3D PRINTING: IMPROVING CREATIVITY AND DIGITAL-TO-PHYSICAL RELATIONSHIPS IN CAD TEACHING

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ABSTRACT

Some undergraduate design and engineering students can struggle with many of the abstract concepts of producing a CAD (Computer Aided Design) model. Features often have to be formed linearly and logically to build up the design intent of an object. Bosses need to be 'added', 'extruded' or 'protruded'. Holes need to 'cut', or 'cored' out of a shape. Some of these 'building' principles are similar to the construction of a 3D hand-drawn sketch, where features are added or subtracted to form the final shape. Both 3D sketching and 3D CAD modelling practices require good understanding and interpretation of 2D orthogonal views to understand 3D geometry. Difficulty arises when parts come together to form assemblies and relationships within a separate environment. Additional difficulty is found when students have to convert 3D objects back into 2D draft drawings. The 2D to 3D and 3D to 2D relationships can be somewhat confusing-but they are vital for engineering design and drawing. To improve the understanding of CAD practice, 3D printed objects have been introduced to enhance teaching activities. The introduction of 3D printed models has been well received, with better student engagement and an understanding of a 3D object within digital and physical space. Students are now inspired to expand their modelling knowledge as now, what was a simple vehicle modelling assignment, has developed into a creative student challenge where the end goal is a physical 3D-printed model of their own CAD work.

Keywords: Computer Aided Design (CAD), 3D Printing, Creativity

1 INTRODUCTION

Proficiency in CAD is an important skill for a designer or engineer. The aim of introducing first year Mechanical Engineering students to CAD is that they will be able to carry out simple design tasks using the software. At the same time, these students are introduced to design processes and visual thinking, producing and interpreting engineering drawings as well as freehand engineering sketches. These activities relate directly to the design projects students will be undertaking in their studies as well as their future careers. Within the first semester CAD skills and design processes/visual thinking are unrelated-separated into different teaching units.

All this is part of the first formative years of a Mechanical Engineering student; however the entry requirements of many engineering degree programmes focus heavily on Mathematics and Physics qualifications. It is only in some more design-orientated courses would one find requirements for D&T (Design & Technology) or Art & Design. Therefore, many engineering students start their academic career with little or no qualifications in drawing, visual thinking and design process. This is despite several pieces of research that indicate skills in visual thinking and spatial awareness contribute to career success in Engineering [1][2].

This is why our Mechanical Engineering students have to start with the basics, producing 2D orthogonal engineering drawings with drawing boards, interpreted from 3D views. After that, they produce 3D isometric views interpreted from 2D orthogonal views, progressing into perspective drawing and freehand sketching.

Equally, students are introduced to CAD from the basics; they learn how to build a part using features, progressing into assemblies using parts, exploded views and 2D drafting. The main learning outcome of these classes is to carry out simple design tasks.
Despite being two separate teaching activities; there is some crossover between drawing 3D objects by hand and using CAD. For example, there is the geometry building technique-in which students draw construction boxes and add or cut geometry away to form a 3D shape (Fig 1.).

