INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2012, ARTESIS UNIVERSITY COLLEGE, ANTWERP, BELGIUM

ASSESSING THE 3D VISUALISATION SKILLS OF ENGINEERING STUDENTS AND DEVELOPING TECHNIQUES FOR SUPPORT

Mark MILNE, Richard MORRIS, Tim KATZ and Derek COVILL
School of Computing, Engineering and Mathematics, University of Brighton, Lewes Road, Brighton, BN2 4GJ

ABSTRACT
The aim of this study was to investigate the 3D visualisation skills of a group of engineering students undertaking a first year BEng course in Mechanical Engineering, and in particular a module in Computer Aided Engineering and Design. It had been noted that some students arrive on the engineering course with a mix of abilities in drawing and visualisation, and that difficulties in spatial visualisation proved to be a barrier for progress for some students.
Difficulties in visualising objects in 3D can lead to issues in interpreting and creating engineering drawings and components, as well as problems visualising forces, effects and other concepts relating to the physical world.
A study was carried out using a standardized test to assess the students' competence in spatial visualisation. The scores were analysed and a group of students identified with potential problems. Study materials, Solidworks models and physical models were used to support the students in additional sessions to assess the nature of their difficulties, and improve their competence in this area. Periodic formative assessments were carried out to look for improvements and gauge the effectiveness of the support. The results provided clear tools for assessment and support for future teaching.

Keywords: Improving spatial visualisation, 3D visualisation

1 INTRODUCTION

1.1 Importance of spatial visualization

Engineering at degree level is often seen as a primarily numerical and analytical subject. Students at school are encouraged to look at a career in engineering if mathematics and a physical science are seen as strengths. Drawing skills (both engineering or Art) are not primarily assessed as indicators for a career in engineering. However, the ability to visualize objects, forces, moments and effects on physical bodies is vital to the development of core engineering skills, and Literature searches substantiate this. "Researchers have found that 3D spatial skills are critical to success in a variety of careers, particularly in engineering and science" [1]."Spatial visualization or the ability to perform complex mental manipulation of objects has been established as a predictor of success in several technology related disciplines" [2].
In discussion with colleagues across engineering disciplines including mechanical, product design and civil engineering, it was apparent that these views were shared. If students failed to visualise effectively, they were unable to correctly apply engineering principles. Visualisation was thus seen as a fundamental skill for engineers and designers, beyond the obvious ability to communicate through drawing or sketching.

1.2 Background to the problem

All first year mechanical engineering students undertake a 20 credit module in Computer-Aided Engineering and Design (ME111). This module starts with basic sketching and then develops skills in communicating engineering information, creating drawings on both traditional drawing boards and using a 2D drawing package (AutoCAD). A significant proportion of the class are non UK students, with many from Africa and the Middle East. Many students arrive on the course with little or no experience in drawing, sketching or producing engineering drawings.

The early part of the course concentrates on general observation and sketching of physical components and then moves onto basic orthographic projection. In recent years it has been observed that a proportion of students appear to struggle to convert from observing three dimensional objects and converting these into two dimensional drawings. There appears to be some significant issues in their ability to visualise in three dimensions. It was observed that some students were proficient in all other modules, but failed to pass the ME111. Even with additional support some failed to reach an acceptable standard.
On reflection and further discussion, it became clear that we could not identify specific teaching techniques to impart spatial visualisation skills, or even an awareness on exactly what this skill was. Why did one person seem able to visualise and manipulate 3D objects and convert between 3D and 2D representations and another struggle?
In order to assess this ability the class were tested using a visualisation test from previous years, and the results showed a good correlation between those students with a perceived issue and lower test scores, and those with high scores and fewer errors in 2D/3D work.

1.3 Literature Search

A literature search was undertaken to identify current thinking on spatial visualisation and how this could be assessed, what techniques proved effective in improving this skill, or indeed if this skill could be effectively 'taught' and if so, in what timescale.
It became clear from the study that a significant amount of research had been undertaken to identify tests and test types that provided a good predictor of success in engineering drawing or graphics courses. Sorby [3] reported that Gimmestad in 1989 found that the Purdue Spatial Visualisation Test: Rotations (PSVT-R) was the most significant predictor of success in a study conducted at the Michigan Technological University (MTU). Many of the other studies also used this test, and it was decided to source this and then test the whole class, which would allow comparison with results from other research studies, as well as identifying a suitable group for support.
In addition, MTU had also developed support materials and software which they had tested, and these showed proven benefits within several weeks. Given the need to develop a successful support class for current students, it was decided to purchase the workbooks and software for the class, and use these in addition to developing some additional materials including SolidWorks 3D models, and physical parts for visualization and sketching exercises. We were particularly interested in observing the students interaction with a range of techniques.
While our approach was a pragmatic one to identify techniques for support for current students, we were also interested in research that may have identified root causes, patterns or groups with difficulties in spatial visualization that may be useful in developing more pro-active approaches for early assessment and support for future students.
A number of studies have identified several factors including age, gender, individual differences and experiences that impact visualization ability [4].

