Novel approaches for teaching and assessing CAD

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Abstract

This paper discusses a number of novel approaches for teaching and assessing the use of computer aided design tools for undergraduate engineers. Whereas as recently as 5 years ago it was acceptable for graduate engineers to leave university with little more than a cursory knowledge of CAD, it is now essential that engineering students graduate from University competent in the use of these tools.

Traditionally teaching CAD has focused on giving students the skills they need to build a certain type of model in a specific CAD package. This paper takes the perspective that it is the students ability to understand how CAD tools work that will enable them to become self sufficient - skilled CAD users. As such the learning outcomes include the links between different aspects of the CAD model and the design intent that should be adopted when creating models.

In the authors' University the majority of CAD teaching takes place in computer laboratories, where the students are set specific tasks to complete in order to become familiar with the tools. This paper details strategies for engaging with students as part of these sessions to ensure they can also be used for formative assessment.

This paper also presents and evaluates a number of different approaches for formally assessing CAD. Whereas traditionally CAD has been assessed in terms of a student's ability to complete certain tasks, which presents problems for summative assessment. This paper presents an approach where the methods of assessment are focused on learning outcomes related to how a CAD system works. Students are no longer required to simply submit CAD models or drawings for assessment, but assessment is also focused on determining how much the student understands about how the model was built, or why they decided to create their model in a certain way. While introducing this new learning and assessment approach the authors have made special efforts to ensure that the time required to assess the course is reduced.

1. Introduction

Engineering design is taught to engineering students throughout their degrees. Its purpose is to teach students the essential elements of engineering required to design a new product. Where as many engineering subjects are theoretical, design has traditionally been practical and used to give students an "enjoyable" experience of the design process. Dutta and Haubold [1] comment that "Introductory first-year engineering courses are imperative to spark student interest in engineering. These courses need to be designed to cater to students with varying interests and different levels of technical background, while introducing students to engineering design as it would relate to their educational career. This is important since basic design skills are important to all fields of engineering design."

Traditional engineering design courses were focused on engineering design skills such as engineering drawing using drawing boards, but their learning outcomes must change to reflect the highly computational advances made in the field of engineering design, in particular the use of computer aided design (CAD) software which is the modern method of creating 3D computer models of components, building assemblies, and producing the engineering drawings created by hand in the previous module structure. This change is needed to equip the students with the knowledge and skills current engineering employers are seeking.

One of the main difficulties faced in engineering design is the varying starting abilities of the students. Yue [2] identified that some students are entering higher education engineering courses having been taught CAD in school, where as others have not. In an attempt to gauge the extent of this issue a survey was conducted of a class of 140 first year engineering students who's abilities ranged from those who were unaware of the existence of a CAD system, through to those who had completed a City and Guilds qualification in the subject. The starting abilities of the students who completed the questionnaire are shown in Figure 1.

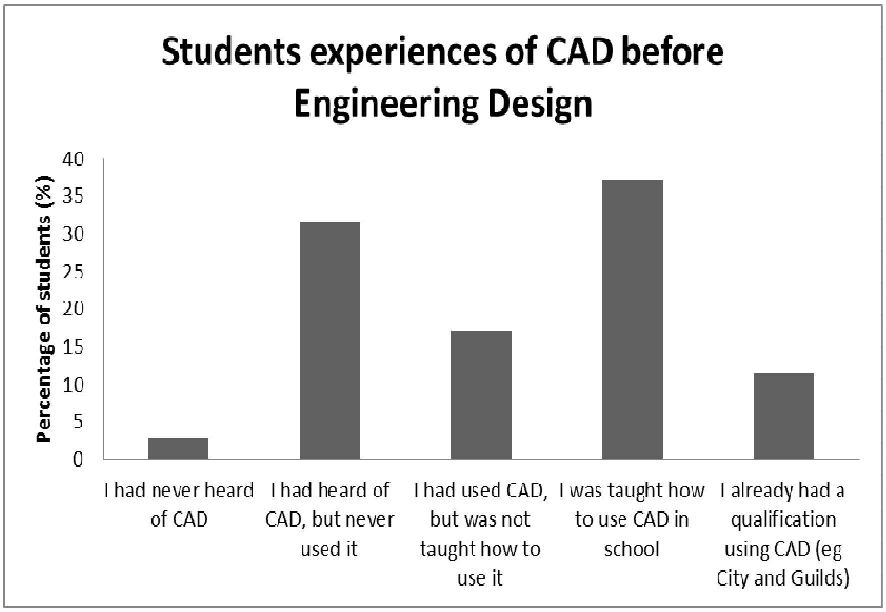

Figure 1. Students' experiences of CAD when coming to university

As the learning outcomes of the City and Guilds qualification are likely to cover all of the learning outcomes in an engineering design course where CAD is introduced, there is a concern that for students who have completed the City and Guilds qualification there will little new learning in an engineering design course. In the authors' opinion a course structure must be devised where all students experience learning.

