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Evaluation of Educational Effects of the Solid Simulator

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Abstract. We have been developing computer graphics software, which can be run on a microcomputer and assists teaching and learning in early undergraduate graphics curricula. It is called "Solid Simulator" in which are available the generation, Boolean operations and dynamic projections of any polyhedra. During the academic year 1996 a new courseware of graphic science with a solid simulator as an additional instruction tool was developed and conducted in the University of Tokyo. In order to evaluate the courseware, we administered a set of student opinion questionnaires, a spatial test (MCT) and a term end test. The results of the evaluation showed that the new courseware was of significance in enhancing students' spatial ability and helping them to understand the contents of the course.

Key Words: CAI, spatial abilities, evaluation
MSC 1994: 51N05.

1. Introduction

We have been developing computer graphics software, which can be run on a microcomputer and assists teaching and learning in early undergraduate graphics curricula. It is called "Solid Simulator" in which are the generation, the Boolean operations and dynamic projections of any polyhedra are available (Sun and Suzuki 1994 [4] and 1995 [5]). It is expected that the system would offer a more effective and convenient environment for early undergraduate graphics curricula. During the academic year 1996 a new courseware, in which this solid simulator was used as an additional instruction tool, was developed and conducted as a pilot course in the University of Tokyo. In order to evaluate the new courseware, we administered a set of student opinion questionnaires, a spatial test and a term-end test. This paper will discuss the results of the evaluation.

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2. The use of solid simulator in Graphics Science course

2.1. Course format and contents

At the University of Tokyo, Graphic Science courses consist of Graphic Science (lecture) course and Graphics Science exercise course. The curricula are the integration of traditional descriptive geometry and computer graphics (Suzuki et al. [7]). At first, descriptive geometry is taught in Graphics Science (lecture) course, which runs for 90 minutes per week over 13 weeks of the second semester. The fundamentals of solid modeling, which plays a key role in 3D CAD/CAM, are then introduced to the students in a part of Graphic exercise course, which runs for 180 minutes per week during 13 weeks of the third semester.

In Table 1, are shown the contents of Graphic Science (lecture) course, in which the solid simulator was used as an additional instruction tool.

Table 1: Contents of the graphic science course

week	*contents*
1.	Guidance and Pre-test (for evaluation)
2.	Projection (concept of projection, various kinds of projection)
3.	Orthographic projection, principal views
4.	Auxiliary views (primary auxiliary views, secondary auxiliary views, elimination of hidden lines)
5.	Principal auxiliary views and Application-1 (true length view of a line and its application)
6.	Principal auxiliary views and Application-2 (point view of a line and its application, relationship between two lines)
7.	Principal auxiliary views and Application-3 (edge view of a plane and its application, relationship between a line and a plane / two planes)
8.	Principal auxiliary views and Application-4 (true size view of a plane and its application, circles in oblique planes)
9.	Polyhedra (rotation, regular polyhedra, quasi-regular polyhedra and applications)
10.	Truncation (polyhedron, circular cylinder, circular cone)
11.	Intersection-1 (intersection between two polyhedra (Boolean operations))
12.	Intersection-2 (intersection of curved surfaces, intersection between two circular cylinders)
13.	Intersection-3 (intersection between a circular cone and a circular cylinder), Post-test (for evaluation)

2.2. Essentials of the use of solid simulator

In the pilot course, drawing on a blackboard was still the key instruction method as in traditional graphics curricula. Physical models were also used in the course. From the third week on, the educational activities would be run by a new courseware, in which the solid simulator was used as an additional instruction tool. A period of using the solid simulator in each section had 10–15 minutes, and the instruction would be run when drawing on the blackboard was finished. The solid simulator was run on a microcomputer (CPU: 200 MHz) combined with a projection TV (Resolution: 800×600, Brightness: 400 Lumen) with a large screen (100 inches).

It should be noted that the solid simulator can be thought like physical models, moreover like materials to create models. That is, the educational effects of the system strongly depend on the way to use it, though the system can generate and process any objects. The instructions by the use of the solid simulator have been carefully designed to fully utilize the advantages of the system (Sun 1998 [3]).