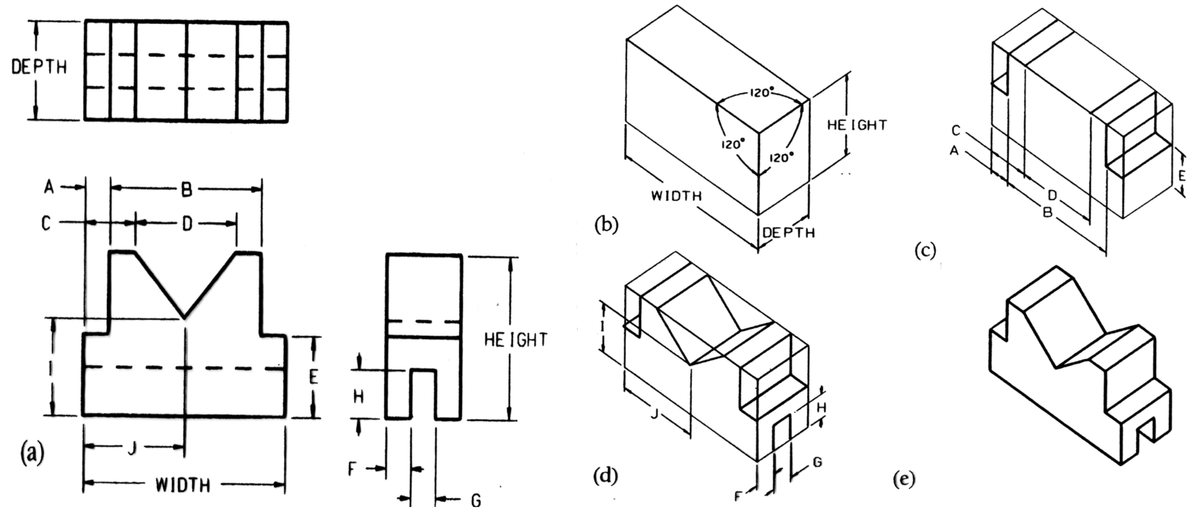

Figure 1. Isometric geometry building from orthographic drawing [3]

This is very similar to the process of adding or subtracting features on a model in CAD. In both cases, geometry and dimensions are defined by orthographic projections. An isometric projection is built from the dimensions defined in the three principle iso views. Equally, 3D geometry is defined from 2D sketches and their respective geometry and dimensions in CAD.
Further crossover is apparent in assessment. For example, students in the sketching classes need to produce 2D engineering drawings from 3D views. They also need to sketch 3D isometric views from 2D orthographics. Finally, they represent an isometric or perspective view of exploded assembly. All of these sketching activities utilise physical artefacts. Students in the CAD classes are required to produce a 3D CAD assembly by producing 3D parts from 2D engineering drawings. They ultimately need to represent the 2D CAD assembly as a 2D engineering drawing and exploded views. Physical artefacts have not been used-until now.

2 3D CAD ‘AND’ 3D SKETCHING-THE PROBLEM

As two separately taught activities, CAD and sketching have a major crossover when it comes to student learning outcomes-and that is acquirement of spatial awareness. Students who struggle with sketching practices can also struggle with CAD. This is because both drawing and CAD involve ‘graphic ideation’ [4] and involve ‘mentally rotating and manipulating images’ [5]. This lack of spatial awareness seems to be common with international students [6] and can be evident in female students [1] but is slowly becoming not so un-common in many home and EU students coming into University with little background in drawing and 3D visualization-attributed perhaps to less sports and craft activities in secondary education [1]. This apparent lack of creativity, special awareness and making skills is why the traditional network of subjects associated with Mechanical Engineering; STEM (Science, Technology, Engineering & Maths) is currently being re-branded STEMA in the UK and STEAM in the US, with the inclusion of Art&Design.
Another problem is that some students do not make the association between engineering drawing practice drawn by hand and that drawn by computer. In the second semester, students are required to use their acquired skills in producing 2D manufacturing drawings for a prototype-designed in CAD. The drawings are expected to use third-angle projection, correct dimensioning and relevant sections but some students struggle with this. Having CAD and sketching as two separate activities in semester one does not help this learning outcome.

Equally, when it comes to building the prototype-some students struggle to interpret the drawing-quickly realizing that designing a prototype in CAD and physically building it accurately is a challenge. After all, making mistakes and understanding how the prototype is made and operates is a key learning objective of this particular exercise.

3 BRINGING CAD TO LIFE-3D PRINTING

Having observed students struggling with spatial awareness as well as part and assembly construction in CAD classes, it was proposed to introduce physical teaching aids to assist the students. Within the teaching sessions, students use in-built, step-by-step CAD tutorials as well as challenging exercises to build up proficiency. The students are assessed by creating parts of a toy car in CAD (Fig 2.), interpreting from 2D orthogonal views, creating an assembly and then producing a 2D assembly draft drawing and exploded view.

