Bridging the spatial visualisation skills gap through engineering drawing using the whole-to-parts approach

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Abstract: *One of the objectives of teaching engineering drawing to engineering students is to develop their spatial visualisation skills. However, students enrolled into engineering programmes often posses mixed entry skills as far as engineering drawing is concerned. Some students may be "experts" due to their exposure to the subject in their secondary school education while others may find the subject to be new to them. This article reports a case study on spatial visualisation skills development involving a class of 29 first year civil engineering students from Kolej Universiti Teknologi Tun Hussein Onn, Malaysia. The group comprised 13 beginners and 16 experts. The objectives of the study were two folds, (i) to determine how large is the spatial visualisation skills gap between the experts and the beginners at entry level and (ii) to see whether using the whole-to-parts approach can bridge the skills gap in a half semester duration. The results showed that there was a spatial visualisation skills gap between the experts and the beginners at the initial stage, which was successfully bridged within half a semester using the whole-to-parts teaching approach.*

Keywords: *engineering drawing, sketching, spatial visualisation ability*

Introduction

Engineering drawing is a common subject across engineering disciplines. Development of spatial visualisation skills has often been cited as one of the goals of teaching this subject to engineering students (Osborn and Agogino, 1992 and Olkun, 2003). Spatial visualisation ability is defined as having the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimulus objects (McGee, 1979). Examples of spatial tasks used for measuring spatial visualisation skills are paper folding tasks (Lohman, 1996), cube construction tasks (Alias Black and Gray, 2002), whole object rotation tasks (Vandernberg and Kuse, 1971,) and engineering drawing tasks. Enhancing spatial visualisation skills in engineering students is important as this ability has been associated with success in problem solving in engineering (Alias, Black & Gray, 2003).

Teaching spatial visualisation skills through engineering drawing have produced mixed results (Atman, Adams and Turns, 2000), depending on a combination of factors such as the teaching approach and the students prior knowledge and skills (Sheppard and Jenison, 1997). Basically there are two approaches to teaching engineering drawing, the "parts-to-whole"

(PTW) approach and the "whole-to-parts" (WTP) approach. The PTW approach is a traditional teacher-centred approach whereby drill and practice is emphasised (Dori and Belcher, 2005) and students are taught in a sequential manner. Typical example of a unit of teaching in the PTW approach starts with drawing points, progressing to lines, to area (2-dimensional) and finally progressing to volume (3-dimensional). The author's over twenty years' experience of teaching the subject to post-secondary technical students indicates that even after receiving instructions at the 3-dimensional stage, students still find it hard to visualise the 3-dimensional object given the 2-dimensional representations of the same object.

The WTP approach on the other hand is the reverse of the PTW approach whereby students start from 3-dimensional object representations, constructing orthographic projections first which consists of plans, elevations and sections progressing to detail drawings. Using this method students get a feeling of the relationships between 2-dimensional drawing and their related 3-dimensional objects straight away (Chen, Zhang, Ou, and Feng, 2002 and Olkun, 2003). It is therefore expected that the WTP approach can produce accelerated learning of engineering drawing skills and spatial visualisation skills among students. The PTW approach is often seen as the best method to teach potential draughtsperson as their major task will be to construct engineering drawings. The WTP approach is less used except by a few instructors as this approach demands more creative efforts to design suitable learning tasks and more cognitive efforts from students (Roussou, 2004) as the completion of such tasks are less dependent on rote memorisation. The outcome of this approach is hypothesised to induce accelerated learning among students.

Engineering drawing curriculum

In Malaysia, engineering drawing is taught at all technical and vocational schools in the fourth and fifth year of studies. Only a few selected academic schools also provide engineering drawing training to students. The fact that not all schools offer engineering drawing means that new students in the engineering programme will not have even the basics of engineering drawing skills. Since engineering drawing experience contributes to spatial visualization skills, it was therefore hypothesized that spatial visualization skills of students with engineering drawing background is not similar to students without the background.