The instructions for each section consist of two parts, i.e., a review part and an enhancement part. In the *review part*, the system represented the graphics similar to those drawn on the blackboard to help students visualize. For example, in the "auxiliary views" section, the objects were shown with rotation around the vertical or horizontal axis to assist students in visualizing the objects and in understanding characteristic features of auxiliary views. In the *enhancement part*, any of graphics which were difficult to be shown by the drawing on the blackboard and physical models would be represented to help student understand the contents of the section more deeply. For example, in the "truncation" section, the cutting plane was moved little by little to assist students in observing the change in the shape of cutting lines.

3. Evaluation methods and subjects

In order to evaluate the new courseware, we administered a set of student opinion questionnaires, a spatial test and a term end test to the students who undertook the course. We also administered the same tests to the students who undertook a traditional course similar to the new course with the exception of the use of the solid simulator. This course was run for comparison sake. In this paper, students who undertook the solid simulator course were designated to an *experimental group* (hereafter, EX-G), and subjects who undertook a traditional course were designated a *control group* (hereafter, CON-G). The students who undertook all of the evaluation tests in EX-G were 73 and in CON-G were 65.

3.1. Student opinion questionnaires

A set of nine-item student opinion questionnaires was administered at the end of the course to get feedback information on the course by using the solid simulator as an instruction tool and on the views of its impact on their learning. The questionnaires used a five-level scale.

3.2. Spatial ability test (MCT)

In order to assess the enhancement of students' spatial ability by the new courseware supported by the solid simulator, a Mental Cutting Test (MCT) was administered at the commencement of the courses ('Pre-test') and at the end of the courses ('Post-test').

The MCT (CEEB 1939 [1]) is one of the spatial ability tests and has been most widely used to evaluate students' spatial ability in relations to graphics curricula (Suzuki et al. 1990 [8] and 1992 [9]). The MCT presents a criterion object, which is to be cut with an assumed

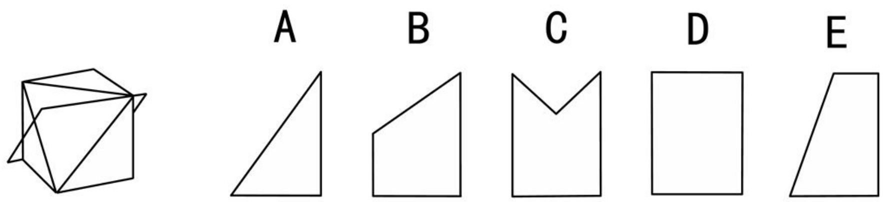

Figure 1: Sample question from MCT

plane in perspective projection, with a correct alternative and four incorrect alternatives (see Fig. 1).

The test consists of 25 items, and maximum score is thus 25. Normally, the time limit for test completion is 20 minutes. It was reported that scores on the pre MCT averaged 22 and gain was 1 during the graphics courses in the University of Tokyo (Suzuki et al. 1992 [9]). If the means were higher, a ceiling effect should be taken into account in assessing the mean scores and the gains between pre and post test. Thus, in order to overcome the ceiling effect, the time limit for test completion was curtailed from 20 minutes to 6 minutes, and the sequence of items was also permuted to balance the degree of difficulty from ins and outs.

3.3. Term end test

A term end test was administered at the end of the courses. The test consists of 3 problems, i.e.,

1. constructing isometric drawings from orthographic drawings,
2. answering about characteristic features of some regular polyhedra, and
3. drawing intersection lines between a cylinder and a pyramid.

4. Results and discussion

4.1. Student opinion questionnaires

Some results of the questionnaires from the experimental group are presented here. In Table 2, are shown the students' appraisals of instruction tools for the "truncation" section. The solid simulator was given higher grades than others. Similar results were obtained in other sections. These results indicated that the solid simulator would be an effective tool to help students' understanding.

Table 3 indicates a migration of the students towards positive values in "visualizing" item (94.5%) and "processing" item (79.4%). It forms a sharp contrast, e.g. almost a half of the students toward negative values in "drawing" item. It should be recalled here that the main goal of the use of the solid simulator is to assist students' visualization (Sun and Suzuki 1994 [4] and 1997 [6]). Based on this point, the appraisal can be interpreted that the goal has been achieved.

As shown in Table 4, 97.2% of the students strongly recommended or generally recommended the use of the solid simulator in the course.

These results indicated that a majority of the students felt that the solid simulator was effective in assisting their visualization and to learn graphics science.

Table 2: Student opinion questionnaire: Proportion of students claiming that the following instruction tools had been effective in understanding the contents of the "truncation" section.