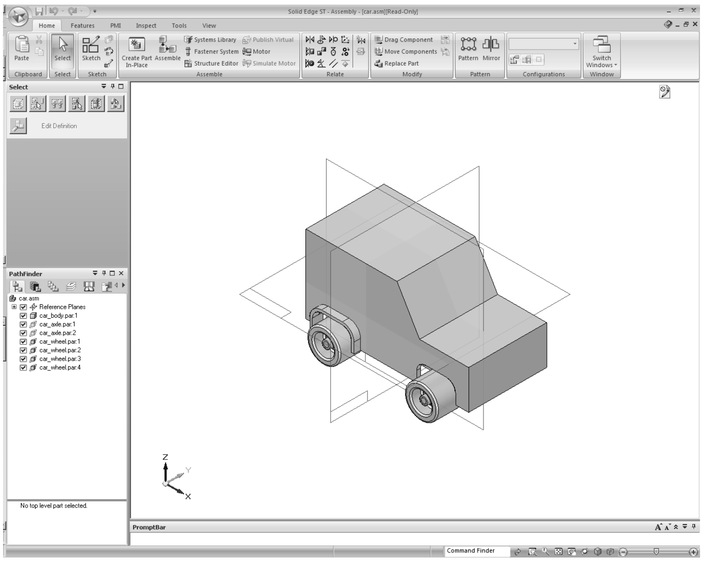

Figure 2. CAD assembly model of toy car

At the time, the department had newly acquired desktop FDM (Fused Deposition Modelling) 3D printers (Fig 3.)-which replaced powder-based 3D printers in the workshops. The FDM printers were ideal for this task as producing models on the powder-based printers would have been time-consuming and cost prohibitive. The 3D printers can produce simple, cheap ABS or PLA models from CAD data. The inclusion of these small, affordable printers has greatly enhanced accessible prototyping activities within the department. Soluble support FDM printers are also being considered to improve model quality.

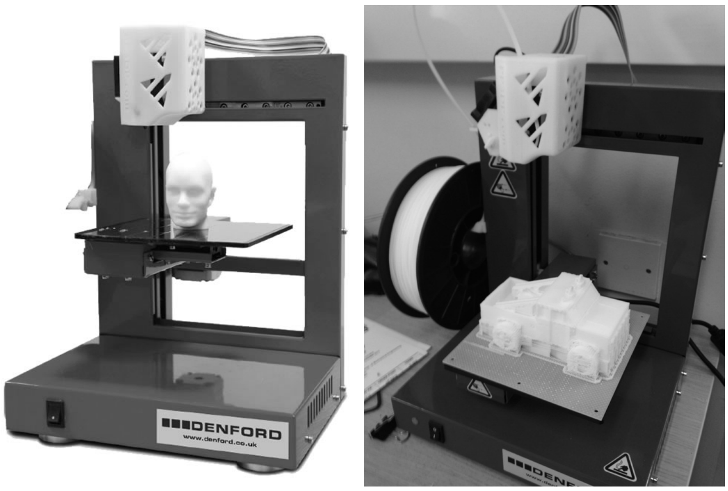

Figure 3. PP3DP Desktop 3D Printer producing a car model

With a 3D assembly of the toy car, which can be touched, rotated and taken apart, students were able to understand key construction features in parts, as well as how parts go together to form an assembly. It brought their CAD activities into context, where they were able to see a physical representation of their CAD model-generated from CAD data (Fig 4.).

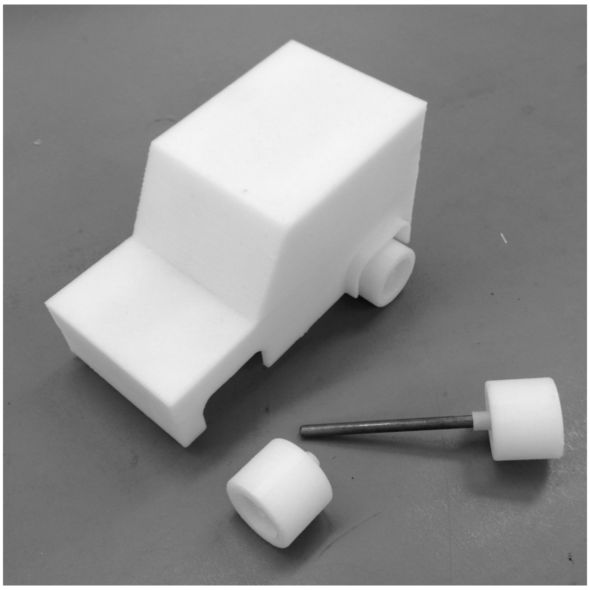

Figure 4. 3D Printed model of basic toy car assembly

4 IMPROVING CREATIVITY USING 3D-PRINTING

Producing a 2D orthographic drawing and exploded view of CAD assembly is the minimum submission requirements for the CAD assessment. It is expected that students spend time customizing their toy car in CAD by adding features like lights, radiator grills and wing mirrors to the model. One can see that the geometry of the toy car is basic-it represents a blank canvas that students can be creative with. The key incentive of this customisation process is that students attain extra marks for additional features. This has been enhanced by introducing 3D printed models of 'best of class' toy cars to inspire the next year (Fig 6.). As with the teaching aids, these 3D printed models also assist with spatial awareness and feature construction.