The general content (in terms of theories) of the secondary school engineering drawing curriculum is similar to the first year manual engineering drawing component of Kolej Universiti Teknologi Tun Hussein Onn's (KUiTTHO) curriculum. Some schools also provide basic training in CAD as part of their engineering drawing curriculum. The school curriculum provides two years of training in engineering drawing while KUiTTHO allocates one semester only for training on manual engineering drawing and advanced CAD engineering drawing. Although computer aided drawing skills is a must for fast production of drawings, manual engineering drawing is still taught to beginners in the University because it provides opportunity for students to develop a "feel" of actual scale and space, a skill that is not easy for the non-experienced students to acquire through computer aided drawing alone.

Problem statement

The need for an approach that supports accelerated learning in engineering drawing is high in KUiTTHO because undergraduate students often come with great disparities in engineering drawing skills. Within a class, some students may be very advanced while others could still be struggling beginners. Teaching the same materials to students with different skills level is not wise as every instructor will testify. A way has to be found to ensure that both groups acquire the same level of skills at the end of the course. In other words, the weaker group has to be improved fast but not at the expense of the more advanced group.

Research purpose

The purpose of this study was to determine if learning engineering drawing through the WTP approach will accelerate learning of spatial visualisation skills among engineering students without engineering drawing background. The hypothesis was "novices who are taught manual engineering drawing using the WTP approach will increase their spatial visualisation ability by an amount to be at par with the set criterion". The criterion used was the score of the expert group in the first test on spatial visualisation ability.

The results of the study were expected to be useful in providing a better understanding of how students learn which can be used for designing instructional strategies towards more effective and efficient development of spatial visualisation skills through engineering drawing.

Methodology

The participants comprised of a class of 29 first year civil engineering students who were divided into two groups according to their educational experience in engineering drawing. Thirteen students had not learnt engineering drawing during their secondary school education while 16 students had learnt engineering drawing in secondary schools. The group of 13 students with no engineering drawing experience was referred to as the novices and the 16 students with engineering drawing experience was referred to as experts in this study. The distribution of participants according to gender and groups is given in Table 1.

Table 1: Gender against group cross tabulation

		Group		Total
		Novice	Experts	
Gender	Male	8	11	19
	Female	5	5	10
Total		13	16	29

Instruments

Two instruments were used to measure spatial visualization skills, the spatial visualisation ability test (SVATI) by Alias, Black and Gray, (2002) and free-hand sketching test. The SVATI consisted of 28 items based on cube construction tasks, engineering drawing tasks and whole object rotation tasks. Examples of the items are given in Figure 1, Figure 2 and Figure 3. The SVATI and the sketching test has an estimated reliability α=0.70 and α=0.98 in the current study respectively. The two measures were considered to be adequately reliable for the purpose of the present study.

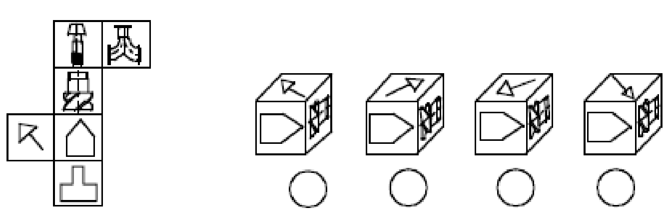


Figure 1 An example of a cube construction item

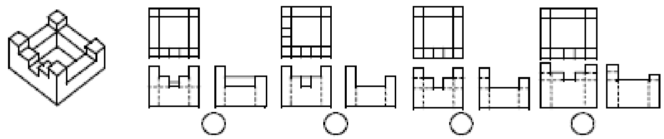


Figure 2 An example of an engineering item

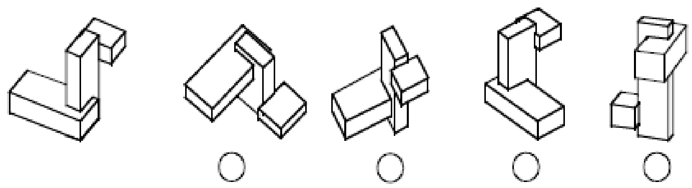


Figure 3 An example of a whole object mental rotation item

The free-hand sketching tasks require students to produce line drawings from solid objects based on observations.