2. What is required from a modern engineering design course?

2.1 Should CAD be taught in engineering design courses?

The first issue to be considered is whether computer aided design is an appropriate subject for introductory engineering design courses. Not all educators agree that such learning outcomes are appropriate. Yue [2] describes opinion as being split between whether:

- CAD should be taught as a subject in its own right
- CAD should be taught as part of a design subject, or linked to a specific project
- CAD should be an assumed ability, much in the same way as it is assumed students can use Microsoft products such as Word, PowerPoint or Excel

It is clear that there is a large amount of learning when starting to use a CAD system. Murphy and Jensen [3] noted "the steep learning curve of 3-D solid-modellers stipulated a move from the 3 lessons devoted to Engineering Design to a full course incorporating many aspects of the software tool." They conducted a study comparing three different approaches to teaching CAD. The three approaches they evaluated were:

- A short course where an overview of CAD was given, and the simple 2D aspects experienced by the students
- A full course involving all the detailed aspects of 3D CAD modelling
- An integrated course where a reduced set of learning outcomes from the full course were taught and the teaching of CAD integrated into a course where its use was also investigated.

After an evaluation of these approaches they propose a solution where CAD was taught as part of a design course where: "Students were required to learn the software, from drafting to assembly creation, during the first half of the semester and then apply the software to an original or re-design problem during the second half of the semester." Their rationale for doing so is that integration of CAD into a design course covers three out of the four areas of the Kolb cycle.

Some engineering design courses that the authors' are familiar with base engineering education around projects. Dym et al [4] comment that such courses "are increasingly referred to as providing design or project experiences, thus exemplifying Kolb's model of experiential learning."

It is the authors' opinions that the assumption students know, or will be able to self-learn CAD, is too great an expectation, and that it is necessary to devote a significant amount of time to teaching it. Out of a class of 140 first year engineering students 89% stated they did not feel they would have been able to teach themselves CAD. It is noted later that "expertise" in CAD is more than knowing how to use CAD software, but is being able to also understand how it works, and the most appropriate CAD modelling features to use to create models for different applications. In the authors' opinion this type of learning cannot be self-taught. Conversations with industrial research contacts have highlighted that many self-taught CAD users have bad habits which are unacceptable to employers.

2.2 How should CAD be taught in engineering design courses?

Before establishing how best to help and equip students in learning CAD, it needs to be established what students should learn. When it comes to CAD and design there are a range of opinions, divided for the most part between those who believe students should be taught how to use a specific piece of software, which, in the authors' opinion will result in shallow learning, and those who feel students should be taught to understand the theory of how models can and should be constructed, including why different approaches to modelling are preferable depending on the application of the model. To the authors opinion this type of knowledge can only be achieved by equipping students to learn at higher levels where they are required to analyse and evaluate the software and its usage for themselves.

Chester [5] commented that "One relative constant is the dominance of a didactic pedagogy being used to teach 3D-CAD in both schools and industry". A good example is Reffold [6] who taught CAD in a lecture format with students following step by step what they saw on the board. A course structured in this way allows students to learn what each of the CAD modelling features in the different steps do, but it is unclear how this approach will help them to select the appropriate features to use for a particular application.

In the authors' opinion, and that of surveyed contacts from industry, it is the ability to identify and use the appropriate features to create a particular shape that makes the students proficient users of CAD, and this in essence summarises the learning outcomes of Engineering Design 1 in 2009. These abilities should be contrasted with the "expertise" referred to by Chester [5] who stated that:

“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)”. Industrial research collaborators of the authors’ endorse this view. They state that graduates know the steps to follow to construct CAD models, but do not understand the most appropriate way of constructing a model for a particular application.

Chester [5] recommends that students should spend more time understanding how models should be built instead of learning how to build them. This could lead to the assertion that the theory is of primary importance over practical skills, however the authors’ opinion is that to focus only on the theory, and not give the student sufficient opportunity to experience using the software, they will experience “shallow learning”.

2.3 Why is CAD taught in engineering design courses?

The goal of teaching CAD as part of a university engineering degree is to equip the students with the skills they will require when they gain graduate employment. When they find employment many graduates are expected to utilise CAD tools which are not the tool they were taught to use. Although most CAD systems operate in a similar way, if the student only knows the steps they are supposed to use, learned through repeating steps demonstrated on a board, they will find this transition extremely difficult. Yue [2] noted that many graduates returned to his institution to retake the same course they had taken previously, simply because the CAD system used had changed.

However, if the students have learned the function and use of the different features, they should find adapting to the new CAD package relatively simple as they will be able to apply their learning to determining how to do the same operations in the new software. Clearly this is the ambition for graduates and engineering design courses should help equip them for this.