2 METHOD

2.1 The PSVT-R Test

The whole class were tested using the Purdue Spatial Visualisation Test – Rotation (PSVT-R) developed by Bodner and Guay [5]. This test consists of a 30 question multiple choice paper, where an isometric view of an object is shown in two states, an original position, and after undergoing single or multiple rotations. A different object is shown, and the student asked to select the correct response from five possible answers using the same rotation or series of rotations. An example is shown in figure 1. To successfully answer, the student needs to be able to visualize the object in 3D and correctly manipulate this mental image.
The suggested threshold for the test is 60% correct responses out of the standard 30 questions. The students with a score of 60% or less were invited to take part in voluntary support classes lasting two hours per week over a nine week period. The group that attended were tested periodically (3 weeks) to monitor progress and the number of hours of support noted for each student.
In addition, those students that did not wish to attend but were willing to undertake a home study course using the workbook and software were also assessed.

It had been noted that students on the Product Design course did not appear to have the same difficulties with spatial visualization, and a random selection of 21 students from this group were also tested using the PSVT-R and their results compared with the ME111 class.

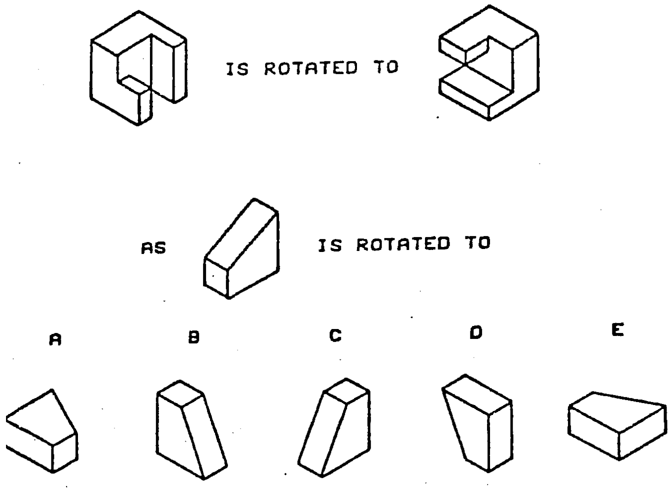

Figure 1. Example from PSVT-R Test

2.2 The Support Classes

The students participating in the support classes were asked to comment on the effectiveness of the three techniques:

1. Workbook and software
2. Using CAD Solid models
3. Sketching physical models in the 'blind' test

The workbook and software was provided by Delmar CENGAGE Learning 'Introduction to 3D spatial visualization an active approach' by Sorby and Wysocki [6].

The students used solid models of three dimensional parts using SolidWorks, exploring these by rotating the objects and creating cross-sections with a series of exercises based on existing solid models as shown in Figure 2 below.

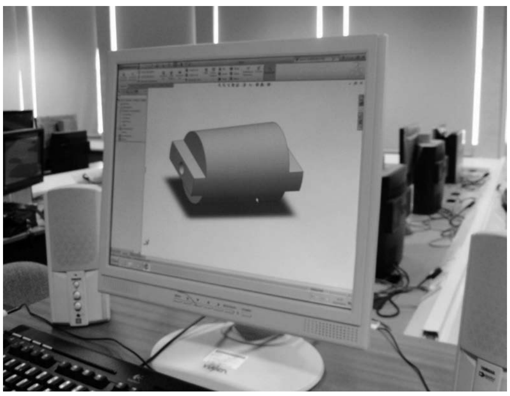

Figure 2. Exploring 3D using Solid models

The 'blind' test involved students having to sketch a 3D component in a bag (Figures 3 and 4), where they were only allowed to explore its features by touch, and therefore construct a purely mental visual picture of the part from which to then draw on isometric paper (Figure 5)

Figure 3. Examples of the physical parts for the 'blind' sketching exercises

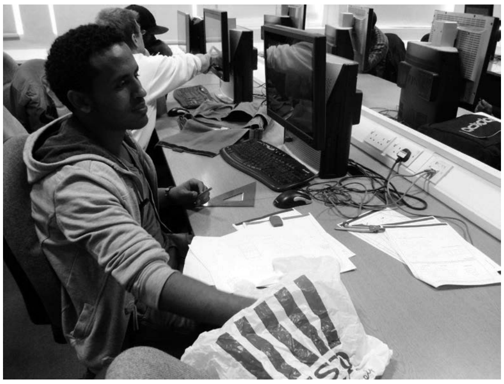

Figure 4. A student exploring a component by touch during 'blind' sketching

3 RESULTS

The ME111 class consisted of 116 students, of which 5% were female and 26% from African, Middle Eastern or Asian origin, with the majority of the class from Europe.
Of the ME111 class, 51 students sat the PSVT-R test and 15 students were identified with a score of 60% or less. These students were invited to take part in the voluntary support classes.
After three classes the support class students were re-tested using the PSVT-R and the results shown in table 1.

