Scientific Visualization Ability Development
-Factor Analysis of Student Difficulties in Figure Transformation Problems using Computer Graphics Function-

Takemi EZAKI
Fukuoka University, JAPAN
ezaki@dgsun.tm.fukuoka-u.ac.jp

Dennis, R. SHORT
Purdue University, USA
drshort@tech.purdue.edu

Abstract

As a method for improving the scientific visual ability of students, the authors have used computer graphics based systems for student practice and the analysis of student responses. The final goal is to develop an effective instructional system by analyzing the underlying knowledge mechanism and reconstructing it for visualization problems. This paper describes the results of the comparison of student performance for 2-3D figure transformation problems under different conditions. The results were used to investigate the sources and causes of projection or solid construction errors for multiview problems. Comparative data for RAR (Right Answer Rate) and TOT (Time On Task), and KOT (Key Operation Times) for student solutions were examined for selected, difficult problems. The errors and the suspected causes of the student's difficulty in solving these problems were related to the student prior knowledge of descriptive geometry.

Key Words : Visual Ability,2-3D Figure Transformation, CG Function,TOT,RAR,Analysis

1. Introduction

The developing Information Society that will lead us into the 21st century will presented fundamental changes in the marketing form and personal needs as they are related to design.[1] As a result of these changes, designers will require new abilities and be expected to work more creatively while dealing with the production and knowledge demands of Computer Aided Design (CAD) and other new tools that allow for increased and even more varied production. The designer of the 21st century will not be able to avoid the necessity of adopting and integrating these tools to allow for more creative designs and enhanced communication. Both of these capabilities require graphics based visualization ability.Traditionally, these visualization skills have been taught in manual graphics courses. These materials presented to the students are based on the subjective experiences of the instructor and vary greatly. There is know general agreement as to what should and can be taught in these introductory courses. This often results in students and eventually practicing designers being deficient in some area of visualization and analysis. The authors of this paper have been involved in the development and evaluation of CAI based systems for the instruction of 2D to 3D transformation problems for several years. [2]-[10] The purpose of this research and development has been to analyze the knowledge mechanism involved in figure transformation problems using the event records of a CAI system to reconstruct student behavior and actions while they were solving transformation problems with the goal of developing improved instructional materials and technique. This understanding of the knowledge mechanism is also essential for the development of intelligent computer aided instruction (ICAI) systems. In this paper the results of the analysis of the evidence of the knowledge mechanisms involved in the solutions of eight figure transformation problems are presented. These problems were presented to two groups of students under different conditions. Students solved these problems in a CAI environment and data was collected as a time series for student activity involved in the solution process. Results were based on an analysis of right-answer-rate (RAR) and time-on-task (TOT).

2. Methodology

The authors investigated the source of student errors for multiview to isometric transformation problem solutions by analyzing RAR (right answer rate) and TOT (time-on-task) of individual line segments. Student performance for the different types of problem settings for figure transformation problems and the effect RAR and TOT were examined. Two different conditions were selected to distinguish the control from the experimental group. The control group, (n=70), solved non-box problems(regular problems) (Figure 1). The experimental group, (n=66), solved phantom-box frame problems. The two groups were randomly selected from a class of undergraduate engineering students taking a required engineering design graphics course. A multiview drawing of the solid was displayed in a graphics-based Computer Aided Instruction (CAI) system. Students were required to produce the isometric- view of the object. The RAR (Right [e. g., correct] Answer Rate) and TOT (Time [in seconds]On Task) for each problem was determined from each student's eight problem solutions (Figure 2). The box effect and related knowledge details are introduce based on the comparison of two groups' results.

