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Improvement in Space Sense of Students in a Computer Graphics Course Using 3D-CG Software

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Abstract. A full-year elective course of Computer Graphics is conducted using High-end 3D-CG software. Lectures and exercises on projection drawing methods and sketch drawing are given at the beginning of the course. MCT was performed at the beginning and the end of the course. This paper examines the results, especially with respect to the relationship between scores on MCTs and scores on assignments of the 2008 class. MCT increased at the end of the course especially in case of students who got higher total subject scores. It became clear that the higher the score on assignments, the more improvement there was in the student's spatial abilities. In assignments significantly correlating with MCT scores, students had to model objects by creating a picture in their mind, because examples were given only by orthogonal projection views or they had to compose by using some abstract conditions like "to include Boolean operation", etc. Thus, the students those who could create clear images of the target objects both geometrically and dimensionally and the students who intuitively understood when they had created the wrong form of the model received good results on assignments and could gain greater understanding of spatial recognition. In conclusion, if we define abilities measured by MCT in terms of cognitive abilities relating to three dimensional objects drawn in a two dimensional plane, completing assignments by making images of objects improves the space sense of students.

Key Words: Spatial recognition, space sense, Computer Graphics Course, Graphics Education, MCT, 3D-CG software

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1. Introduction

In courses on graphics at the undergraduate level of study, 3-D spatial abilities have received much attention lately. In fact, various tests have been created to evaluate the spatial abilities

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of students. Among the tests, the Mental Cutting Test (hereafter, MCT: a sub-set of CEEB Special Aptitude Test in Spatial Relations, 1939) was used by Suzuki et al. [16] in 1990, for measuring spatial abilities in relation to graphics curricula. In the research it was concluded that the students' spatial ability as evaluated by MCT was improved through the education of descriptive geometry. Then Suzuki et al. [15] (1992) reported the results of experimental studies on MCT for more than 1200 students. In this paper, the MCT problems were classified into two categories, i.e., "Pattern" problems in which the answer was determined by identifying only patters of the sections and "Quantity" problems in which the answer were determined by identifying not only patterns but also the quantity in the sections. In addition to this, they referred to problem solving processes of the MCT and suggested that the MCT reflected the students' abilities to form correct mental images of 3D objects from pictorial views, i.e., visualization abilities. Since then, improvement of students' spatial ability has been discussed among graphics educators, and various experimental studies on the MCT have started to evaluate the spatial abilities of students from the viewpoint of how they are related to graphics education.

N. Tsutsumi [18] (1990) pointed out the gender difference in the MCT results for the first time. Tsutsumi et al. [17] (1991) administered the MCT to the female students in a course of "descriptive geometry for the construction of clothing" in which the essential parts of descriptive geometry were taught in the first half of the class. In this course most of students have had the feeling that they were not suitable for math and science subjects. As the results of MCT experiments, although the average score of post-test was improved significantly, that of pre-test was fairly low (10.94 points out of 25). Furthermore there were a lot of "no answer" in the pre-test. The fact indicated that female students felt difficulty in even reading 2D representation. Leopold et al. [5] (1996) and Gorska et al. [2] (1998) also reported the gender differences in spatial visualization and the effect of graphics instruction on the development of those skills through international comparisons. Saito et al. [7] (1998) discussed the relations between spatial ability evaluated by the MCT and engineering graphics courses. They reported that the students in engineering courses achieved significant gains in the MCT mainly in "pattern" problems. The results indicate that engineering graphics courses improved the students' ability in creating mental images of 3D objects from 2D representation. They also described that the relation between MCT scores and the semester-end test scores indicated that the pre-test scores of the MCT could predict the students who would feel difficulty in learning descriptive geometry. Prieto et al. [6] (2002) analyzed the MCT by the Item Response Theory with Rasch model and resulted that the MCT could be useful in detecting those students with different performance levels in teaching drawing.

There are many reports that the visualization skills are increased through courses in graphics education and through special courses for spatial abilities. In the courses the MCT has been used as one of the predominant measures of the skill. In various experimental studies, the authors concluded that the courses that stress hand-on sketching and freehand drawing, the use of many manipulative and models tend to improve spatial skills (Sorby et al. [10] (1998), Sorby et al. [8] (1998), Field [1] (1999), Leopold et al. [3] (2001)). Suzuki [13] (2000), [14] (2002) discussed the factors which contribute to the development of spatial ability. He compared the course differences among the MCT results of 53 groups, sorted by gender, at 16 universities in 5 countries in which courses on "Descriptive Geometry (DG)", "Engineering Graphics or Engineering Drawing (EG)" and "Engineering Graphics (3-D CAD)" were included. As a result he indicated that with regard to the content of education: "geometry or drawing", it is "geometry" and with regard to the method of education: "hand-drawing or CG/CAD", it is "hand-drawing" which are more effective with the development of spatial ability.