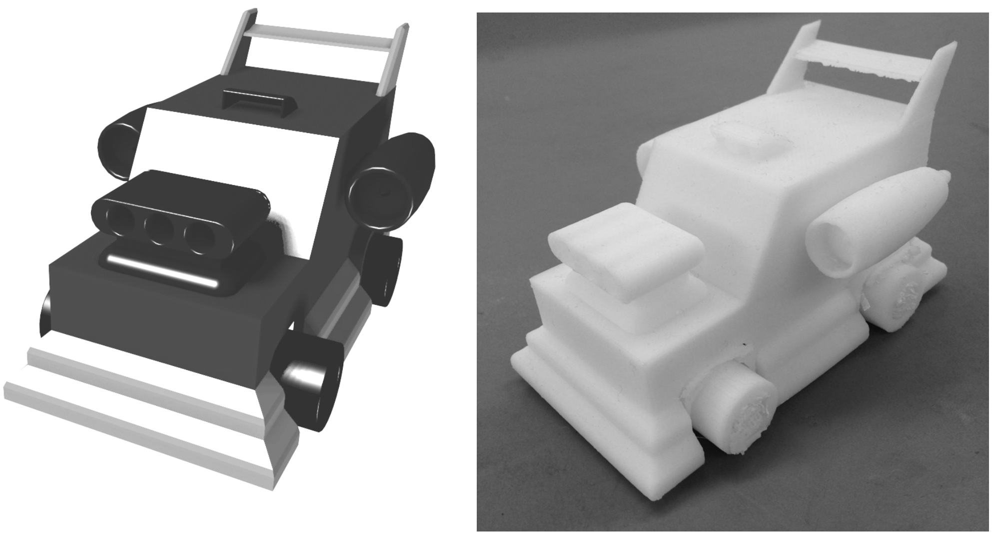

Figure 5. 3D CAD model and 3D print of a customised toy 'rocket car' with additional features

After each class, the best car is chosen by the teachers and the winning student is contacted to transfer the CAD files. The students tend to be keen in seeing the 3D printing process in action and their finished model-which is beneficial as they will become accustomed to prototyping in the next semester. Also, similar reward based methods for enhancing CAD teaching has produced promising results in secondary education D&T classes [5].

Thus, the incentive to be creative has been enhanced as students are:

- able to have their creative output physically printed as exemplars
- keen to out-do their predecessors and produce a winning car
- able to keep their models once the following year has run its course

Equally, the more features students add to the CAD model, the more marks are attained. This incentive is key in bringing the class average distribution of marks up. It also helps engage students who would otherwise pass with an average grade. Some additional learning outcomes of the enhanced CAD teaching could now include:

- Enhanced 3D spatial awareness, visualization skills and creativity
- Introduction to 3D printing to build physical models from CAD

5 INDICATIONS OF ENHANCEMENT

The following table shows the changes in average mark percentage for the CAD coursework submission, along with standard deviation, over four academic years (Table 1.).

Table 1. Average mark difference and SD

Academic Year	**Difference in average mark from previous year(%)**	**Standard Deviation (%)**
2010 to 2011	+1.99	14.91
2011 to 2012	+2.83	12.22
2012 to 2013	+3.08	11.12
2013 to 2014	+1.12	11.84

The following graph represents an infographic of average mark improvement, annotated with changes to the CAD teaching element over time (Fig 6.).

