

## **3D-CAD: MODERN TECHNOLOGY – OUTDATED PEDAGOGY?**

For some teachers it may be hard to believe that 3D-CAD has now been taught in secondary schools for more than twenty years. My own experience dates back to around 1984 with the introduction of the British architectural package ‘Scribe’ into schools in Canberra, Australia. Despite a brief, and totally unsatisfying, foray into 2D-CAD in the late 1980’s I have been teaching 3DCAD to students, undergraduate Design and Technology teachers and teachers ever since. In late 2001 I somewhat recklessly volunteered to coordinate ProDesktop training throughout Australia on behalf of the Industrial Technology and Design Teacher’s Association and am now in the early stages of working out how to introduce ProEngineer. I mention these facts in order to provide a context for an admission that for the majority of this time I taught 3D-CAD in the manner I was taught. That is, teaching how to use 3D-CAD through a process of learning algorithms – this is how to extrude, this is how to revolve etc. However, over the last few years I have begun to question the effectiveness of this pedagogy.

One reason I began to question this pedagogical approach again relates to my experience. 3D-CAD is an emerging technology and as such has developed considerably over the last 20 years. My philosophy has always been that I should try to give my students the best possible learning experience and I have therefore tried to always teach with the best software I could afford, and that would run on the computers currently available to me. Consequently I have changed programs eight times and versions within programs many more leading me to begin questioning what it is that makes a person good at 3D-CAD. Since this sounded like a good topic for a PhD I took up the challenge and have been researching 3D-CAD ever since. What have I found?

One relative constant is the dominance of a didactic pedagogy being used to teach 3D-CAD in both schools and industry. I believe this is due in part to the historical timing of the development of CAD which occurred at the around the same time as the behaviourist movement in education. Behaviourism advocated the didactic approach whereby content was broken down into individual behavioural steps that were then presented to learners in a carefully sequenced order. Sounds familiar doesn’t it? It was assumed under this method that learning all the individual steps, and providing sufficient practice, would lead to mastery of the domain. What does the CAD research tell us? It highlights a number of things:

1. The didactic approach is still the dominant pedagogy in both education and industry.
2. Initial teaching plus experience does not lead to the development of expertise – experienced CAD users still use sub-optimal modelling methods that are often time consuming and difficult to modify.
3. Expertise in CAD is not differentiated by levels of command knowledge (e.g. knowledge of the steps involved to extrude – most people can learn the steps in a sequence) but by the application of strategic knowledge (knowing what alternative modelling strategies are available and how to choose between them).

After finding out this I embarked on a process of finding out more about expertise to see if what had been found in other domains could be applied to 3D-CAD. The research with experts in chess, electronics, figure skating, dance, music, bridge and computer programming, to name a few, highlights a number of characteristics of expertise. Experts have:

1. high levels of domain knowledge
2. superior speed of task performance
3. superiority of both short and long-term memory in their domain of expertise
4. the ability to do “automatically” things that non-experts find difficult or impossible
5. the ability to recognize large and meaningful patterns in the domain of their expertise
6. the ability to utilize the executive control processes of planning, monitoring and revising while undertaking much of the other information processing automatically and in parallel with these processes.

The first four of these characteristic were, I felt, fairly self evident and things I would expect of a 3D-CAD expert. A little bit of thinking about recognition of patterns led me to conclude that, like chess experts who recognise patterns of pieces on a board, 3D-CAD experts would recognise shapes that could be modelled through the use of various algorithms. The final characteristic executive control, or metacognition warranted more investigation. What followed was a lengthy process of investigating 3D-CAD expertise with 3D-CAD experts. This research not only enabled me to confirm that experts in 3D-CAD exhibited similar characteristics to experts in other domains but that the current conceptualisation of expert 3D-CAD knowledge, which concentrates on the ability to choose between alternative algorithms is too narrow. I have now concluded that 3D-CAD knowledge should be reconceptualised to include three types of knowledge: declarative command knowledge, specific procedural command knowledge and strategic (or metacognitive) knowledge.

- Declarative command knowledge is knowledge about the commands or algorithms that are available within 3D-CAD. Thus, an individual may know for example that it is possible to mirror lines, copy objects and create a solid by extrusion. This knowledge is general in nature and is applicable across the majority of CAD software. You need to know about these algorithms before you can do them and you need to know they exist so that you can find them in a new piece of software.
- Specific procedural command knowledge is knowledge that enables the operator to execute the necessary commands to, for example, mirror lines, copy objects and create a solid by extrusion within specific CAD software. Specific procedural command knowledge thus varies from one CAD software package to another and may also vary from one version of a CAD software package to another. This is the type of knowledge concentrated on in 3D-CAD instruction however this type of knowledge changes and may therefore become redundant and need to be relearned.
- Strategic 3DSM-CAD knowledge includes a range of metacognitive processes. Metacognition is generally accepted to include process such as planning, monitoring and revising and I have confirmed this in 3D-CAD experts. In addition my findings indicate that due to the parametric nature of

much of today's 3D-CAD software experts engage in more predicting. This occurs in order to ensure that the choice of algorithms will enable the construction a model that will maintain its integrity during subsequent production and allow for later ease of design modification. In the words of one expert the choice of modelling strategy depends on whether "it is easy to change". For this reason it was also found that 3D-CAD experts tend to minimise the use of geometry in favour of the use of algorithms. For example, they will round the edge of a solid rather than fillet the geometry used to develop the solid.