In connection with Computer Graphics education, Sun et al. [11] (1994) developed a Solid Simulator for the use in early undergraduate graphics education and they evaluated the educational effect of new courseware with the Solid Simulator using MCT (Sun et al. [12] (1999)). The results showed that the new courseware was of significance in enhancing students' spatial ability and helping them to understand the contents of the course. Leopold [4] (1998) demonstrated a new instructional approach for descriptive geometry courses. Examples of virtual models created with VRML were shown as alternatives to physical models for the suitable "visual" education. Sorby et al. [9] (2000) developed a multimedia software for the development of 3-D spatial skills. They reported that students who worked with only the software and workbook were able to perform as well as or better than their counterparts in a traditional lecture/lab course. Furthermore they concluded that a combination of the use of multimedia software and classroom instruction is optimal for developing spatial skills.

Above-referenced research results suggest that the spatial abilities of female students are lower than those of male students and the spatial ability can be developed through graphics related education. Further, the courses that stress hand drawing or the use of models tends to improve spatial skills. With regard to the efficiency of the development, the trend is: DG > ED/EG (hand drawing) > 3D-CAD. In the case of the development of spatial ability in the newer 3D-CAD courses, Suzuki [13] (2000) reported that the increase of MCT scores resulting from the courses was the same order as the practice effect, meaning that the ability wasn't significantly enhanced through these courses. However, there are few studies on the development of spatial abilities in relation to graphics education using 3D-CG software.

The author is conducting a full-year elective course of Computer Graphics to 3rd and 4th grade students of the School of Social Information Studies, Otsuma Women's University. High-end 3D-CG software ('3ds Max 9', Autodesk Inc.) was adopted by the course in 2007. In this course, the most difficult aspect for students has been to embody their own ideas into computer graphics in 3-D space and to recognize three dimensional objects in two dimensional views, i.e., projection drawings. The interest in this research topic is a relation between enhancements of spatial ability for female students and Computer Graphics education.

Based on what we've learned in the past research results, lectures and exercises on projection drawing methods and sketch drawing were adopted in the computer graphics course, before students learn to use the 3D-CG software because the curriculum of the course puts emphasis on 3D shape representation.

This paper examines the course results, especially with respect to the relationship between scores on MCTs, scores on assignments and total subjects scores of the 2008 CG class at Otsuma Women's University.

2. Curriculum and assignments

Table 1 shows the contents of the curriculum and assignments. Fourteen assignments were given during the course. Assignments are shown using italics and the Roman numerals indicate the assignment number. The end-of-term exam for each semester was performed as a paper-pencil test. Although the number of registered students in this course was 54, only 33 students submitted all the assignments. Thus, analysis of this course included these 33 students.

Table 1: Curriculum and assignments

Week	*First semester*
1	Guidance, pre-MCT
2 – 3	Projection drawing method, *I, II: Principal views**, *III, IV: Isometric views*
4	Sketch drawing, *V: Sketch drawing of mobile phone*
5 – 8	Polygon-base modeling, *VI: Polygon modeling of mobile phone*
9 – 11	Entry-level use of 3D-CG software, *VII: Modeling using loft surface*
12 – 13	Various 3D shape modeling, *VIII: Modeling of familiar housewares*
14	End-of-term exam
15	Interim summary, Explanation for the answer of end-of-term exam
Week	*Second semester*
1 – 3	Geometrical transformation, *IX, X: Selection of camera views*
4	Material
5	Lighting
6	Shade and shadow
7	Rendering, *XI: Scene rendering*
8 – 11	Animation, *XII: Motion of objects, XIII: Walkthrough*
13 – (15)	Comprehensive assignment, *XIV: Animation under several conditions**
14	End-of-term exam
15	Summary, Explanation for the answer of end-of-term exam, post-MCT

* Assignment is shown using Italics.

