

Improvement of Mental Rotation Ability using Blender 3-D

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Abstract—Mental Rotation (MR) is an aspect of spatial ability. MR ability is important in various fields ranging from art and education to engineering and technology. MR ability can be improved by computer based training. Most existing techniques require weeks of training and are based on proprietary software. We developed a three-hour training module using Blender, an open source software. In this paper, we present experimental details of the effect of our training on the improvement of MR ability. Our sample was 42 first year engineering undergraduate students and we used Vandenberg's Mental Rotation Test for pretest and post-test. We analyzed the results and found them to be significant, leading to a large effect size for the entire sample. We also found that females and low achievers are more likely to benefit by such training.

Keywords- mental rotation; spatial ability; Blender; engineering students

I. INTRODUCTION

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 [3]. Spatial ability is important for various domains ranging from art and education to science and engineering [4]. Many studies have shown that spatial ability can be improved by training [5], [6], [8], [9], [12].

Mental rotation (MR) is an important aspect of spatial ability. Maier defines it as “*the ability to rapidly and accurately rotate a 2D or 3D figure*” [2]. MR ability is especially important for activities such as engineering drawing, mechanical drafting, animation development and 3-D modeling [5], [12]. Interventions to improve MR ability range from physical activities [5], [7], to computer based training [12], [13], [14], [15] [16].

The interventions that involve computer based training are summarized in Table 1. They spread the treatment over weeks and use proprietary software. While this is valid, the use of proprietary software has prohibitive costs for large scale implementation in the Indian context. Also, since explicit spatial ability training is not part of any formal engineering curriculum, we felt that retaining students for a lengthy treatment would be difficult. Hence we wanted

to explore the effect of short duration spatial ability training, using open-source software, in the Indian context.

The focus of our current study is specific to the improvement of MR ability with respect to 3-D objects, using Blender (an open source software) [19], in a 3-hour training given to first year undergraduate engineering students. We first administered a pretest based on Vandenberg's Mental Rotation Test [11]. Then we trained students to perform various rotation tasks in Blender such as, rotation of object in 3D space along different axes, using 3D rotation manipulator, and rotation with multiple views enabled. After the training we administered a post-test. Subsequently we gave a questionnaire to determine the strategies used by students for solving the post-test.

Our training (N=42) resulted in an average gain of 0.26. The paired-sample t-test was significant and the effect size (Cohen) was 0.26 (large effect) [18]. We also found that the results for females were significant, and the effect size for females was 0.36. Also, students who had low achievement scores in the pretest showed the largest improvement in the post-test (average gain of 0.37).

In Section II we present the related work, followed by a brief description of Blender in Section III. Sections IV, V and VI give the details of the research questions, methodology and treatment, respectively. The results and analysis are in Section VII, followed by discussion in Section VIII.

II. RELATED WORK

There are many definitions of spatial ability [1], [2], [3], [4]. In [1], Linn and Peterson identified 3 categories of spatial ability as: Spatial Perception, Mental Rotation and Spatial Visualization. In [2], Maier extended Linn and Peterson's work to include two more categories: Spatial Relations and Spatial Orientation. We adopt Maier's definition of Mental Rotation, viz., “*the ability to rapidly and accurately rotate a 2D or 3D figure*” [2].

Shepard & Metzler used perspective line drawings of the same 3-D shape for performing MR experiments [10]. Based on their findings, Vandenberg & Kuse developed the Mental Rotation Test (MRT) to assess MR ability [11]. We adopt MRT as the instrument for our study.

There are many studies related to the improvement of spatial ability [5], [6], [8], [9], [12]. Our interest is on studies that specifically focus on MR ability. Interventions to improve MR ability range from physical activities [5], [7], to computer based training (CBT) [12], [15]. Our interest is on studies that attempt to improve MR ability through CBT. These are summarized below in Table 1.