%	++	+	○	−	−−
Solid simulator	45.5	39.4	11.3	2.7	1.0
Drawing on the blackboard	28.4	47.3	14.0	9.2	1.0
Physical models	22.6	41.1	22.9	12.0	1.4
Text book	14.4	34.2	33.6	12.0	5.8

(++: strongly positive, +: positive, ○: hard to say, −: negative, −−: strongly negative)

Table 3: Students opinion questionnaire: Proportion of students claiming that the solid simulator had been successful in developing the following skills:

%	++	+	○	−	−−
Visualizing 3D objects	60.3	34.2	5.5	0.0	0.0
Processing 3D objects (truncation, intersection)	45.2	34.2	17.8	2.8	0.0
Completing drawings in DG	15.1	24.7	35.6	17.8	6.8

(++: strongly positive, +: positive, ○: hard to say, −: negative, −−: strongly negative)

Table 4: Student opinion questionnaire: Responses to the question "Would you recommend that all students taking Graphics Science (lecture) course be taught through the use of the solid simulator?"

Strongly recommend	80.8 %
Recommend	16.4 %
Hard to say	1.4 %
Would not recommend	0.0 %
Strongly would not recommend	1.4 %

4.2. MCT

Figs. 2 and 3 display the distribution of scores for the MCT of both groups in Pre-test and Post-test. And Table 5 displays the means, standard deviations and t values of gains of each group.

Results from the both groups showed a wide spread of scores, so that, the ceiling effect was not given recognition. Figs. 2, 3 and Table 5 display that both groups got large gains in post-test, and those gains were significant (p: 1%).

Table 6 shows the difference of gains between two groups. The gain of experiment-group was 5.8 and that of control-group was 4.3. The difference of the gain was 1.5, which was statistically significant (p: 1%). Since the two courses are similar to each other with the exception of the use of the solid simulator, the difference can be considered to be due to the use of the solid simulator. Saito et al. (1996) [2] reported that the MCT mainly reflects the abilities of creating and processing mental images of 3D objects through their 2D