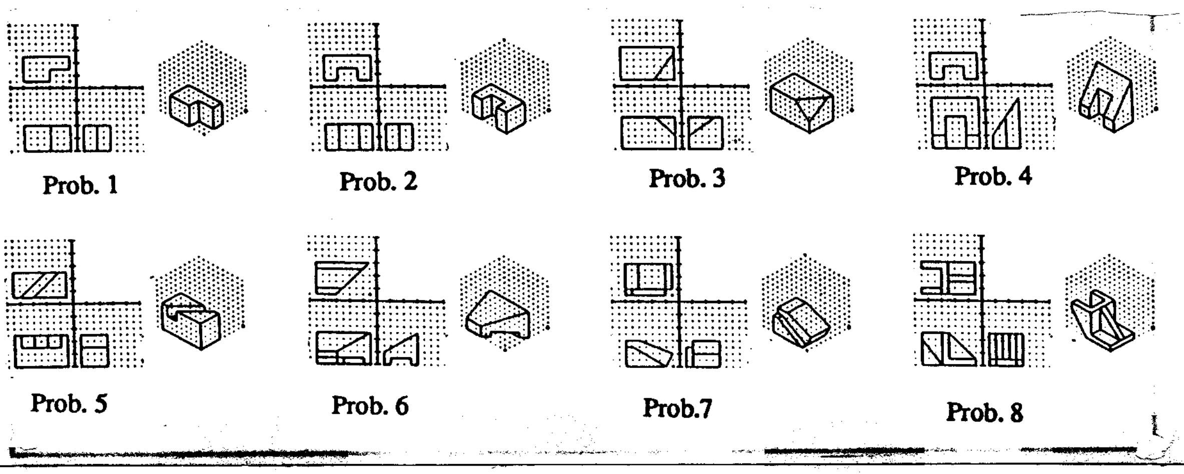

Fig 1 Solved Problems

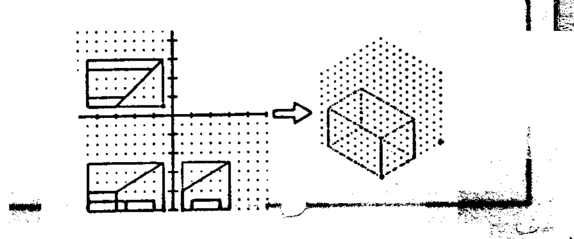

Fig 2 Example of Phantom Box

3.Results

The results, shown in Figure 3, indicate that box frame effects are significant for problems six and seven when comparing RAR values for the two groups. However, for problems three, four and five, there were no significant difference when

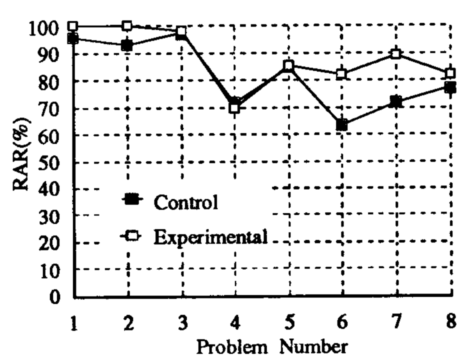

Fig 3 Comparison of RAR

the two groups were compared. In Figure 4, the TOT values for experimental group were quite low in comparison to the control group. The box frame effected and reduced the drawing time required by the students for all problems. The most significant difference between these groups is for problems six, seven and eight. However, this TOT is dependent on the number of lines in drawing since view generation difficulty is dependent on the complexity of the object. This is reflected by both RAR and TOT values for the problem set.Considering the results, the per line task time for each problem was examined in detail. Figure 5 shows the result of TOT on a per line basis. In these results, both group's results are different for Figure 4. Time-on-task is con