3. MCT

The MCT consists of 25 problems for which a perfect score is 25 and test time is 20 minutes. In each problem, subjects are given a perspective drawing of a test solid which is to be cut with an assumed cutting plane. Subjects are asked to choose one correct cross section among 5 alternatives (Fig. 1).

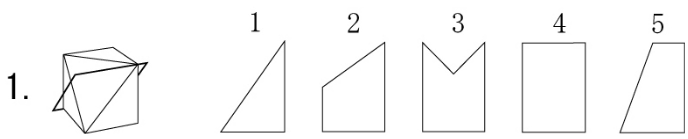

Figure 1: An example of Mental Cutting Test

MCT was performed both at the beginning (pre-MCT) and end (post-MCT) of the course. The average score of pre- and post-MCT were 10.76 and 12.79, respectively. Correlation coefficient was 0.76 and there was a significant difference ($p < 0.05$) between the average scores (Table 2).

Figure 2 represents a scatter diagram of pre-MCT and the gap between post-MCT and pre-MCT scores. The figure shows that students who had lower scores in pre-MCT tended to gain more scores in post-MCT.

Table 2: MCT results

Year 2008	
Number of students	33
Pre-MCT score	10.76
Post-MCT score	12.79
Difference	2.03
p	5% *
r	0.759

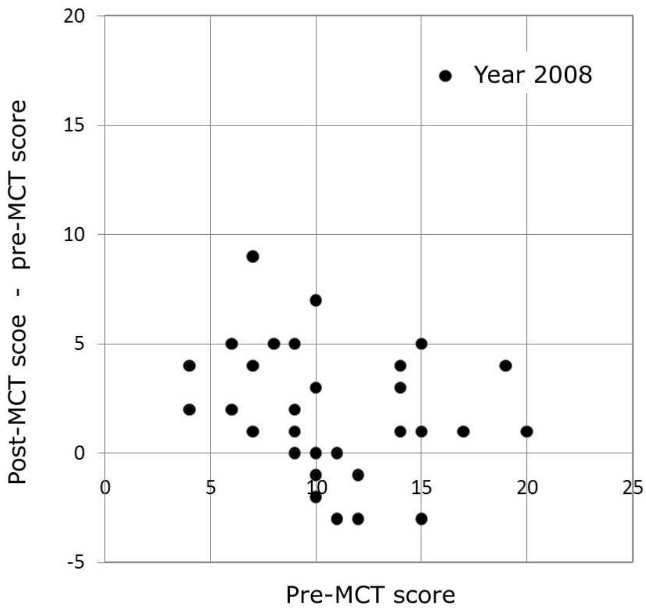

Figure 2: Scatter diagram of pre-MCT and the gap between post-MCT and pre-MCT scores

4. Correlation between total subject scores and MCT scores

Total subject scores were calculated from the sum of scores for biannual end-of-term exams (40%), scores on 14 assignments (50%) and attendance (10%). The end-of-term exam for the first semester included a fill-in-the-blank section for knowledge of projection, drawings of principal views from an isometric view, drawing of an isometric view from principal views, and a fill-in-the-blank section for knowledge of the modeling process. The end-of-term exam for the second semester included a fill-in-the-blank section on the process of 3D-CG rendering and questions on animation track views.

There was no statistical significance in r $(= 0.26,\ p = 0.14 > 0.05)$ between pre-MCT scores and the total subject scores, however, there was statistical significance in r $(= 0.59,$ $p = 0.0003 < 0.01)$ between post-MCT scores and the total subject scores. Figure 3 indicates that the scores of MCT increased at the end of the course especially for students who got higher total subject scores.