Procedure

Both groups were administered the SVATI and the free-hand sketching test in the third week at the beginning of the semester. Both tests were timed tests with 18 minutes given to the SVATI and one hour given to the sketching test. The objects sketched for the free-hand sketching test were drawing equipments such as protractors, pencils and instrument box. Marks on free-hand sketching were given based on proportions and scale. The mean scores on the pre-test of the two groups (experts and novice) were compared to determine skills gap between groups.

The novice group was then assigned to a manual drawing class using WTP approach taught by an experienced instructor (the first author) while the experts' group was assigned to a CAD class taught by another lecturer during the first half of the semester. The purpose of this study however, was not to compare the effectiveness of the CAD method and the manual method in learning engineering drawing. The purpose of the study was to determine whether a half semester of manual engineering drawing using the WTP approach would be sufficient to close the spatial visualisation and engineering drawing skills gap identified earlier. Separating the group was done to provide opportunity for more focussed instructions. Sketching was made a major component of the manual engineering drawing class as sketching has been identified as an important contributing factor in the development of spatial visualization skills (Sorby and Baartmans, 2000).

The same tests, the SVATI and the free-hand sketching test were again given as post-tests to both groups at six weeks into the semester. The score on the post-tests of the novice were again compared to the initial score of the experts, to determine whether the skills gap has been closed. After the mid-semester break both groups were united in one class under one lecturer (the first author) and students used CAD for learning from then onwards. Through out the semester, students were administered tests at regular interval to assess their progress using manual engineering drawing tasks in the first half and CAD tasks in the second half of the semester.

Results

The performances of the novices' and experts' group throughout the semester are illustrated in Table 1. The initial spatial visualisation skills scores based on tests prescribed at the beginning of the semester indicated that the novices were less skilled than the experts on measures of spatial skills, the SVATI and the free-hand sketching.

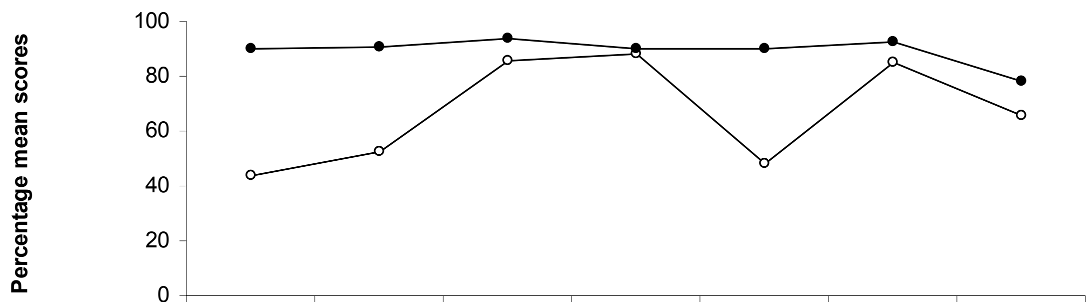
Table 1 Percentage mean scores of novices and experts on tests through out the semester

Assess-ments	Pre-test		Sketch. 1	Sketch. 2	Post test		Mid-sem Exam	CAD1	CAD2	Final Exam
	SVATI	Sketch.			SVATI	Sketch.				
Novice	43.7	43.9	52.3	85.4	52.5	84.2	87.9	48.1	84.8	65.9
Experts	49.8	89.7	90.9	93.8	70.3	90.9	90.2	90.3	92.3	78.4
Time	wk-3		wk-4	wk-5	wk-6		wk-7	wk-10	wk-12	wk-14

On the SVATI pre-test, the novices' mean score was 43.7% and the experts' mean score was 49.8%. A score of less than 50% is considered a fail. Both groups performed badly on the SVATI pre-test and this outcome is consistent with that found in a study by Leake (2001) on engineering students in the United Arab Emirates. In his study students also failed on their spatial visualisation ability measure which was the Purdue Spatial Visualisation Test: Rotations (PSVT:R) despite being given extra time to complete the test. In the KUiTTHO's study students were not given extra time to complete the test. On the free-hand sketching task, the novices' mean score was 43.9% which is 50% lower than the experts' mean score (89.7%). The lower scores of the novices on both measures compared to the experts' scores were taken to be an indication of their poorer spatial visualisation ability. In other words, there existed a gap in spatial visualization ability between the novices and the experts that needs to be resolved.