2.4 Difficulties with teaching CAD in engineering design courses?

One of the difficulties faced when implementing the new module was how to communicate to students what it was they were required to model using CAD. This is similar to a concern raised by Jerz [7]. Typically this information is communicated using sketches or engineering drawings which are a topic in itself, and an output of the CAD modelling they are being taught. Jerz [7] concluded that the start of a CAD course should consist of teaching sketching on paper to help visualise what is being modelled and that CAD modelling should follow after sketching has been learned. A similar approach is adopted by Myszka [8], although the solution here is to have the initial sketching/drawing as a separate module.

McCarthy [9] also observed that “Practising engineers spend far more time reading drawings than actually creating them, yet this is a skill which is often overlooked.” This is an issue the authors have been made aware of when having discussions with students in the practical sessions associated with their own courses. Therefore the authors feel the ability to understand engineering drawings needs to be reflected in the module learning outcomes. Of 140 first year engineering students surveyed 20% of students disagreed with the statement that they were able to understand the engineering drawings they were given in class, which meant it was impossible for them to create the CAD model they were being asked for.

3. The importance of assessing CAD learning

Engineering design subjects are difficult to teach and assess, a view shared by Armarego and Roy [10] who state “Learning design skills is, however, a non-trivial problem: there are no simple means of teaching them and assessing their development in a totally objective way. Design remains, as perhaps it should, a part of the art that makes an engineer a designer.”

The difficulty in objective assessment has also been noted by Dutson et al. [11]) who state "The very nature of design courses often leads to subjective evaluations."
Traditionally engineering design subjects are continually assessed, which is viewed by many of my colleagues as the best form of assessment, as it allows you to help students learn through constant monitoring of their work and feedback. Although good in theory, Murphy [12] comments that, "continuous assessment can still focus on summative assessment goals such as 'assessment for grading', unless genuine attempts are made to use such processes as the basis for feeding back."

Many design courses are continually assessed, and as such regular submissions are required from students, however Race [13] suggests that when students are faced with repetitive assessment their focus is on the submission of the assessment but their overall learning is not deepened. Heywood [14] identified: "The rise of interest in continuous assessment in Britain brought with it the idea that 'everything should be assessed'".

Another reason continuous assessment is preferred in design subjects is logistical. Design is a practical subject, and to properly assess the learning objectives the use of engineering design tools and software is required. These cannot be accommodated in a traditional examination setting. This is especially true as most CAD packages require high end computing hardware, the like of which is not available in a typical examination hall.

In the authors' opinion the lab based format of the traditional engineering design course lends itself to the majority of practical sessions becoming formative assessment sessions during which feedback is provided but no submission is required, with summative assessment exercises, which make up the final mark in the subject, happening three or four times throughout the course. This also allowed students to be well rehearsed in the requirements of the course. Race [13] states "where there is only end-point formal assessment, earlier opportunities should be provided for rehearsal and feedback."

3.1 Formative assessment

Race [13] identifies that "ideally, feedback to students should be continuous." In the formative assessment sessions students are given tutorial questions to complete. At the end of each question they are asked to have their work checked by a postgraduate demonstrator or the lecturer, at which point feedback is provided. A record is kept of completed questions allowing participation to be monitored rather than just attendance. Race [13] also commented that "students may not have had the opportunity to make sense of the feedback they receive, particularly when there is a delay getting feedback to students." The continual nature of the feedback which happens in a practical session like as described is continuous, whereas marking a submission from each student would mean there would have been a feedback "lag".

Brown et al. [15] comment that "students need constructive feedback on their performance – otherwise learning is minimal". Due to the nature of the subject it is not always the outcomes of the questions on which feedback is required, but on the methodology and reasoning. This information could easily be discovered when the student is available for discussion, but would have been impossible to determine had the work been submitted.

To determine the students feelings on feedback of this nature 140 students were asked to consider the statement "I consider having each tutorial question checked, and errors highlighted, is feedback". The average score was 4.6, where 4 was for "Agree" and 5 was for "Strongly agree".

3.2 Summative assessment

Where summative assessment is used it is the authors' opinions that that task should simulate working life as closely as possible. It is proposed here that during summative assessments students should be allowed to make use of their lecture notes, and other material. This is in concurrence with the view of Habeshaw et al. [15] who noted that "In practice professionals do not rely heavily on memory for information: they keep key textbooks and other reference sources at hand and consult them when they need to" and concludes "it does not seem sensible to deny students access to these everyday tools of the trade". In industry design engineers would have access to documentation, so to deprive them of it in an assessment setting is to destroy the simulation.