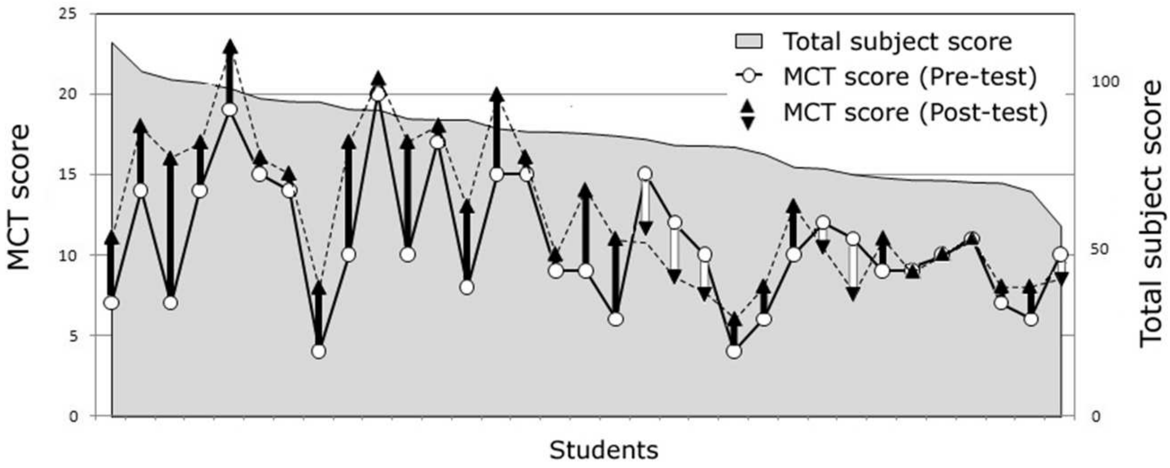

Figure 3: Relation between pre- and post-MCT scores and total subject scores

5. Correlation between assignment scores and MCT scores

Figure 4 shows the correlation coefficients between the scores of seven typical assignments and pre- and post-MCT scores.

In most assignments correlation coefficients with post-MCT scores were larger by 0.15 points compared to pre-MCT scores. The results show that improvement in spatial ability was assured through this course and the improvement was concerned with various processes of assignments.

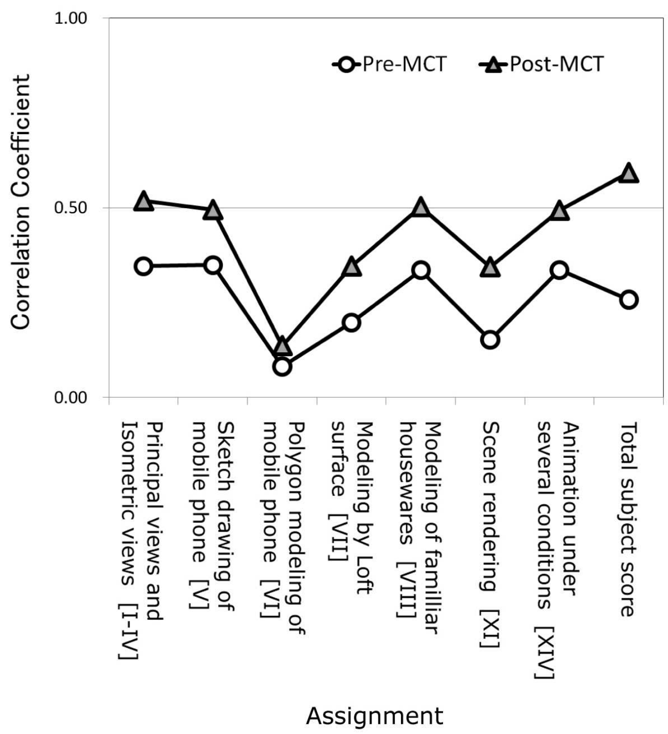

Figure 4: Correlation coefficients between the scores of seven typical assignments and pre- and post-MCT scores

5.1. Assignments correlating weakly with MCT scores

When the sample size is 33 there is a statistically significant correlation when r is more than 0.35. Figure 4 shows that in assignments like "Polygon modeling of mobile phone (VI)", "Modeling using loft surface (VII)", and "Scene rendering (XI)", the correlation coefficient between the assignment score and MCT score was relatively lower and had no statistical significance ($r \leq 0.35$).

Figure 7 shows the scores of such assignments with MCT scores. In Fig. 7(a) students were arranged in the order of the pre-MCT score. In Fig. 7(b), they were arranged in the order of the post-MCT score.

In these figures no clear aspect could be found with respect to the relationship between assignment scores and MCT scores.

Figure 5 shows typical 3-D models of mobile phones, generated in assignment VI. Before this assignment, students sketched and drew principal views while observing their own mobile phone (Assignment V). As most of the recent mobile phones have rectangular bodies with rounded corners, it is not so difficult to capture the shape if they keep a correct aspect ratio. So a number of students must have made a model precisely capturing the equipment's characteristics.