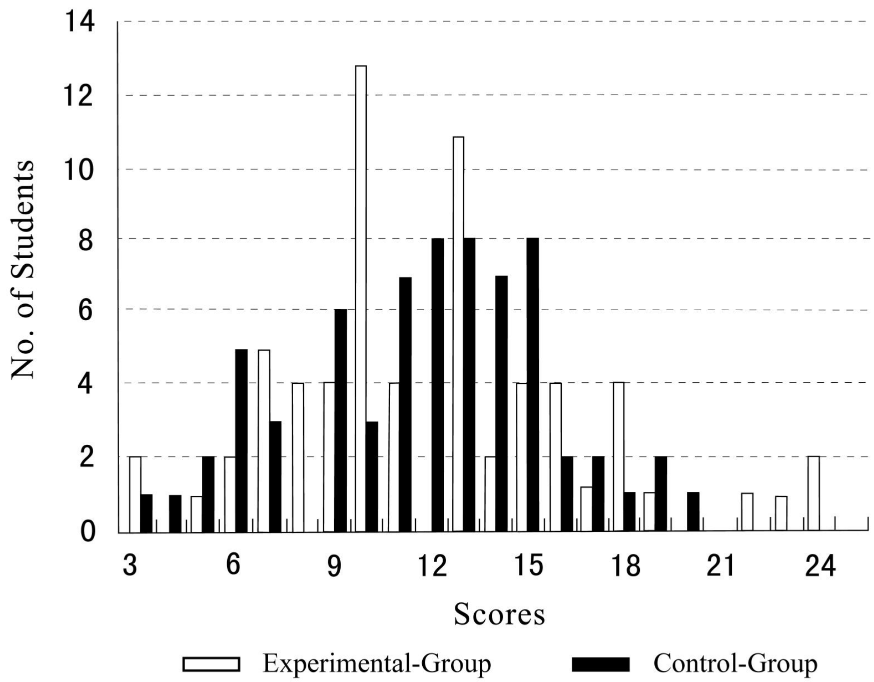

Figure 2: Pre MCT

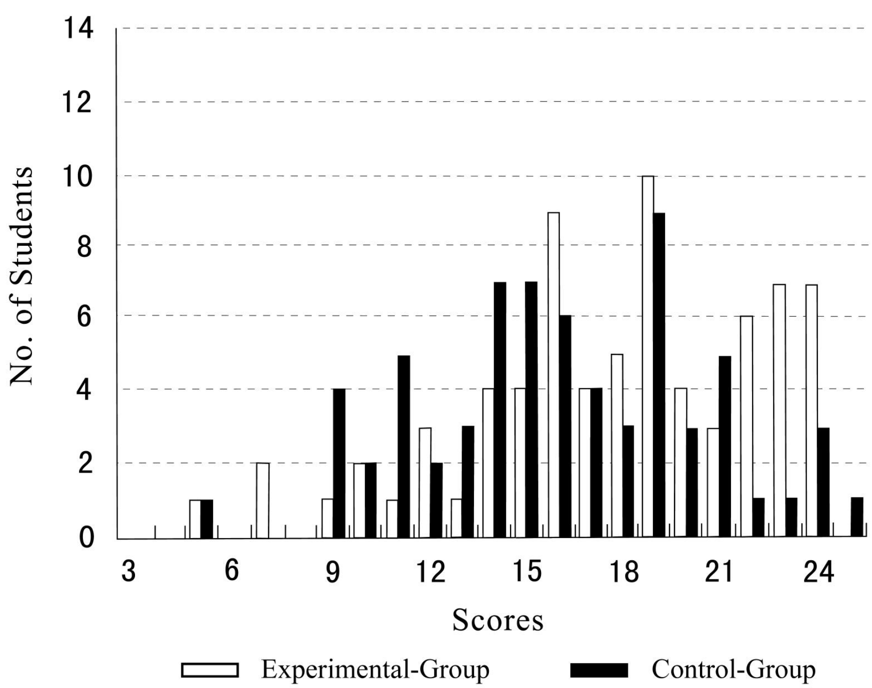

Figure 3: Post MCT

Table 5: Mean scores on Pre and Post MCT

	Pre	*Post*	*t*
EX-G	12.0 (4.5)	17.8 (4.7)	16.4*
CON-G	11.9 (3.8)	16.2 (4.4)	9.8*

* P < 0.01

Table 6: Gains between Pre and Post MCT

gain		*t*
EX-G	5.8 (3.0)	2.6*
CON-G	4.3 (3.5)	

* P < 0.01

representations, that is to say, reflects the ability of visualization. The results of the MCT revealed that the use of the solid simulator was effective in enhancing students' ability in visualization.

4.3. Term end test

The results of the term end test are shown in Table 7. As shown in this table, the mean on the term end test of the EX-G is 56.9 and the other is 54.3. Although the former is a little bit higher than the latter, the difference between the two groups was not statistically significant (t: 0.99).

Table 7: Results of the term end test

	EX-G (73) *mean (SD)*	CON-G (65) *mean (SD)*	*t*
Total (Max: 80p)	56.9 (15.4)	54.3 (14.9)	0.99
P-1 (Max: 20p)	18.7 (3.0)	18.3 (3.2)	0.79
P-2 (Max: 20p)	17.3 (3.8)	16.0 (4.1)	1.97*
P-3 (Max: 40p)	20.9 (12.2)	20.1 (11.8)	0.40

* P < 0.05

As also shown in this table, the means of Problem-1 for EX-G is 18.7 and that for CON-G is 18.3. The difference between the two groups is not significant. One possible reason of the insignificance may be the ceiling effect, i.e., the scores are so close to the full score.

The mean of Problem-2 for EX-G is 17.3 and that for CON-G is 16.0. The difference is statistically significant. In this problem, students were asked characteristic features of some regular polyhedra. The results indicated that the new courseware could enhance students' understanding on regular polyhedra. The mean of Problem-3 for EX-G is 20.9 and that for CON-G is 20.1. The difference is not significant. The students were required to draw the intersection lines between two polyhedra in Problem 3. The results indicated that the new courseware by the use of the solid simulator could not enhance such drawing skills of students.

Over all, it can be interpreted that the courseware using the solid simulator might partly help the students to understand but might not enhance their drawing skills. The drawing skills could be enhanced only if they practice well.

5. Summary and conclusion

A new courseware of graphic science with the solid simulator was developed and conducted in the University of Tokyo. In order to evaluate the courseware, we administered a set of student opinion questionnaires, a Mental Cutting Test and a term-end test. The results of the evaluation indicated that the new courseware was of significance in enhancing students' spatial ability and helping students to understand graphics science.

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