TABLE I. SUMMARY OF STUDIES RELATED TO MR IMPROVEMENT THROUGH CBT

Ref	Treatment duration	Test type	Tool	Sample (background & no.)	findings
[12]	Not specified	Computer based (CB)	CAD	157 engineering students, 34 high school seniors	Improved in performance
[13]	5 weeks, 1.5 hrs per week	CB	CAD	58 undergraduates, Information Technology and Comm.	Treatment was effective in terms of accuracy
[14]	8 weeks, 2 hr per week	CB and online	CBMT (free)	98 secondary school students	Statistically significant
[15]	6 hour with three 2 hour sessions	Paper pencil + web based	Proprietary	78 low achievers from 461, engg	Positive impact
[16]	Experiment 1: 37 minutes Experiment 2: 60 minutes	CB	Game Studio	Exp1: 107 Exp2: 67	Effective for limited trained objects

As can be seen from Table I, most existing studies spread the treatment over weeks and use proprietary software. While this is valid, we wanted to explore the effect of short duration MR training, using open source software, for students in the Indian context.

We have provided the details of our treatment in Section V, to enable easy replication and adoption of our work. In the next section, we briefly describe the Blender software used in the training.

III. BLENDER

Blender is a free open source 3D content creation suite, available for all major operating systems under the GNU General Public License (Blender website, 2009). It supports a variety of geometric primitives including polygon meshes and fast subdivision surface modeling. Currently, Blender has been used in different entertainment domains like animated movies, short films, television commercials, and gaming and also in eLearning [17], [19].

The user interface of Blender allows users to perform various tasks efficiently. These are:

- 1) *Hot key utilization:* Navigation in Blender has a support of intuitive keyboard shortcuts for 3-D

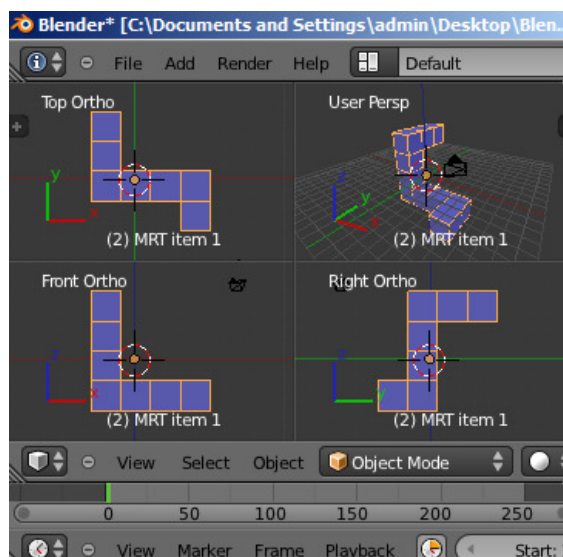


Figure1. Blender screen with quad view.

transformations of objects. This makes it easy for students to use Blender during our training.

- 2) *Numeric input:* Along with the alphabetical keys, Blender also supports numerical inputs to enable easy interaction. Ex: If a user wants to rotate an object in z axis by 45 degrees, Blender shortcuts are: r (rotate) + z(axis) + 45(degrees of rotation).
- 3) *Workspace management:* This is not relevant to our study but is a useful features for animators, as they can organize the interface to suit their requirements.

IV. RESEARCH QUESTIONS

At a broad level, our question is: What is the impact of the use of CBT on the spatial abilities of the learner? This is operationalized into the following 2 specific research questions:

- 1) Does a 3-hour Blender training improve the mental rotation ability of first year undergraduate engineering students?
- 2) What skills from the Blender training do students apply while doing mental rotation?

V. METHODOLOGY

A. Sample

Sample consisted of 42 undergraduate students (17 males and 25 females) from first year engineering course from a college in Mumbai. Convenience sampling was used as these were volunteers for the training.

B. Data collection:

To measure improvement in MR ability, students' performance scores on Vandenberg's MRT test were collected. To determine the Blender skills used, students'

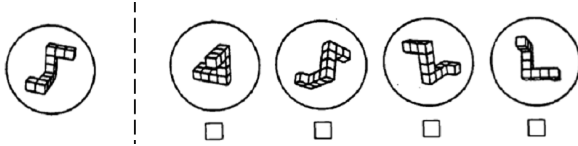


Figure 2. Vandenberg's MRT test item

responses to our questionnaire (3-point likert scale) were collected.

C. Instrument:

Vandenberg's Mental Rotation Test (MRT) [11] was used as the test instrument. It is a paper-pencil test developed by Vandenberg & Kuse (1978). MRT contains 20 items with five sets of four items. A sample item is shown in Fig. 2. Each item consists of a criterion figure, two alternatives, and two incorrect ones. The two correct alternatives are always identical to the criterion figure in structure but are shown in rotated position. The other two are incorrect ones. We used 10 items each for pretest and post-test assessment.