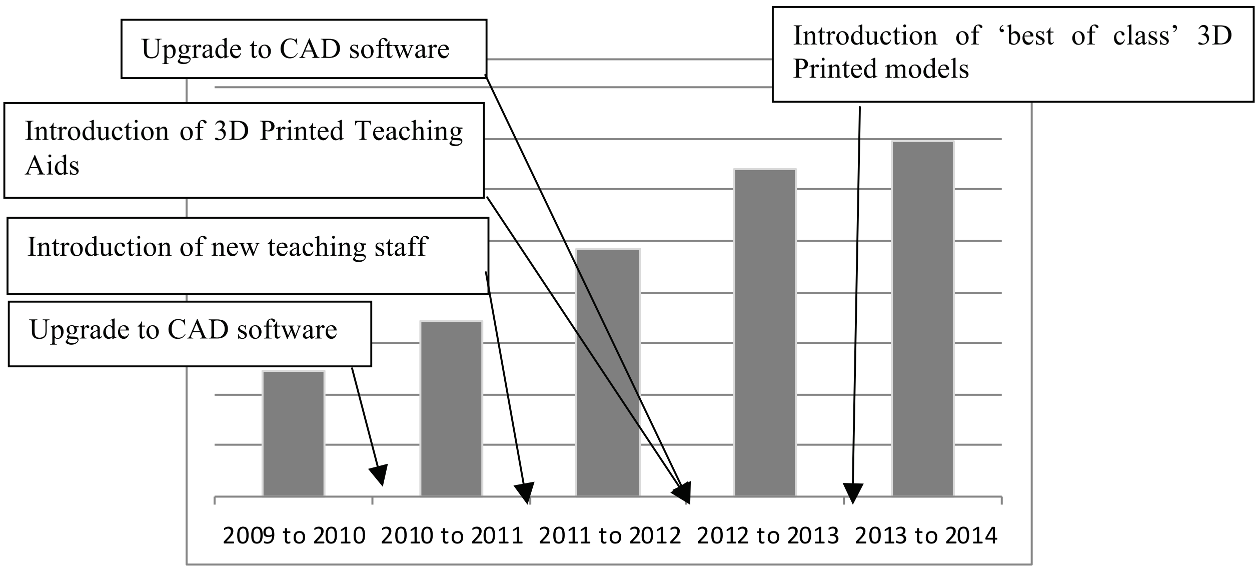

Figure. 6 Graph of average mark improvement

From observation, one can see a steady increase in average marks, regardless of inclusion of 3D printed teaching aids. However, note that the year of inclusion shows the largest increase in marks.
Other factors to note are the bi-annual upgrades to CAD software, which generally improve user interface and tutorial-based learning. Also, new teaching staff were introduced in 2011. The inclusion of 'best of class' models may have led to a slight improvement in results, however, the competency of students (now that CAD is accessible at secondary education level) also tends to increase. There are also external factors-such as computer gaming [1] when considering enhanced spatial 3D awareness.

7 FURTHER WORK & DISCUSSION

It is difficult to fully ascertain improved creativity and spatial awareness from summative marks alone. An alternative method could use spatial awareness exercises such as the Purdue Spatial Visualisation Test [7]. However it is difficult to isolate CAD teaching as students are currently enhancing their spatial awareness with drawing and model-making activities. Perhaps this is a cause of the problem-CAD teaching should not be isolated from 2D hand-drawings as well as 3D physical models and prototypes as they are interlinked, associated activities. For example, within a real physical space all views are naturally perspective-both 2D drawings and 3D CAD models can help explain and represent this phenomena-further enhancing spatial awareness.
The separation of CAD and hand-drawing in different teaching units could be due to legacy-and simply not appropriately updated for 21st century engineering practice. Plans to move CAD teaching into a design-led unit are being currently discussed. Hopefully this will improve the association of CAD with sketching, design processes and engineering drawing. The enhanced creativity element of CAD teaching would also help reinforce the change. In this respect, CAD could be taught in harmony within the design-orientated unit, with CAD visualisations supporting sketching activities.

8 CONCLUSION

It's hard to judge spatial awareness and understanding on summative information alone. A fundamental conclusion is the process and principles of teaching CAD and 3D sketching are interlinked-and support visual thinking and spatial awareness. To enhance further, artefacts can be used to improve spatial awareness, feature construction and assembly building. Accessible and affordable 3D printing technology can aid in the construction of 3D teaching aids-which could enhance 3D spatial awareness, understanding and promote creativity, however this requires further verification.

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