Table 1. PSVTR Results

Group	Average	Standard deviation
ME111 whole class (51)	74.7%	17.6%
Support Group (pre classes)	53.6%	12.3%
Product Design (21)	80.6%	17.0%
Support Group (3 classes)	70.8%	16.0%

The support classes were staffed by the course leader and the CAD instructor who provided one to one support to the students as required. It was observed that the students were very focused and quickly engaged with the workbook and software exercises. The variety provided by the CAD solid models where they investigated the relationships of views and explored the 3D shapes, along with the 'blind' sketching activities was commented on favourably by the students. The shapes were made progressively difficult and the students seemed to relish the progressive challenges.

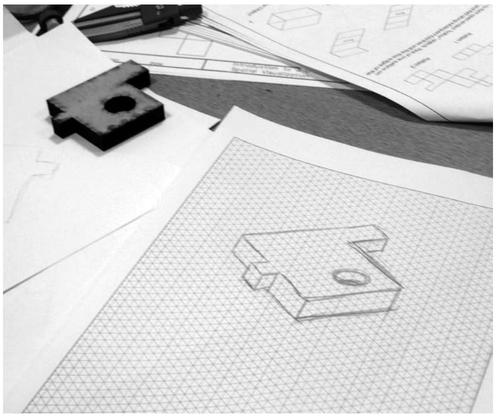

Figure 5. Completed 'blind' sketch

4 ANALYSIS

To date, even with a short period of support study, most of the students have shown a significant improvement in PSVT-R score with the average improving from 53.6% to 70.8%. This can be compared with other studies as shown below.

Table 2. PSVTR results from other published studies

Group	Pre classes	Post classes	Study
PoN	52.2%	63.8%	Ault and John 2010
Purdue	66.7%	80.0%	Harris 2009
VSU	52.2%	74.7%	Study 2006
MTU	51.0%	78.0%	Sorby 2007

The variety of exercises has been well received by the students, and this is borne out by the literature search which indicates that sketching is an important tool in the development of spatial visualization skills, and thus a range of approaches would seem to be both stimulating and effective. All the students responded favourably to all the methods, and commented that they found different benefits from each activity. The blind drawing activity was very useful in consolidating their skills and they found it both challenging and satisfying. An interesting observation was how focused the students appeared during the computer exercises, and how they appeared to visually manipulate the objects in space using their hands to 'virtually' rotate the objects as shown in Figure 6 below.

Figure 6. Student 'visualising' an object rotation during the workbook exercises

In difficult exercises they were observed to sketch the objects, and even use both orthographic and isometric sketches to aid visualization. Previously many of the students had simply guessed at the answers when they found it difficult to visualize, particularly in the multiple rotation exercises. As the exercises progressed the students were forced to connect visualization and drawing as a route to solving these problems, thus strengthening their spatial visualization skills.

Some of the students identified with low scores and invited to take part in the support classes were unwilling to commit to the additional time. It is envisaged that these students may undertake the workbook and software course as a home study activity. These students would be tested periodically and their results compared with the support class. If this proves successful, then a number of strategies can be adopted to assist students. Certainly, it appears that the support classes are significantly improving spatial visualization, and this should have significant benefits for these students both in successfully completing the ME111 module, and in the development of their general engineering skills.

5 FURTHER STUDY

The origins of the development of spatial visualization requires further study, and in particular some analysis into the observed increases in the percentages of African, Middle Eastern and Asian students exhibiting difficulties. A study comparing the spatial visualization skills of students from the Polytechnic of Namibia, with engineering students from the US [7] showed similarities with our results and observations. There is some research indicating that this may be due to their educational experience which is more analytical, and less involving play and construction [8]. Some discussion with the support students indicated this may be a factor. Exploring this in further studies may assist in developing earlier assessment and intervention to support these students, and allow them to develop the skills in engineering drawing and design, without the pressure and frustration of difficulties in 3D visualization.

REFERENCES

[1] Sorby S.A. Developing 3D spatial skills for engineering students*, Australasian journal of Engineering Education*, 2007, Vol 13 No.1, pp. 2.

[2] Strong S and Smith R. Spatial Visualization: Fundamentals and Trends in Engineering Graphics. *Journal of Industrial Technology*, 2001, Volume 18, Number, pp. 2.

[3] Sorby S.A. Developing 3D spatial skills for engineering students*, Australasian journal of Engineering Education*, 2007, Vol 13 No.1, pp. 4.

[4] Strong S and Smith R. Spatial Visualization: Fundamentals and Trends in Engineering Graphics. *Journal of Industrial Technology*, 2001, Volume 18, Number, pp. 3.

[5] Bodner G.M. and Guay R.B. The Purdue Visualisation of Rotations Test, 1/Vol.2. No.4, *The Chemical Educator*, 1997 Vol pp 8.

[6] Wysocki A F and Sorby S.A, *Introduction to 3D Spatial Visualisation: an active approach*, 2003 (Delmar CENGAGE Learning).

[7] Ault H.K and John S. Assessing and Enhancing Visualisation Skills of Engineering Students in Africa*: A Comparative Study, Engineering Design Graphics Journal*, 2010 Vol 74 No. 2.

[8] Sorby S.A. Developing 3D spatial skills for engineering students*, Australasian journal of Engineering Education*, 2007, Vol 13 No.1, pp. 2.