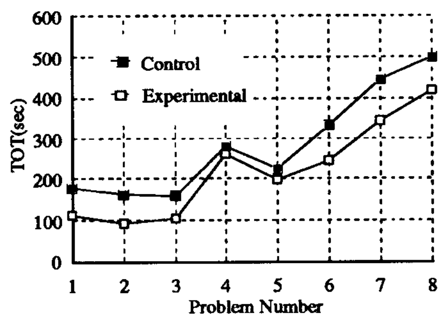

Fig 4 Comparison TOT

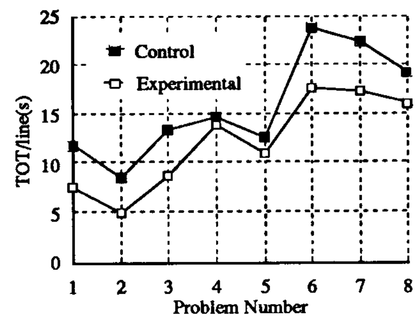

Fig 5 Comparison TOT/Line

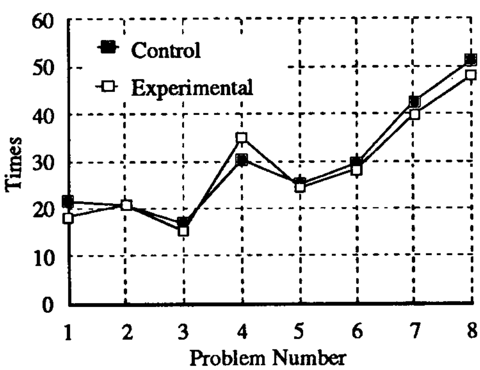

Fig 6 Comparison of KOT

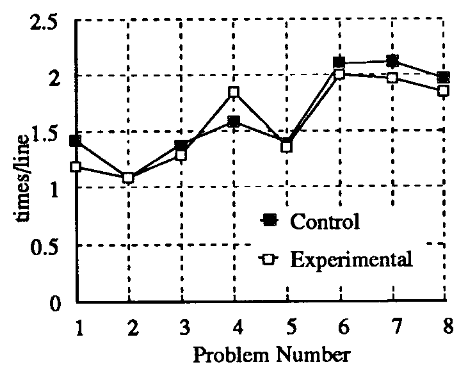

Fig 7 Comparison of KOT/Line

sistent for problems one through five. For problems six through eight, TOT increases and significant difference can be seem for problems six and seven.

As a problem difficulty evaluation guideline, the key (manual interactive) operation time during line solution was examined. As shown in Figures 6 and 7, both problems' results show the same tendency for TOT, but box effect solution has lower operation time. We can consider that drawing has two functional components: interpretation and manual answer generation. From these results, we can assume that phantom-box representation of a problem has no effect on the manual answer generation time but the phantom-box representation does simplify the interpretation and solution of the problem as a mental model. The displayed box frame does have an effect on the "seeing and thinking" elements of a problem solution. Factors that effect problem solutions are shown and classified in Table one. The principle classification is based on the type of problem, solid modeling multiview. Each problem is then further sub-classified by the number of lines, type of view presentation, and type of solid problem. Solid modeling problems are also classified as Boolean operation or cutting method problems.[11] Point is concider getting from Monge's three plane intersection.[12] The effect of a phantom-box was significant for problems six and seven for RAR, TOT, and TOT per line. Problems six and seven involved most of the classification factors factor shown on table 1. The origin is not indicated on the solid for these two problems requiring student to establish an origin for determining measurement values. The origin is established from the indicated origin for the orthographic views. The lack of an established origin may have been one of cause the of difficulty students had with problems six and seven. The time required to count the dots to establish each point of solid may have added significantly to the time-on-task for these problems and may have effected the accuracy of the drawings. The number of lines contained by these problems did not contribute significantly to measured student performance. Interpreting the views of the solid surface are related to a cutting plane problem 6 that has an edge view of C2 in top view and an edge view of C1 in the side view. Both of these view combinations make visualization of the solid difficult. There is also a problem determining the hidden elements indicated by the broken line. The box set makes clear the drawing starting point from the origin on the views. For the solid modeling, problems six and seven have two cutting planes and one Boolean component. However, the Boolean part of the problem is subtractive in problem 6 and is additive in problem 7. The problem solid modeling process required to solve these two problems is shown in Figures 8 and 9. When considering the source of student difficulty for problem 6 we shoul observe that

Table 1 Solid and View Factors

	Prob. Number		1	2	3	4	5	6	7	8
	The Number of Line		15	19	12	19	18	14	20	26
View	No Set Origine on Solid	Top	○					○	○	
		Front							○	
		Profile								
Solid	Modeling	Boolian	○	○		○	○	○	○	○
		Cutting			○	○		○	○	○

