Impact of Blender Based 3D Mental Rotation Ability Training on Engineering Drawing Skills

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***Abstract*— Spatial ability training is useful in developing problem solving skills in engineering drawing (ED). Mental rotation (MR) is a substantial part of spatial abilities. In a previous work we described a three-hour computer based 3D MR training module and showed that it improves MR skills of first year engineering undergraduates. In this paper, we present a study on the effectiveness of a two-week computer based 3D MR training on students' problem solving skills in ED. We performed a two-group experimental study and found that students who learned via computer based 3D MR training performed significantly better on ED posttests than students who learned the same concepts via traditional instruction. Responses of experimental group students on an open ended question revealed that they found the 3D MR training to be useful in resolving their ED problem solving difficulties.**

Keywords - mental rotation ability, engineering drawing; spatial ability; Blender; orthographic; isometric; computer based training.

I. INTRODUCTION

Spatial abilities, such as mental rotation ability play an important role for acquiring knowledge in domains such as art, science, engineering, and especially in engineering drawing [3], [18], [20], [23] One major subset of spatial abilities is MR ability. As per Maier, MR is "the ability to rapidly and accurately rotate a 2D or 3D figure mentally" [2]. MR ability has key importance for learning concepts that involves 3D visualization of an object, such as in engineering drawing, mechanical drafting, 3D modeling and animation development [4], [9].

First year undergraduate engineering students encounter several difficulties in learning concepts of ED course [8], [15], [22], mainly due to a lack of MR ability. Hence there is a need for interventions to improve students' MR abilities and also to examine the effect of such interventions on learning of ED concepts. We identified orthographic projections and isometric projections as the major concepts in ED that might be impacted by MR training [1], [10], [13].

In a previous work we found a three-hour computer based 3D MR training module to be useful in improving 3D MR skills of first year engineering undergraduates. In this paper we present a two-group experimental study to investigate the effect of computer based MR training on ED problem solving skills of first year engineering undergraduates (N=34). This training is a modified version of our prior three-hour computer based MR training. Experimental group received the treatment for two weeks with total four sessions of two hours each. The control group received equal hours of classroom teaching. The posttests were based on the spatial visualization ability test (SVATI) [2] and were administered after every session. Students' responses on difficulties faced while solving the tests were collected.

We found that MR training is effective in improving ED problem solving skills. Independent sample t-test showed that the results are statistically significant. Students' responses also suggest that the ED problem solving difficulties such as converting 3D views to orthographic views and vice versa, visualizing in 3D, and identifying the hidden surfaces, got resolved during the training.

II. BACKGROUND AND RELATED WORK

A. *Challenges in Learning Engineering Drawing*

The difficulties that students face while solving ED problems include analyzing the shape of surfaces, interpreting and analyzing the orthographic and isometric views; identifying multiple views [8]. Major difficulty is to perform the transformations between 2D and 3D, [1], [10], [13], [15] i.e. converting isometric view into its orthographic views; and constructing isometric view by interpreting orthographic views of an object.

It is also challenging for the teachers to explain the three dimensional concepts of orthographic and isometric views [12], [22]. The possible reason for these difficulties could be the student's poor spatial ability or the instruction method. Thus in order to minimize these difficulties there is a need for the improvement in visualization abilities of student, along with appropriate instruction method.

B. *Mental Rotation and its Importance in ED*

'Spatial ability is the ability to perform mental rotation of objects, visualize how objects appear at different angles, and conceptualize how objects relate to each other in 3-D space.' [21]. MR is an important aspect of spatial ability and deals with performing the mental rotation of objects.

MR is especially important in ED [17], [20]. MR can be improved by various interventions such as physical activities [7], [16] and computer based training [18], [23]. This indicates the need to investigate the effect of the MR training on learning ED concepts. We found [19] as the only study in which researchers have investigated the impact of MR and spatial visualization training on orthographic drawing performance. Rest of the studies measured the impact of spatial ability training on ED problem solving skills. Studies are either focused on improving spatial ability [20], [23], or

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on using various instructional methods such as conventional, CAD and multimedia based learning [4], [5], [9], [14].

Hence this leads us to the implementation of our work. In this work we have developed two-week computer based 3D MR training for improving ED problem solving skills.

C. Improvement of 3D MR Ability Using Blender

In our prior work we developed a three-hour 3D MR training module. We used Blender, an open source 3D modelling software for content creation and as a training tool. The results of experimental study on the effect of our training on the improvement of 3D MR ability on 42 first year engineering undergraduate students revealed that, the training was effective with significant improvement in MR ability. Training tasks were oriented towards acquisition of 3D MR strategies. [11]. In this paper we present the study in which we investigate the impact of an extended version of MR training on solving ED problems. The existing three-hour training module was modified to accommodate for the duration of two weeks. The training details are given in section IV.

III. PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

The purpose of this study was to investigate the effect of Blender based 3D MR training on students' ED problem solving skills. We scope this study to the ED problems for the following concepts: (i) Orthographic projections: conversion of isometric view to orthographic views; and (ii) Isometric projections: conversion of orthographic views to an isometric view. We address following research questions:

1) Does a computer based 3D MR training improve ED problem solving skills of the first year undergraduate engineering students?

2) Does computer based 3D MR training help students in resolving the difficulties faced by them in solving ED problems?

IV. METHODOLOGY

A. Sample and Research Design:

Sample consisted of 42 undergraduate students from first year engineering course from the engineering institution in India. Convenience sampling was used as these were volunteers for the training. We used two group posttest only research design for this study. The groups were created by randomized assignment, while ensuring that they were equivalent based on their previous year's performance scores. The group size for experimental group and control group was 21 each. Eight students were unable to be present for all the sessions, this resulted in actual group size as 18 and 16 for the experimental and control group respectively.

B. Instrument and Data collection:

SVATI - Spatial visualization ability test [2], was used as the test instrument to measure the improvement in ED problem solving skills. The posttests were conducted at the end of each session. We exclusively considered the engineering drawing tasks items from the test set. Each posttest consists of four items. Posttest-1 and posttest-2 questions were based on the orthographic projections in which for a given isometric view student have to identify the correct set of orthographic views. A sample item is shown in figure-2. Posttest-3 and posttest-4 consists of questions based on the isometric projections in which for a given set orthographic views students have to identify the correct isometric view. For each correct answer student gets two marks. Test duration was 20 minutes. To determine the difficulties faced by students while solving posttest after each session, we collected students' responses on an open ended question in a written form immediately after every posttest.

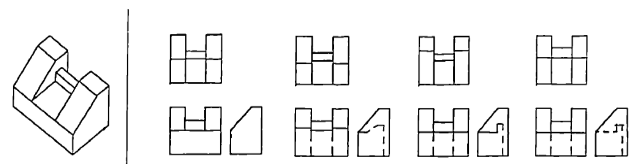

Figure 1. Posttest item from SVATI [3].

C. Blender Based 3D MR Training

In this section we present the details of our computer-based 3D MR training given to the experimental group.

The training was spread over two weeks with total of four sessions. Duration of each session was two hours. The topics selected for the training were orthographic projections and isometric projections with two sessions allotted for each. We conducted the posttest after each session.

The training consists of four parts: (1) Introduction to Blender User Interface, (2) Observing objects in multiple views including 3D space, (3) Rotation of views and rotation of 3D objects, (4) Rotation of engineering drawing items from the posttest of previous session by applying techniques learnt in previous parts.

Our training method was based on the instructional strategy demo-drill-practice (DDP): (i) Demo (10 minutes): students watch a demonstration being given by the instructor, (ii) Drill (10 minutes): students carry out the step-by-step actions specified by instructor for a given object, (iii) Practice (10 minutes): students (a) practice the tasks on their own for the same object, and (b) practice with the posttest items from previous session and verify their answers. [11]

D. Training Activities and 3D MR Strategies:

The training activities were designed in such a manner that the Blender commands were focused to the 3D MR strategies relevant for solving ED problems. The 3D MR strategies are [11]:

1. Observation of an object by keeping it stationary.
2. Use of side of an object as a reference to compare with the given figure
3. Use of various extrusions of an object and the angle between them for comparison with the given figure.
4. 3D Rotation of an object about x, y and z axes by identification of its center to compare with the given figure.

The activity in each part along with its instructional goal and rationale is explained below. Each activity follows the instructional strategy DDP.

1) Introduction to Blender User Interface:

a) Activity: Demonstration of Blender user interface given by the instructor, followed by step-by-step drill and independent practice by the students.

b) Instructional Goal: Students should be able to make use of the basic user interface features and commands of Blender such as: (i) to open a new scene, (ii) to operate the default settings.

c) Rationale: the skill to use these features of Blender is essential for performing subsequent activities from other parts of the training.

2) Observation of objects in multiple views:

a) Activity: Demonstration of observing objects in single as well as four views, followed by drill and practice. We used colored cube as an object for the demonstration.

b) Instructional Goal: Students should be able to view and observe orthographic views like top, side and front at once of an object, along with the 3D view. They should be able to learn the technique of observing an object from various angles to distinguish between various views.

c) Rationale: visualizing object in a multiple view is the foundation for ED skill; especially in converting the orthographic view to isometric and vice versa.

