus provides support for the contention that the use of CAD may inhibit the creativity of the design process in a number of ways. In each case the reduction in the use of sketching as part of the design process with the advent of CAD is mentioned. The importance of sketching as a means of developing and communicating ideas and concepts is the theme of considerable research particularly as it relates to mental imagery or ‘visual reasoning’. Middleton (1999) proposes a model for solving complex design problems based on a problem space, which is made up of three zones; problem zone, search and construction space and a satisficing zone. Middleton establishes the role of visual mental images in traversing the search and construction space using both generative and exploratory procedures. Further, he makes a case for the equivalence of sketches and visual mental images in this process. Schon and Wiggins (1992) and Oxman (1999) maintain that visual reasoning is “uniquely significant” and therefore there is a need for the teaching of design to take into consideration the fact that designing is a cognitive activity that requires specific approaches to learning. Oxman (1999) provides support for a constructivist approach whereby students become progressively aware of what it means to think in a designerly way. This allows the development of an understanding of the cognitive processes used by designers when engaged in design tasks and provides a
progressively richer ability to apply these same strategies. Successful designing is the result of a range of cognitive strategies (mental imagery/visualization; spatial abilities such as rotation, combination and restructuring; emergent shape recognition; and image reversal) all of which it appear are facilitated in some way by the design sketch.

Visual imagery or visual mental imagery is a process whereby images are created or remembered totally within the mind and then manipulated through a range of processes to form new images. Visual mental imagery is seen as a pre-requisite to the production of external images (Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998) and the solving of complex design problems (Middleton, 1999). The design sketch, on the other hand, provides an externalization of the cognitive processes of mental imagery and, according to Suwa, Gero and Purcell (1998) and Newell and Simon (1972) provides a representation through which further design may occur. The design sketch therefore becomes a means of external memory thus enabling further mental imagery to occur and the design process to proceed. This view is further supported by van der Lugt (2005) who argues “sketches can stimulate creativity, especially in the immediate individual idea generation process” (p. 108).

Verstijnen, et al, (1998) provide an interesting insight into the design process. They discuss the differences between two processes associated with design tasks, combining and restructuring. Combining is the process whereby a new object is formed by the combination of a number of individual shapes or existing objects. Restructuring, however, involves new shapes emerging out of the decomposition of the initial shapes, the recognition of a new shape as a result of the juxtaposition of parts of a number of existing shapes or shapes emerging as a result of the spaces between existing shapes. The outcome of their research is of interest for a number of reasons. There is firstly a suggestion that both strategies may be required in order for creative discovery to occur. Secondly, the results of their experimental research found that combining can be achieved through mental imagery whereas restructuring requires the stimulus of an external sketch. This is presumably because the mental imagery process holds the component parts as fixed in memory in order to prevent cognitive overload.

The centrality of the sketch in the design process has long been proposed. Newell and Simon (1972) and Simon (1981) proposed the concept that the sketch provides an externalization of the design ideas that can then be used during later reinterpretation processes. This allows the freeing up of short-term memory for other tasks such as restructuring or emergent shape recognition. Suwa, Gero, and Purcell (1998) and Purcell and Gero (1998) suggest that the design sketch enables designers to identify new features, to see the spatial relationships and to revisit specific sections of the design. Liu’s (1995) research addressed the emergence of shapes from within other shapes especially in the drawing process. The ability to recognize emergent shapes is one of the key components of the design process as the designer uses “drawings not as a medium for recording already conceived mental images but as active participants in his [sic] thinking” (Lui, 1995, p. 369). The results of the research indicate that some shapes can immediately be ‘seen’ while others, particularly those of a more sophisticated nature, need to be searched for. Shapes immediately recognized are all explicit, closed and named e.g. square, triangle, circle while those of an implicit nature require not only effort but practice as well. Implicit shapes are those resulting from spaces between other shapes, unclosed shapes and ‘holes’ in existing shapes. The findings of each of these sets of research suggest that the cognitive actions of identifying relationships,
recognizing emergent shapes and restructuring of ideas do not occur at the time of the sketching but after it concludes. The results of these cognitive processes are then used to draw again in order to further develop the design.