MRT is suitable for our study since it is specific for MR ability. Other tests such as PSVT [12], also test for factors such as development of 3-D object, which are not relevant to our study.

In order to determine the Blender skills used in solving the MRT post-test, we developed the 7-item questionnaire shown in Table II. Each item corresponds to a specific Blender skill that is useful for MR. After solving the post-test, students were asked to respond to the questionnaire items on a 3-point likert scale (mostly-sometimes-never).

D. Procedure

1) *Icebreaker*: We started with a 15 minutes activity to highlight the importance of MR ability.

2) *Pretest*: Then we conducted a 15 minutes pretest. Ten items from MRT were used and each student had to attempt them individually.

3) *Treatment*: The pretest was followed by 3-hour Blender training. This was divided into 5 parts: (i) Introduction to Blender User Interface, (ii) Multiple views of objects in 3-D space, (iii) Placement of objects in 3-D space, (iv) Rotation tasks using Blender, and (v) Rotation of pretest items. The tasks in each part of the treatment were oriented towards acquisition of MR strategies. Our training method consists of activities that require a student to do: (i) watch a demonstration being given by the instructor, (ii) carry out the step-by-step actions specified by instructor for a given object, (iii) repeat the actions on their own for the same object and (iv) repeat the actions for different objects. The treatment is described in more detail in the next section.

4) *Posttest*: Then we conducted 15 minutes post-test. The remaining ten items from MRT were used, thereby ensuring equivalence of pretest and post-test.

5) *Questionnaire*: We ended with giving a 15 minutes questionnaire having seven items, to capture MR strategies corresponding to Blender activities (Table II).

Each student had to respond whether he/she used to each strategy on a 3-point likert scale (mostly-sometimes-never).

6) *Analysis*: We performed quantitative analysis of the pre-test and post-test scores. We computed average gain for the whole group and for sub-groups based on pre-test achievement (low-medium-high) and gender. We then determined significance using paired-sample t-test and computed the effect size. We also found the frequency of responses to each questionnaire item and correlated them with post-test, using Pearson's correlation.

E. Pilot

We conducted a pilot run of the experiment, using ten volunteers outside the sample. This helped us to fine-tune the sequence of the treatment and the time allotted for each part. It also confirmed that our data collection instruments were unambiguous and timed appropriately.

TABLE II. MENTAL ROTATION STRATEGIES USING BLENDER

	Strategy
A	Keeping the object still and moving around the object, observing it from various positions
B	Choosing a side of the object and using it as reference to compare with the given image
C	Performing various extrusions of the object and using the angle between them to compare with the given image
D	Identifying the center point of the object and rotating it along a particular axis (x or y or z) and compare with the given image
E	Identifying an axis (x or y or z) and rotating along the axis and compare with given image
F	Rotating the object in the given angle incrementally and compare with given image
G	Mapping the x, y and z axis to the object and comparing its correspondence in the given image, followed by rotating the object to get the angle for the given image

VI. TREATMENT DETAILS

In this section we present details of our Blender training to show the logic for the sequencing and contents of each part, and to enable replication of our treatment.

We introduced Blender as a 3-D graphics content creation tool for 3-D modeling and 3-D animation. In the Icebreaker activity, to highlight the importance of MR, we displayed the top view and side view of an object (See Fig. 3) [5] and asked students to draw possible options for front view and 3-D view of the object. This helped not only to engage the students but also underlined the importance of MR.

Blender training was planned with the focus on Blender commands that are relevant for MR, such as different views and rotation. This led to a 5-part training: (i) Introduction to Blender User Interface, (ii) Multiple views of objects in 3-D space, (iii) Placement of objects in 3-D

space, (iv) Rotation tasks using Blender, and (v) Rotation of pretest items.

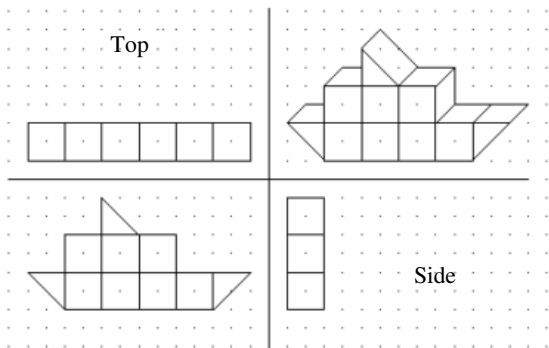


Figure 3. Icebreaker activity object

In each part, students had to do: (i) Watch a demonstration of an instructor manipulating an object in Blender, (ii) Perform the same manipulation of the same object in-tandem with the instructor by following step-by-step actions, (iii) Practice the actions on their own for the same object, and (iv) Apply the actions on different objects. Teaching assistants were present to help students during practice.