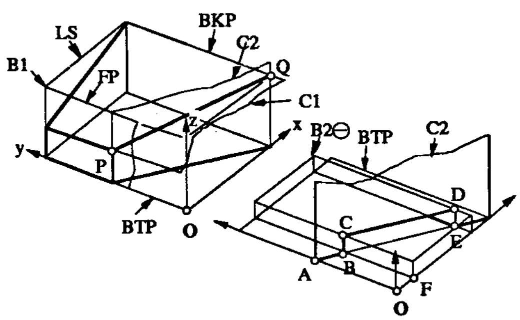

Fig 8 Solid Modeling Process of Prob.6

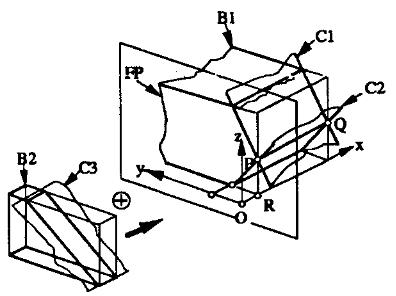

Fig 9 Solid Modeling Process of Prob.7

this solid has two cutting planes C1,C2 and that these cutting planes are independently perpendicular to left side and bottom plane grounded inclines. Moreover, these planes are situated toward the back side of the solid. These factors make it difficult to visualize the shape of the object. The reverse block cut is also difficult to drawing in an isometric drawing. Problem six also has two features that are difficult modeling. One is the feature produced by the intersection of the inclined cutting planes. In main block B1,point P, which is produce as a result of the three plane intersection is difficult since it includes two incline planes. Point Q is easy due since it is a corner point. In this problem, the phantom-box set is makes clarifies the relationship of the inclined planes so students can obtain point P as intersection line of front plane FP and to determine its relationship to the origin. This allows the student to locate on the block intersection point B, C, D, E. In problem seven, the solid, B1, is constructed from the two cutting plane and a positive block, B2, Boolean. The main block, B1, is constructed from two inclined cutting planes, C1,C2, but these planes are different from problem 6 as both cutting plane are perpendicular to front plane FP. Thus both planes are in the same direction relative to FP. The point P intersection with FP and C1,C2 are easy determine on the FP, but location is difficult to locate on the view. However, the box frame makes clear the location and distance from origin of this feature. The box frame is effective in aiding the student in the location of the inclined cutting plane, especially the different inclined planes. Operation time of Figures 6 and 7 show no difference between control and experimental groups. The data in these Figures indicates same tendency as Figure 4 and 5 in that the phantom-box frame does not influence the student's solution.

4. Conclusions

Analyzing transformation problem results is essential to the process of constructing an effective CAI system for 2-3D transformation problems. In this paper, the authors have produced a preliminary and restricted method for establishing the knowledge used in figure transformation problems. By comparing the most effective constructive elements of a figure with RAR, TOT, and Operation Time we can classify clearly the two types of knowledge, visualization of the measurements relative to the origin and the solid construction techniques that are needed in terms of phantom-box frame effect. A future paper will present a more detailed, point level analysis, of the data collected in this study.

References

[1] T. Hiroshima,T. Chiba,Sophisticated Information Society,Information Processing Society of Japan,vol. 36,No. 9,1995

[2] Dennis R.Short,Takemi Ezaki,and Takeshi Yamato:Instractional Problem Difficulty and User-Interface Effect in PC-Badsed CAD, Proc. of The 6th Int. Foruum on CAD, 1991

[3] Takemi Ezaki, Satoshi Nagae, Dennis R. Short, Koichi Fukuda,and TakeshiYamato: Effective Use of Descriptive Geometry for 2-3D Transformation Problems, Proc. of The 5th Int. Conf. on Engineering Graphics and Des criptive Geometry, 1992

[4] Takemi Ezaki, Dennis R.Short: Determination and Analysis of Transformation Problem Difficulty by Sectioning Method, Proc. of The 1st China-Japan Joint Int.Conf.on Graphics Education, 1993

[5] Koichi Fukuda, Dennis R.Short, Satoshi Nagae,and Takemi Ezaki: A CAI based system for the Instructio of Projection and Transformation:The Effect on the Level of Learner Understanding, Proc. of The 5th Int. Conf. on Engineering Graphics and Descriptive Geometry, 1992

[6] Takemi Ezaki, Nobuo Ohtsuki, Kunio Irie, and Satoshi Nagae: An Investigation of Factor Effecting 2D to 3D Figure Transformation,Proc. of The 1st China-Japan Joint Int. Conf. on Graphics Education,1993

[7] Takemi Ezaki, Dennis R.Short, Koichi Fukuda,and Kunio Irie: The Analysis of a CAI Tutor Module's Effect on Student Performance of Graphics Transformation Problems, Proc. of The 6th Int. Conf. on Engineering Computer Graphics and Descrip tive Geometry, 1994

[8] Kunio Irie,Dennis R.Short,and Takemi Ezaki:The Effect of Box Method Visual Cues on Student Performance Solving Graphics Transformation Problems, Proc. of The 6th Int. Conf. on Engineering Computer Graphics and Descriptive Geometry,1994

[9]Satoshi Nagae, Dennis R. Short:Michimasa Maeda, Kunio Irie, Takemi Ezaki,View Variation and Their Effect on Student Solutions to Transformation Problems,Proc. of The 6th Int.Conf. on Engineering Computer Graphics and Descriptive Geometry,1994

[10] Takemi Ezaki, Dennis R.Short, and Michimasa Maeda:Study on 2D-3D Graphics Transformation : Box Frame Representation Effect on Isometric-View to Multi-View Drawing Problems-, Proc. of The 4th Int. Conf. on COMPUTER- AIDEDDRAWING, DESIGNAND MANUFACTURING TECHNOLOGY, 1994

[11] Ezaki T.,Descriptive Geometry for Visualization, Richo Co.,1994

[12] Booker, Peter Jeffrey, A History of Engineering Drawing,NorthgatePublishing, 1979