3) Rotation of views and rotation of 3D objects:

a) Activity: In this, initially rotation of views was demonstrated by keeping an object stationary, followed by the rotation of object by keeping the view stationary. Rotation of an object was demonstrated about various axes such as x, y, z and an axis perpendicular to the screen. This was done by using various specific features of Blender, such as keyboard shortcuts, mouse, 3D rotation manipulator and transformation properties. These rotation activities were also repeated in multiple views.

b) Instructional Goal: Students should be able to use following Blender features for rotating the views and rotating an object: mouse, keyboard shortcuts, 3D rotation manipulator and transformation properties. They should be able to identify the axis for rotation.

c) Rationale: Rotation various axes enables student for observing the object with different ways. Rotation with multiple views enables the observation strategy to observe the same object getting rotated in different views, and they can observe the transformations.

4) Rotation of engineering drawing items from the posttest of previous session by applying MR techniques (this is applicable to the sessions 1, 2 and 3):

a) Activity: we repeated the part 3 activities, for demonstrating the solution strategies for one engineering drawing item from the posttest. It was modelled in Blender (Figure 2); and was constructed as per the default orientation given in the original test as per Figure 1. Students then practiced remaining test items in Blender to verify their answers of the posttest.

b) Instructional Goal: Students should be able to apply all the skills acquired in the previous parts of training. They should also be able to identify the association between Blender actions and the strategies required for solving the engineering drawing items from the posttest.

c) Rationale: practicing with the posttest objects in Blender may give more clarity towards solving the other ED problems. It may help students to resolve the difficulties faced in solving the posttest. It may also make ED problem solving strategies stronger in terms of Blender operations.

E. Instructional Procedure for the Experimental Group:

Experimental group (N_1=18) received computer-based 3D MR training for two weeks that consisted of four sessions and the duration for each session was two hours. The first week (sessions 1 and 2), comprised of orthographic projections. The second week (sessions 3 and 4), comprised of isometric projections. Posttests were conducted at the end of every session, followed by students' responses on an open ended question on difficulties faced for solving the posttests. The solutions of each posttest were discussed at the beginning of succeeding session.

Session 1:

We started with icebreaker activity in order to highlight the importance of MR in ED and to introduce orthographic projection as well. It was then followed by introduction to Blender user interface. DDP was used to train students for the 3D models of objects for the topic of orthographic projections. The contents were used from standard ED textbook. DDP was used for first two objects and then students practiced for other two. The total duration of the session was two hours. We then conducted Posttest-1 with four test items on orthographic projections.

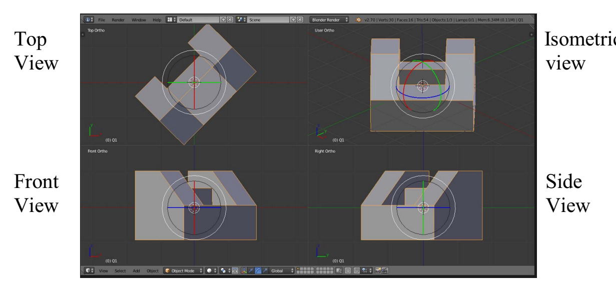

Figure 2. Rotation of object in multiple views in Blender.

Session 2:

This session was the continuation of MR training for orthographic projections. Students had to apply MR training techniques learnt in session-1 to verify their answers of posttest-1. 3D models of the posttest-1 items were used for the training purpose. Then each question was discussed by instructor in order to resolve any difficulties faced by students. Two more objects from ED textbook were used for MR training. The total duration of the session was two hours. We then conducted Posttest-2 with four test items on orthographic projections.

Session 3:

The topic of isometric projections was introduced in this session. Then students verified posttest-2 answers by applying MR training technique, followed by discussion with instructor to resolve difficulties. 3D models of the posttest-2 items were used for the training purpose along with the two objects from ED textbook. The total duration of the session was two hours. We then conducted Posttest-3 with four test items on isometric projections.

Session 4:

This session was the continuation of MR training for isometric projections. Students had to apply MR training techniques learnt in previous sessions to verify their answers of posttest-3. 3D models of the posttest-3 items and two objects from ED textbook were used for the training purpose. Then each question was discussed by instructor in order to resolve any difficulties faced by students. The total duration of the session was two hours. We then conducted Posttest-4 with four test items on isometric projections.

F. Instructional Procedure for the Control Group:

Control group (N_2=16) received formal classroom teaching over the two weeks. The duration and topics for each session was identical to that of the experimental group. The teaching was done by using presentations and blackboard teaching. The posttests, discussion of solutions, and open-ended question on difficulties, were also done in an identical way to the experimental group.

G. Data Analysis Procedure:

We calculated the means, average gains and performed quantitative analysis of the posttest scores using independent sample t-test and computed the effect size. We analysed the students' responses and coded the common trend of words, phrases and statements as the difficulty faced by the students while solving the posttests. We then summarize these codes as a list of difficulties. In a similar manner we identified, the ways in which training helped them to resolve the difficulties.