The Objective and Rationale for each part of the training was:

1) *Introduction to Blender User Interface:*

a) *Learning Objectives:* Students should be able to use the basic features and commands of Blender like: (i) Opening a new scene, (ii) Manipulating the basic panels which open in a default scene.

b) *Rationale:* Ability to use these features of Blender is required for performing subsequent activities aimed at improving MR ability.

c) *Activity:* Demonstration of Blender user interface (10 minutes), followed by step-by-step drill (10 minutes), and independent practice (10 minutes).

2) *Multiple views of objects in 3-D space:*

a) *Learning Objectives:* Students should be able to use the commands (shift+alt+ctrl+q) to view an object from four different views like top, side, front and 3D at a time. They should also be able to see a particular view in full screen (shift+spacebar) and to view the object from various angles. Students should be able to distinguish between the orthographic view, isometric view and 3D view.

b) *Rationale:* Familiarity with various views is a basis for the MR strategy of visualizing. The possibility of viewing the object simultaneously in multiple angles (strategy B) assists the MR ability

c) *Activity:* Demonstration of getting four views of the object in a single screen (10 minutes), followed by step-by-step drill (10 minutes) and independent practice (10 minutes).

3) *Placement of objects in 3-D space:*

a) *Learning Objectives:* Students should be able to place and move the objects in 3-D space. Additionally,

they should be able to explain the effect of moving the objects in a viewport and the changes in other viewports.

b) *Rationale:* This facility in the software helps the user to actually see the changes in different viewing angles (strategy C, E and F), in realtime. This helps to visualize intermediate steps while performing MR tasks.

c) *Activity:* Demonstration of some primitive objects (like chair) which had distinct difference in their construction, when seen from different viewing angles. Demonstration was shown (10 minutes), and a drill was conducted (10 minutes), before the students has individual practice (10 minutes).

3) *Rotation tasks using Blender:*

a) *Learning Objectives:* Students should be able to use the Blender features of: 3-D rotation manipulator, keyboard shortcuts and transformation properties. They should be able to use these features initially to identify the axis they need to rotate the object on, rotate an object along different axes (x, y, z axes), as well as rotate along the axis perpendicular to computer screen.

b) *Rationale:* These Blender skills correspond to the MR strategies of fixing the axis first, and then rotating an object along single or multiple axes (strategies A, C, E and F).

c) *Activity:* This was divided in two parts. One where the object is still and the user can view it from various angles (middle mouse button). Later, the students were shown how to rotate the object. For this, the axes of an object were explained. The keyboard shortcut for incremental rotation (numpad arrow keys) and rotation of a 3-D cube using keyboard shortcuts ('r' followed by the axis 'x, y or z' and the degree of rotation 'numerical') were shown (10 minutes). The other options like, using mouse, using 3D rotation manipulator (spherical lines around the object with colour codes denoting the axes), and combining rotation with changing views covered earlier in part 2 (5 minutes) was demonstrated. Then step-by-step drill (15 minutes) was conducted, followed by independent practice (15 minutes). Additionally, students applied their skills in an exercise to match two different orientations of 3-D model of 'chair' object (10 minutes).

4) *Rotation of pretest items using Blender:*

a) *Learning Objectives:* Students should be able to apply all skills learnt in the previous parts. Also, they should be able to recognize the correspondence between Blender actions and MR strategies for solving the pretest.

b) *Rationale:* Working with the pretest objects in Blender may help students to concretize MR strategies in terms of Blender operations. This may in turn enable them to later apply MR strategies explicitly and systematically.

c) *Activity:* Demonstration of solving one pretest item (From Fig 1) was modeled in Blender. The criterion figure was constructed as the default orientation (See Fig 3). Performing Blender rotation on the criterion in order to get the alternative figures, was demonstrated (10 minutes).