Figure 6 shows a loft surface model and the pre-MCT score of each student (Assignment VII). This model can be generated using a helical path and two contour shapes. The angle of helical rotation and the shapes (a circle and a stellated polygon) were given. Although there are a few inaccurate models, most of the models were well done. Eight models at the bottom of the figure were generated by the students who withdrew from the class. They did well also except one.

Thus, it could be considered that the assignments in which most of students could reach a desirable level of proficiency have a weak correlation with MCT score. Models generated by the students who withdrew from the course differ little from those by the students who got through the course.

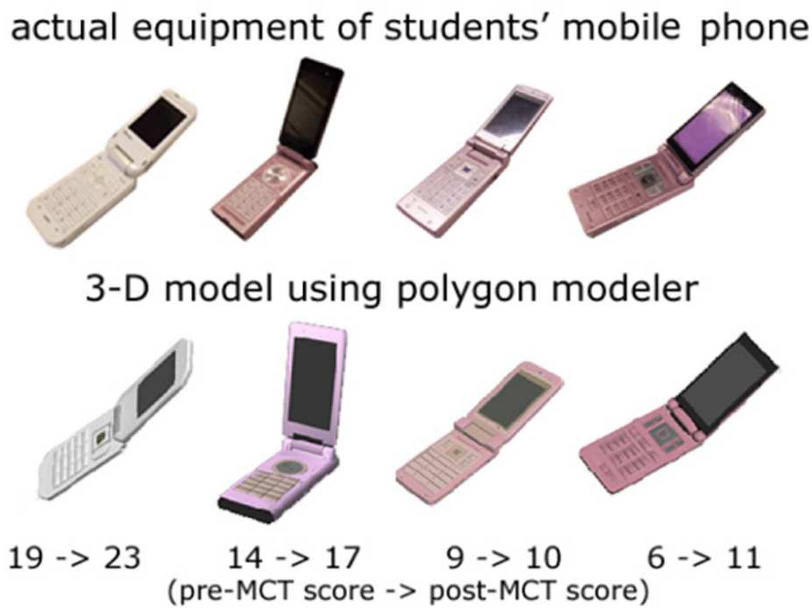

Figure 5: Polygon model for 4 students (Assignment VI)

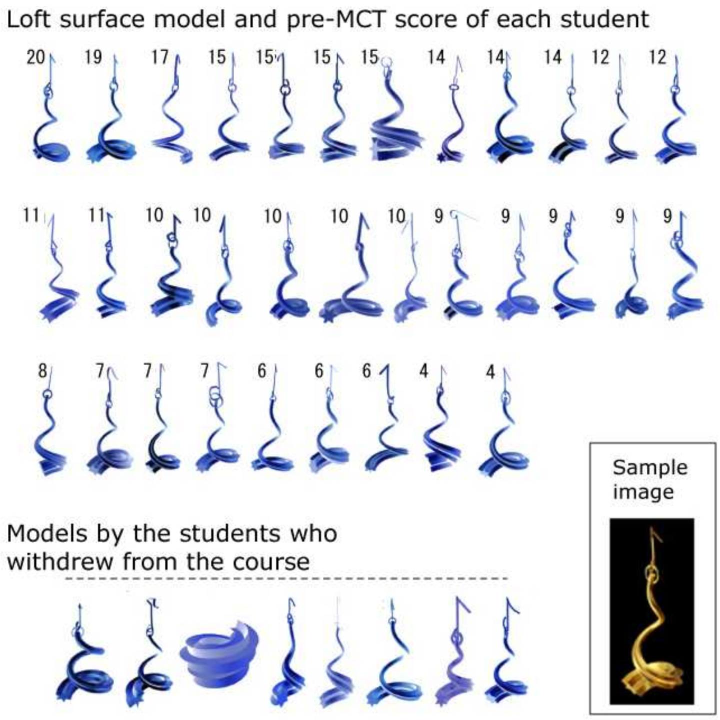

Figure 6: Modeling using loft surface (Assignment VII)

5.2. Assignments significantly correlating with MCT scores

In several assignments like “Principal views and isometric views (I-IV) ”, “Sketch drawing of mobile phone (V)”, “Modeling of familiar housewares (VIII)”, and “Animation under several conditions (XIV)”, the correlation coefficient between the assignment scores and MCT scores was relatively high and had statistical significance ($r > 0.35$).

Figure 8 shows the scores of such assignments with MCT scores. In Fig. 8(a) students were arranged in the order of pre-MCT score. In Fig. 8(b), they were arranged in the order of post-MCT score.