What are the implications of this reconceptualisation? I believe there is a need to rethink the way we teach 3D-CAD to place more emphasis on the development of strategic knowledge at the same time as specific procedural knowledge is learned. In this manner our students will be better able to cope with changes; changes from one 3D-CAD package to another and from one version to another.

Never one to leave anything at the theoretical level I have now spent the last two years developing and testing a successful alternative pedagogical approach to the teaching of 3D-CAD in order to try to develop more 'expert' approaches in novice learners. The approach that was developed and successfully tested was based on a number of factors identified through the research literature. The first of these is that efficient use of CAD software is in some way dependent on the users' ability to visualize various options: options for the use of different algorithms, options for the identification of the geometry necessary to invoke the algorithm and options for the efficient generation of the geometry. Anecdotally, teachers report that many students cannot recognize how to model individual parts thus they have difficulty with basic command knowledge. Nor are they able to 'see' alternative modelling methods that may enable them to be strategic and therefore efficient in their 3D-CAD use. Both of these problems appear to be related to the inability to visualize possible approaches to the modelling process. This suggests that there could be a relationship between an individual's spatial ability and their ability to use 3DSM-CAD.

It is assumed by many that the use of solid modelling will enhance students' visualization skills however, the conclusion drawn from the CAD research is that merely working with 3D-CAD software does not improve the spatial abilities of students. It appears therefore that even though many aspects of the CAD modelling process involve visual mental imagery the use of 3D-CAD does not necessarily improve visual mental imagery. Therefore specific mental imagery training was incorporated into the new pedagogical approach. A number of strategies that have been found to improve spatial ability were employed. These included pre-exposure to perceptual differentiation, experience with manipulative tasks and the use of sketching. Pre-exposure involved the teacher explicitly explaining the characteristics of a particular shape that identify it as being able to be modelled using a particular algorithm. Manipulative tasks engaged students in predicting, and sketching, the shape of a model when viewed from an alternative location then changing the orientation of the model either physically or on the computer screen to check the accuracy of the prediction. Sketching was used wherever possible in the development of strategies as sketching has been found to be highly effective in the development of

spatial abilities. A student workbook of models was also developed and used for this purpose. Students were given the task of sketching as many alternative modelling strategies as possible for each model as the instruction progressed and their command knowledge developed. Students were then asked to choose and justify the most effective strategy for each shape based mainly on the “it is easy to change” prediction.

In addition to the development of spatial abilities there is also a need to address other cognitive processes including prediction and problem solving strategies in order to develop 3D-CAD expertise. These were addressed via three approaches; expert teacher modelling, scaffolding and group problem solving. Expert teacher modelling of the 3D-CAD problem-solving heuristics involved the teacher consciously making explicit the processes they were undertaking in which normally silent reasoning processes were spoken aloud. This is different to the normal explanation of the steps involved in the specific procedural command knowledge, it involved the reasons why commands were chosen, what characteristics of the model led to the choice, why particular pieces of geometry were positioned on specific work-planes or at origin points etc.

Scaffolding of learning was associated with this process. Initially repeated learner observation of the particular process being attempted was undertaken in order that students were able to mimic that process. While student practice was occurring, guidance from the teacher was also being provided. This guidance included both direct help and coaching which was gradually withdrawn as knowledge of the target process was gained. Repeat demonstrations were also used during which the students were required to provide the reasoning behind the decisions being made by the teacher. Questions included such things as why did I choose that algorithm? Why was the sketch placed there? Why was the extrusion done symmetrically about the work-plane?

Cooperative learning or group problem solving activities was also used as a means of developing strategic 3D-CAD knowledge. The workbook was initially used as a basis for group discussion with each group being given a different model to work on, to decide on the best modelling strategy and to then report back to the rest of the class. This instructional technique provided an opportunity whereby teacher intervention could occur in a public environment where all students could observe the process. It also facilitated group decision-making and the need to choose among alternative solutions, which in itself provides discussion regarding the utilisation of various processes. Seeing other students struggle with the problem-solving process also had the advantage that it helped to overcome some individual student insecurity. Later students provided their own examples for discussion.

It is interesting to note that the new pedagogical approach involved students spending less time on the computer and more time in sketching, discussion and analysis. However, my research found that, when compared to students who had command and specific procedural command instruction only, and therefore more time on the computers, those exposed to the new approach had equal command knowledge but greater strategic knowledge.

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