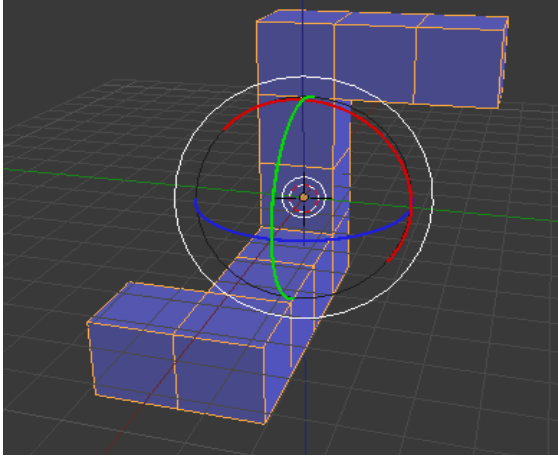


Figure 4. MRT pretest item in Blender with 3D Rotation manipulator

Step-by-step drill was not done for this part as they were already familiar with the Blender rotation skills. Instead, they did independent practice using the same item (15 minutes). They were also encouraged to reflect on the correspondence between their Blender actions and MR strategies. They applied their MR strategies along with the Blender skills in an exercise consisting of *two more* pretest items (10 minutes). They were not shown the solution for these items nor given any further demonstration.

After the end of this 3 hour treatment, the post-test and questionnaire were given. Their results and analysis presented in the next section.

VII. RESULTS

The results are as follows:

A. Pretest – posttest: Mean and Gain scores

TABLE III.

Test	N	Mean	Std. deviation	Std. error Mean
Pretest	42	8.95	5.45	0.84
Post test	42	11.79	4.46	0.69

First we found that the Percentage improvement in the post-test score = 31.7%, which is significant.

Then we calculated the average gain as:

$$\text{Average gain} = \frac{(\text{posttest score} - \text{pretest score})}{(\text{maxscore} - \text{pretest score})}$$

and found overall average gain = 0.26 (i.e., 26%)

Then we calculated average Gain based on pretest achievement as shown below:

TABLE IV.

Pretest level	Number of students	Mean of pretest	Mean of post-test	Avg. gain
High 15-20	6	18.33	16.33	-1.2
Med 8-14	16	11.13	12.06	0.11
Low 0-7	20	4.4	10.2	0.37

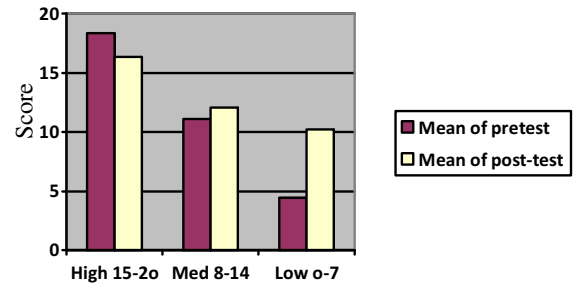


Figure 5. Scores based on Pretest Achievement

As can be seen from the above graph, those who scored low (0-7) in the pre-test, showed the largest improvement for post-test.

We found the number of students in various gain levels to be as follows but these numbers are not sufficient to draw any inference.

TABLE V.

Gain level	Total
High (60+)	6
Medium (31-60)	10
Low (1-30)	11
Negative (<0)	11
No gain (=0)	4
	42

B. Analysis based on paired sample t-test:

TABLE VI. PAIRED SAMPLE T-TEST

Pair	Mean	Std. dev.	Std. error Mean	T	df	Sign (2-tailed)
Pretest – Posttest	-2.83	4.75	.73	-3.87	41	0.000

Result shows that the experiment is statistically significant ($t=-0.387$, $p<0.05$). So we continued on to compute the effect size (Cohen) [18] as:

$$\text{Eta squared} = \frac{\xi^2}{\xi^2 + (N - 1)}$$

Effect size was found to be 0.26 (large effect). This shows that our treatment was indeed effective.

C. Correlation of Blender strategy with posttest scores

a) We analyzed students' responses to the seven item questionnaire. For a gross analysis, we combined the responses of 'mostly' and 'sometimes' into one, as both choices denote the use of Blender skill while solving the posttest. 170 (58 %) total responses say that they have considered Blender skills when solving posttest and 124 (42%) responses did not. (See Table VII).