On the post-tests that was given at six weeks into the semester, the novices' mean score on the SVATI improves by 8.8% to become 52.5% which exceeds the initial mean score of the experts' (49.8%). The 8.8% increase in spatial ability obtained in this study is comparable to that found in a study by Leake (2001) whose students obtained an increase of 11.6% in their spatial visualisation ability after 14 weeks of instructions on drafting. The novice's mean score on free-hand sketching increases by 40.2% to become 84.2% which is approaching the initial score of the experts (89.7%). The improvements provide support for the hypothesis that the spatial skills gap between the novices and the experts can be closed within a short duration using the WTP approach. Short duration here is as compared to two years of instructions in secondary schools.

Figure 4 illustrates the development trend of students' engineering drawing skills through out the semester for both groups. The first four test results were based on manual drawing tasks and the last three test results were based on CAD tasks. The first four test results indicate steady improvements in engineering drawing skills for the novices and their performance approaches that of the experts by mid-term examination (week 7). After the break, the novices did poorly in the first CAD assignment, CAD1, which was expected since the assignment was given after only two weeks of instructions on CAD. They however performed nearly as well as the experts on the second CAD assignment given at week 12. On the Final examination which was also on CAD tasks, both groups did less well with the novices trailing behind. The final examination was designed to be more challenging than the others and some students failed to complete their tasks on time.



	Sketch Pre-test	Sketc 1	Sketch 2	Mid sem. exam	CAD1	CAD2	Final sem. exam
Novice	43.9	52.3	85.4	87.9	48.1	84.8	65.9
Experts	89.7	90.9	93.8	90.2	90.3	92.3	78.4

Figure 4 Students' progress in engineering drawing through the semester

Discussion and conclusion

Initially the novice group had lower spatial visualisation ability compared to the experts group and the difference was statistically significant. At six weeks, the spatial ability of the beginners based on the SVATI has surpassed the experts' initial spatial ability although still lagging behind the current spatial ability of the experts. Spatial visualisation ability as measured by sketching however indicated that theirs are at par with the experts' current ability. The outcome is highly significant considering the novices had only six weeks of instruction against the experts who had had two years of training in engineering drawing as part of their school curriculum. The bridging of the spatial visualisation skills gap within the six weeks training is therefore academically significant indeed. This study has demonstrated the effectiveness and efficiency of the WTP approach in bridging the spatial visualisation ability gap between novice and experts. Although, surpassing the initial spatial ability of the experts, novices' spatial ability based on the SVATI was still behind that of experts' current spatial ability at six weeks of instructions.

Although the study has demonstrated the effectiveness of the WTP method it has not ruled out that the possibility that the PTW approach may be better or equivalent because a comparison group (using the PTW) was not provided in the study. Nevertheless, the findings in this study support the conclusion that the teaching of engineering drawing using the manual WTP approach can bridge the spatial visualisation skills gap between experts and novice students within the expected duration, i.e., half a semester. The bridging in skills gap has enabled the two groups to be reunited within one class and for the novices to advance to CAD along with the experts. The excellent appraisal given by students to the lecturer (4.5 out of 5) at the end of the semester further supports the effectiveness of the method.

The findings from this study support the conclusion that the manual WTP approach is effective in bridging the spatial visualisation skills gap between experts and novice in engineering drawing. The knowledge can be useful to other engineering instructors who face similar situations where teaching engineering drawing to mixed skills groups is necessary.

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