There was no strong correlation between pre-MCT scores and the assignment scores ($r = 0.35$, 0.35, 0.34 and 0.34, respectively), however, there was a rather strong correlation between post-MCT scores and the assignment scores ($r = 0.52$, 0.49, 0.50 and 0.49. respectively). Figure 8(b) shows that students whose post-MCT score was higher than 14 tended to get high scores on these assignments and they increased the MCT score. The average MCT scores increase among them was 3.8 . In the meantime, in the case of two students, no. 6135 and no. 6232, they received high ratings on both assignments and a total subject score, in spite of low pre-MCT scores (7 and 4, respectively).

6. Discussion and conclusion

6.1. Average scores of MCT

The average score of MCT increased by 2.03 at the end of the course. This increase was a little bit larger than the so called “learning effect by receiving pre-MCT”. Thus we can say that spatial ability as it is measured by MCT was improved through this course.

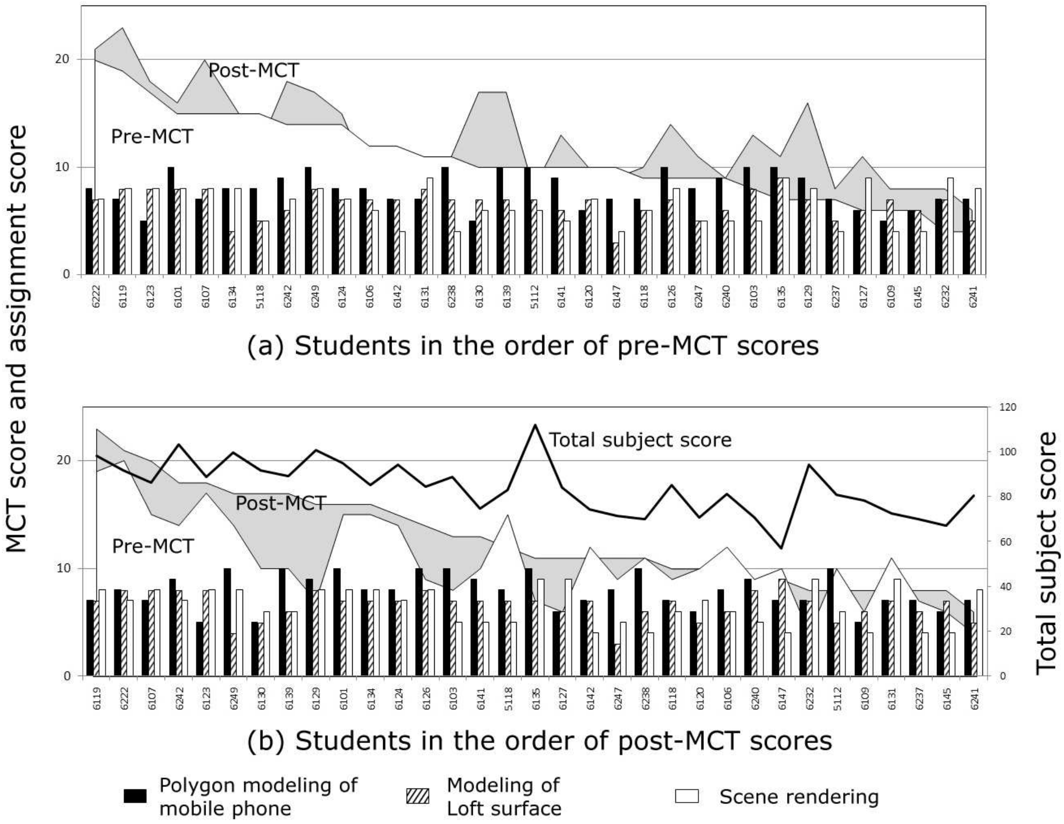

Figure 7: Scores of assignments correlating weakly with MCT scores

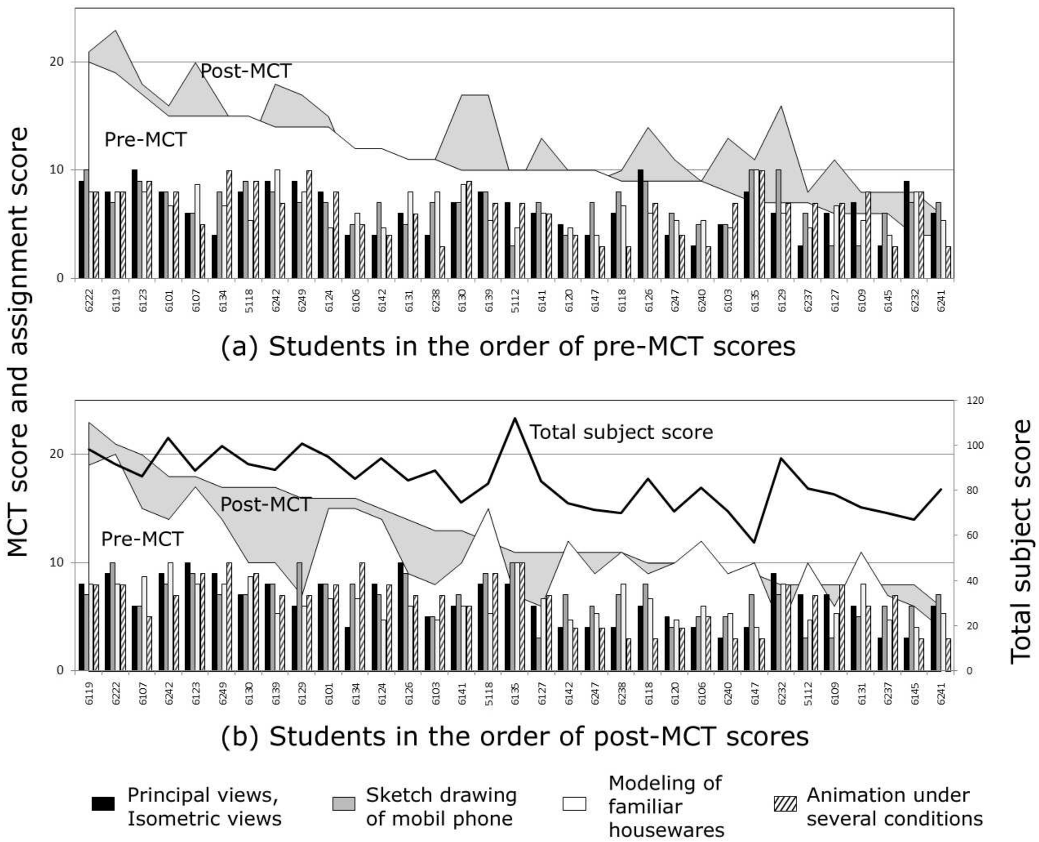

Figure 8: Scores of assignments significantly correlating with MCT scores

6.2. Degree of scores on assignments and MCT scores

There was a significant correlation ($r = 0.59$) between post-MCT and total subject score. It seemed that spatial abilities measured by MCT must be improved to some extent through assignments, considering that there was no significant correlation ($r = 0.26$) between pre-MCT and total subject score, and that 50% of the total subject score reflects the sum total of 14 assignment scores. Many students who got high total subject scores increased their MCT scores at the end of the course.