TABLE VII. STRATEGIES USED WHILE SOLVING POSTTEST

Frequency of use	A	B	C	D	E	F	G	Total
Mostly	17	12	2	15	13	10	6	75
Sometimes	17	14	14	9	13	16	12	95
Never	8	16	26	18	16	16	24	124
Total	42	42	42	42	42	42	42	294

Refer Table II for list of strategies A to G.

b) In order to determine the correlation of Blender strategies with post-test score, we computed a score to represent the amount of Blender strategies used by each student. For each strategy A-G (in Table I), we assigned a value of 2 for a response of 'mostly', a value of 1 for a response of 'sometimes' and a value of 0 for a response of 'never'. For each student, we computed the Blender score to be the sum of the student's responses for all the strategies (A-G).

c) Then we did a Pearson's correlation analysis between the Blender scores and the posttest scores. We found $r=0.107$ ($p > 0.05$). This shows that there is a positive correlation, albeit low.

d) A comparison of mean pre-test and post-test scores based on grouping of Blender scores is shown below.

High Blender: 8-10; Medium: 5-7; Low: 0-4

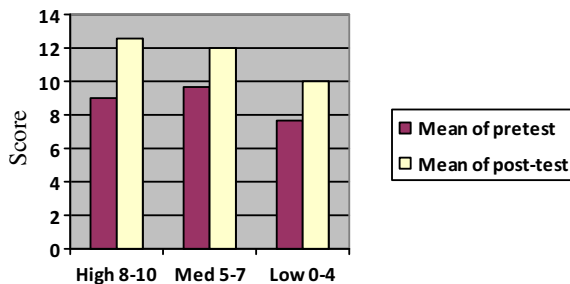


Figure 6. Scores based on Blender strategies used

D. Gender differences

We found mean scores for males and females in pretest and posttest respectively as:

TABLE VIII.

Test	Mean (Male)	Mean (Female)
Pretest	9.18	8.8
Post test	11.4	12

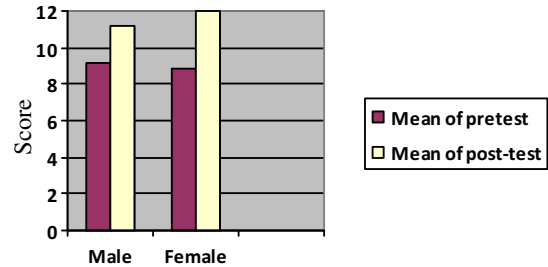


Figure 7. Scores based on Pretest Achievement

We calculated average gain for males and females:

Average gain for males = 0.21

Average gain for females = 0.29

We also determined the significance of difference between pretest and posttest scores for male and female students separately, as shown below. Results were not found to be significant for males ($t=-1.73$, $p > 0.05$), but were significant for females ($t=-3.706$, $p < 0.05$).

TABLE IX.

Pair	Mean	Std. dev.	Std. error Mean	T	df	Sign (2-tailed)
Pretest – Posttest Male	-2.24	5.3	1.29	-1.73	16	.103
Pretest – Posttest Female	-3.24	4.37	.87	-3.706	24	.001

We went on to compute effect size for females = 0.36 (very large effect). We also found the effect size for males = 0.15 (large effect), although the numbers are not significant.

Our results show that the mean post test scores for female participants was marginally higher than male counterparts. Average gain for females was also seen more than males. Findings of this study are contrary to the limited literature survey we did on this topic (male out performed females as mentioned in [1], [20], [21], [22] and [23]; and not out performing females as in [24]). Since, gender differences was not a main objective of our study, more detailed investigation needs to be done.

E. DISCUSSION

As seen from the results, our treatment for improving MR ability through 3-hour Blender training was effective (Effect size of 0.26 for entire sample). We also found that

low achievers on the pretest showed the largest improvement on the post-test.

We also found that the treatment was effective for females (Effect size of 0.36), but since the numbers are small, it is difficult to conclude this strongly.

Although the Pearson's correlation result is not significant there is a positive low correlation. The low correlation could be due to the aggregation of a variety of Blender usage responses into a single score. We are in the process of investigating this at a more fine-grain level.

The fact that it is a 3-hour training implies that it can be easily included as a tutorial within a 1st year course, such as Engineering Drawing. This may be of immense benefit to low pretest achievers (Avg. gain of 0.37).

It is important to note that the training method needs to ensure that students are fully engaged with the tasks related to acquiring spatial ability, rather than exploring other features and interfaces of the software.

We are in the process of doing further experiments to examine the generalizability of these results. We are also developing Blender training modules for improving other spatial abilities.

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