V. RESULTS

A. Quantitative analysis

1) Means and Average gain: We first calculated the means of all posttest performance scores for both the groups. Mean for all the posttests is higher for the experimental than that of the control group (Table I). We calculated average gain between the two posttests of each topic, as we conducted two posttests for each topic. To calculate the gain for the orthographic projection topic we considered posttest-1 and posttest-2 scores. To calculate the gain for the isometric projection topic we considered posttest-3 and posttest-4 scores.

The average gain of the students from the experimental group for the orthographic projections (86%) is significantly higher than for the students from the control group (54.4%).

Also for isometric projections, the average gain for the experimental group students is 55%, whereas for the control group students it is negative i.e. -15.4%. This shows that our treatment was indeed effective as compared to the formal teaching of ED course.

2) Independent sample t-test analysis and effect size: we performed independent sample t-test analysis for all the posttests and results are shown in table-II. Posttest means of experimental group are higher than the control group means for all the posttests. To calculate the Cohen's effect size (Eta squared) for independent samples in a t-test we used following formula [6]: *Eta squared* $= t^2 / (t^2 + (N_1 + N_2 - 2))$

Posttest 1: Though the mean of experimental group was higher, the treatment was statistically not significant as $p>0.05$.

TABLE I. INDEPENDENT SAMPLES T-TEST AND EFFECT SIZE

	Posttests means			
Topic →	**Orthographic projections (Sessions 1 and 2)**		**Isometric projections (Sessions 3 and 4)**	
↓ Group	**Posttest-1**	**Posttest-2**	**Posttest-3**	**Posttest-4**
Control (N_2=16)	3.87	6.12	4.75	4.25
Experimental (N_1=18)	4.00	7.44	5.77	7.00
t value	-0.179	-2.425	-1.744	-5.031
Std dev. Control & Experimental	1.70 / 2.27	1.99 / 0.92	1.91 / 1.51	1.61 / 1.57
P	0.256	0.004	0.130	0.000
df = $N_1 + N_2 - 2$	32	32	32	32
Effect size (Cohen) Eta squared = $t^2 / (t^2 + df)$	-	0.155	-	0.441
	-	a very large effect	-	a very large effect

Posttest 2: We found that there was a statistically significant difference between the posttest-2 scores of the two groups with experimental group performing significantly better than the control group (formal teaching). Further Cohen's effect size (Eta^2=0.155) suggests a large significance. It can be inferred that the MR training would be effective after two sessions.

Posttest 3: Even though the mean of experimental group is higher, the treatment is statistically not significant as $p>0.05$.

Posttest 4: The treatment is statistically significant ($p<0.05$) and has a large effect with Cohen's effect size of 0.441. It shows that our treatment is effective.

B. Students' Responses

1) Analysis of student's' responses: Based on the content analysis of students' responses we summarize following as the difficulties faced by students, in solving ED problems from all the posttests.

1. Identifying and distinguishing between the orthographic views correctly.
2. Identifying the surfaces with hidden lines.
3. Visualizing the object in 3d.

Our findings confirm that, the difficulties faced by the students in solving ED problems are identical to the difficulties mentioned in various research articles [1], [8], [10], [13], [15] from literature.

Students from the control group mentioned the need of more time to solve the posttest as well as the need of different approach for solving the ED problems from the tests. Students from the experimental group faced these challenges during the posttest-1 only. The analysis revealed that, training activities helped them in getting over the difficulties and motivated them for learning ED concepts. While solving the posttests 2, 3 and 4, comparatively it was easier for the students to (i) identify orthographic views distinctly, (ii) identify surfaces with hidden lines with more accuracy, (iii) visualize the object in 3d. Students also mentioned that due to the training activities, they learnt various approaches to observe the object, majorly the rotations. To support our analysis, below we quote some of the students' statements from the content.

- "Because of the training I understood that, how to observe the object by rotating."
- "Imagining object from all side was much easier due to training."
- "This training session helped me to visualize the object from different views."
- "Initially I have difficulties in dealing with invisible lines, but after the training I can solve it quickly."

VI. Discussion

Our first research question "Does a computer based MR training improve ED problem solving skills of the first year undergraduate engineering students?" was answered by the results of experimental study which showed that the group who learned ED concepts via a computer based MR training performed significantly better than the group which learned the same concepts from formal teaching method.

The second research question "Does computer based MR training help students in resolving the difficulties faced by them in solving ED problems?" was answered by analysis of students' responses on the open ended question: What difficulties did you face while solving the posttest and how did you try to resolve it?

MR ability has been known to be a key factor for learning ED concepts [2], [9] and our findings reconfirmed this. Our finding suggests that computer based MR training is desirable for learning ED concepts as it reduces the complexity in learning ED concepts

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