The implications of the research on the effect of CAD on design creativity and the central role of the sketch in designing suggest that a pedagogical approach to the use of CAD in Design and Technology needs to be considered whereby sketching becomes an integral part of the process. However the work of Hodgson and Fraser (2005, 2006) suggests three important outcomes. Firstly, students do not necessarily perceive of CAD as a designing activity. Secondly, in a manner similar to engineering designers and architects, Design and Technology students may also see the CAD model as the product or an end in itself. Thirdly, students are not always willing to sketch over their CAD printout in order to develop their design further. A pilot study was developed in order to address these issues. Subjects were 10 Year 1 undergraduate Design and Technology students undertaking an introductory CAD course. They ranged in age from 18-45 years. As a part of the course they were required to undertake an individual design exercise (toilet roll holder) in which design documentation was expected to be presented. The aims of the study were to:

- enable students to document their design thinking
- reduce circumscribed thinking and premature fixation
- overcome the tendency of students to be unwilling to sketch over their CAD printouts.

In order to address these issues students were each provided with copies of the CAD software and a relatively cheap Wacom Bamboo graphics tablet for their personal use. The graphics tablet software enabled screen images or exported graphics images (JPEG, BMP etc) from the CAD software to be easily imported and then sketching and notation to occur using the graphics tablet. A particular feature of the software was its ability to recognize pen weight in a manner similar to a normal pencil. Thus thick and thin, dark and light lines were able to be produced without having to use software menus or features. Students were given limited instruction in the use of the graphics tablet in class and allowed to borrow the tablet for the period of the design exercise. The use of the graphics tablet was deliberately chosen for a number of reasons. It is able to be used concurrently with the CAD software without the need for printing and it enabled digital documentation of the design process. It was considered that the graphics tablet may be motivational for the students and, in particular, had the advantage of enabling students to sketch over CAD images without the feeling of destroying the printout as had been previously found by Hodgson and Fraser (2005, 2006). At the end of the period computer files from both the CAD and the graphics tablet were collected and an eight question questionnaire was completed by each student with both fixed response and open response feedback to further elaborate on student reaction to the use of the graphics tablet as a design tool.

The questionnaire was designed to find out students’ reactions to the use of the graphics tablet and in particular how it affected the design process. Responses to the questionnaire are included in the table below:

| Table 1 |
Neutral responses to questions two and four may indicate that students required more time to become familiar with the operation of the graphics tablet which is supported by the strong response to Q 5. This was supported by open responses:

“I was getting frustrated because I was unaware of how it works but I can see the advantages if I had more time to play with it.”

“With further practice it would have become as easy as (freehand).”

“It takes time getting used to the idea of using a pad to write text/draw freehand.”

“I found it difficult to get the right pressure and position, but I assume with more use I would adapt and get used to it.”

Student responses to the graphics tablet and its potential to motivate school students and to incorporate it into the design process of Design and Technology were positive. Of
particular interest was the positive response (4.90 - Strongly Agree) to the question “the requirement to sketch my ideas on the graphics tablet away from CAD helped in the development of my final solution.”

“Because I then had a visual reference to cement my ideas as well as improving my ideas once I was using CAD.”

“Because it was based on what I wanted to design, not what I could (model).”

“It helps you not to get caught up in the actual construction of the design – it helps to make sure you think about the overall design.”

“Using sketching is a good method to allowing creativity to emerge.”

“It develops cognitive and metacognitive skills - planning and testing ideas before using the CAD process.”

“Sketching encourages prior thought, which in my mind is the most important part of the design process.”

These responses are particularly interesting for two reasons. Firstly, they support the research that argues for the importance of the sketch in the creative design process making specific reference to improving ideas, thinking about the overall design and planning and testing ideas. Secondly, and importantly for this research, students were aware that the sketching process on the graphics tablet allowed them to develop ideas that were not restricted by what they could model and assisted in preventing them being caught up in the modeling process. That is, the mechanisms of circumscribed thinking and premature fixation were reduced as an outcome of sketching on the graphics tablet.

Examples of student interaction with the graphics tablet in the form of the electronic files indicate that students were also happy to sketch over their CAD images thus overcoming the tendency identified by Hodgson and Fraser (2005, 2006) for students to treat the CAD model as the product rather than a means of developing design ideas. Student files also provided a rich description of the design process undertaken by some students.

The outcomes of this pilot study indicate that there are possible advantages in the use of graphics tablets as a design tool in Design and Technology classes as a means of overcoming the potential negative effects of CAD on design creativity and in providing greater insight into the design process undertaken by the students.

References