It may also be verified by the fact that the r of the post-MCT scores and assignment scores were larger than the r of pre-MCT scores and assignment scores in 7 assignments, as seen in Fig. 3. It becomes clear that the higher the score on assignments, the more improvement there was in the student's spatial abilities.

6.3. Characteristics of each assignment and spatial recognition

Correlations between assignments and MCT varied according to the characteristics of each assignment. In case of the assignments correlating weakly with MCT scores, students could model objects taking and observing actual equipment in their hands (assignment VI) or students were given measurements of the example objects (assignment VII).

In the meantime, in assignments significantly correlating with MCT scores, students had to model objects by creating a picture in their mind, because examples were given only by orthogonal projection views (assignment VIII: targets of modeling were bottles of famous shampoo and mouthwash brands, a milk frother, a whisk, and a pear) or they had to compose by using some abstract conditions like "to include Boolean operation", "to use basic 3 point lighting", "to move camera", etc. (assignment XIV).

Thus, the students those who could create clear images of the target objects both geometrically and dimensionally and the students who intuitively understood when they had created the wrong form of the model received good results on assignments and could gain greater understanding of spatial recognition. However, there might also be other factors at work, like the level of proficiency with the software.

In conclusion, if we define abilities measured by MCT in terms of cognitive abilities relating to three dimensional objects drawn in a two dimensional plane, completing assignments by making images of objects improves the space sense of students.

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