Race [13] encourages assessors to make "sure that we're using assessment to measure exactly what we set out to measure – students' evidence of achievement of the intended learning outcomes". One factor that the authors' have observed is that many students suffer from poor computer literacy, but in courses which focus on CAD it is hard not to penalize the student for this as it is probably not a learning outcome of the course. To mitigate against this the authors propose that every assessment should have an element which does not require the use of a computer, giving the student the opportunity to demonstrate learning without using a computer. Clearly where the learning outcomes are based on the use of CAD such mitigation may not be possible.

4. Methods of assessing CAD learning

As part of a stage 2 Product Design Class, students were taught an Advanced CAD course having learned the basics at stage 1. A mixture of assessment methods were used, including individual report submission, interviews and submission via video with audio commentary. An approach of the students simply submitting their final CAD model for assessment was deemed unsatisfactory as we want to assess the students CAD knowledge and not just their ability to create a model. Initially when the course was designed the assessment procedure consisted of students submitting 4 reports -one for each assignment required to complete the course.
The danger with this approach was that the students were effectively being assessed on their report writing skills rather than their CAD skills. There were several examples of students who had demonstrated good CAD knowledge during the formative assessment process but whose final marks did not reflect their CAD ability thus concurring with observations made by Race [13]. Most students also complained about the time required to write a report and its lack of relevance to the course. To improve the situation 2 new assessment approaches were implemented. These consisted of student interviews and an opportunity for the student to submit a summary of their work via video with audio commentary

4.1 Interviews

In one assignment the students were asked to attend an interview whereby they had to give a 5 minute presentation summarizing their work followed by 10 minutes of questions which were a mixture of specific questions on their work and general questions on the subject area e.g. "Why did you use a loft to create this section rather than a sweep?". As an assessor this was undoubtedly the most reliable method of assessment. Following the completion of each interview a clear picture emerged of exactly how much a student had understood what they were doing thus enabling the assignment to be assessed based on the students expertise as defined by Chester [5]. The downside of this approach is the time required for the interview. With 140 students a 15 minute interview would take a full working week which would not be practical, however in this particular class there only 19 students meaning the interviews were complete in less than a day. The time taken for the interviews must however be balanced against the time taken to mark reports and provide satisfactory feedback to students. One of the other big advantages of the interviews is that the feedback to the student can be instantaneous. A disadvantage is that a large pool of questions is required to ensure a fair assessment of the students. It became obvious that as the interviews went on students had been briefed by their colleagues. The student's opinion on the interviews was mixed. Some preferred it so that they didn't have to write a report, others thought the interview process intimidating and through there performance suffered as a result.

4.2 Video/Audio submission

Students were given the option for one of the assignments to submit a formal report or submit a video. A video and audio log of their work could be recorded using the Camtasia software enabling the student to record the commands they were using to create their CAD model and make a commentary of what they doing and why they were doing it. Surprisingly only 2 out of 19 students took the option of the video submission. As the marker the author found the video/audio submission easier and more enjoyable to mark. It provided a better insight into the methodology used in creating CAD models thus again enabling "expertise" (Chester [5]) to be assessed rather than ability to follow/mimic instructions to create a CAD model. The students were questioned on their thoughts of this assessment method. Both students had similar thoughts in that they found it a more enjoyable experience than writing a report but found that it was just as time consuming to do as they needed to prepare the audio commentary to ensure a professional presentation on the video. The students who chose to submit via report were questioned on why they hadn't taken the opportunity to use the video submission. The majority response was that they didn't want to waste the time learning another piece of software.

Discussion

The authors' believe engineering design modules should teach CAD, and the theory behind how and why models should be constructed in a certain way. Later modules should allow the students the experiential learning which is gained through applying their CAD learning to generic, real world design problems. This is similar to the approaches employed by many of the educators cited earlier.

It is hoped that by doing this, even students who have previous experience in CAD will achieve learning. Learning outcomes should also be included related to the student's ability to understand the drawings used to portray to students what it is they are required to model.

However through a questionnaire given to students on completion of the course, it was shown that in general students felt there was a significant increase in their CAD abilities as a result of Engineering Design 1. On average the sentiment rose from a feeling of being able to do very basic CAD modelling with difficulty before sitting Engineering Design 1, to being able to do reasonably complex CAD modelling with ease. Hopefully new learning outcomes at the higher levels of Bloom's Taxonomy will increase the learning of the entire class even further.

In terms of assessing CAD, it is important to have a means of assessment that identifies what the student knows and understands of the process of creating a CAD model. Through the submission of a report on their work it is difficult to gauge if the student actually understands what they are doing or are simply following a series of commands. Assessment via video/audio submission and interviews has been conducted as alternative methods of assessment. Both of these methods of assessment solve this problem, giving the opportunity for the student to easily present evidence that they understand what they are doing. For classes with small numbers (< 30), it seems that the most reliable and efficient method of assessment for CAD is through student interviews.

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