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The Impact of Using 3D Animation in Students' Spatial Ability

Jiong GUO[a], Yuhui MA[b*] & He GAO[b]
[a] *Educational Technology College, Northwest Normal University, China*
[b] *Education and Sports Science College, Bohai University, China*
*shixiaoran@163.com

Abstract: The purpose of this study is to investigate the impact of using animation in a multimedia environment designed to improve students' mathematical spatial ability. Sixth grade students (N = 44) were randomly assigned to one of the two experimental conditions with animation or non-animation as factors. The results show that participants provided with animations performed better than their peers provided with non-animations.

Keywords: spatial ability, 3D animation, multimedia environment

1. Introduction

Spatial ability is one of the most important abilities for many disciplines, such as mathematics, physics, chemistry, science et.al. But many students have difficulties in solving spatial problems. As multimedia technology rapidly develops, three-dimension technology has been introduced into the domain of education to help improving spatial ability. And many researches have proved that multimedia technology can improve students' performance if the design is rational. In recent years, many multimedia learning systems with three-dimension animations or software have been proved effective in improving students' spatial ability (Yeh, A, 2004; Hauptman, H. & Cohen, A, 2011; Hauptman. H, 2010; Christou, C., Pittalis, M., Mousoulides, N., & Jones, K., 2007).

Folding and unfolding problem solving is one of the spatial ability for students. It is a bridge between two-dimension figures and three-dimension figures. By solving folding and unfolding problems, students would know that polyhedron can be folded by two-dimension figures, and polyhedron can be unfolded into two-dimension figures in different ways. The traditional method in the classroom of teaching folding and unfolding in China is that students are asked to cut cube paper boxes or fold papers into cubes to perceive the process of folding and unfolding. Different students may cut the cube paper boxes in different ways, and that would produce different unfolding two-dimension figures. These different figures will be shown to the students as demonstrations. But the disadvantages of the traditional method are obvious. First, the paper boxes taken from home by students are not big enough to show to all students in the classroom. Second, paper boxes would not be reused when they are cut. So we developed the multimedia learning system to help solving folding and unfolding problems. In this system , 3D animations are contained to simulate transforming between 2D figures and 3D figures.

This study investigated the impact of 3D animations for students' solving folding and unfolding problems. We assumed that the students who received feedback with textual instruction and 3D animations would perform better than the students who received feedback without 3D animations. Furthermore, students' learning intrinsic motivation, cognitive load (including intrinsic load, extraneous load and germane load) are measured to investigate the effects of animation. A multimedia environment to learn folding and unfolding problem solving was developed to support this study.

2. Literature review

2.1 Spatial ability

Spatial ability is one of the most mathematical ability, and it has been defined as skill in "representing, transforming, generating, and recalling symbolic nonlinguistic information" (Linn & Petersen, 1985). But students have difficulties in solving spatial problems. A number of studies have proven that spatial abilities can be improved with appropriate exercise (Ben-Chaim, Lappan, & Houang, 1988), especially with learning by computers.

2.2 3D Animations in Spatial Education

Using 3D animation has been recognized as an effective method to improve students' incomplete mental models (Wu & Shah, 2004, Ferk, Vrtacnik, Blejec, & Gril, 2003). So there have been some researches about applying 3D animation to improve students' performance. Hauptman have developed a Virtual Spaces software environment to improve students' spatial thinking (Hauptman, 2010). By learning with Virtual Space, students can exercise the abilities to build spatial images and to manipulate them. According to Hauptman, Virtual Spaces enhanced students' spatial thinking.

Korakakis et.al. explored whether specific types of visualization (3D illustration, 3D animation, and interactive 3D animation) combined with narration and text contribute to students' performance (Korakakis, Pavlatou, Palyvos & Spyrellis, 2009). And the results showed that multimedia applications with interactive 3D animations as well as with 3D animations increased the interest of students and make the material more appealing to students.

3. Method

3.1 Participants

Forty four sixth grade students (twenty three females and twenty one males) from elementary school in northeast China were invited to participate this experiment. Their average age was 11 years old, and they could operate computers and learn with computers. The participants were divided into two groups according to the class. There were twenty four students in the group of animation (experiment group), and twenty in the group of non-animation (control group).

3.2 Multimedia learning environment

The multimedia learning system was developed to improve students' spatial ability. In this system, the animations that simulated two-dimension figure folded into a shape of cube or a cube unfolded into a two-dimension figure were included. Firstly, a folding or unfolding problem was presented, and then student submitted the answer. System would present "true" or "false" according to the students' answers and some cues about the problem (i.e. "Think why this two-dimension figure can not be folded into a cube, and how to change this shape to be folded into a cube"). Then a static figure about the problem was presented. An animation would be played if the students of experiment group pressed the button of "folding". These animations were developed with 3D MAX, it could simulate the process how and whether the two-dimensional figure folded the cube, or not. A sample segment of animations with hints is shown as Fig.1. The animation would not be presented if students were assigned to non-animation group. There were fifteen items with corresponding animations in this multimedia learning environment.

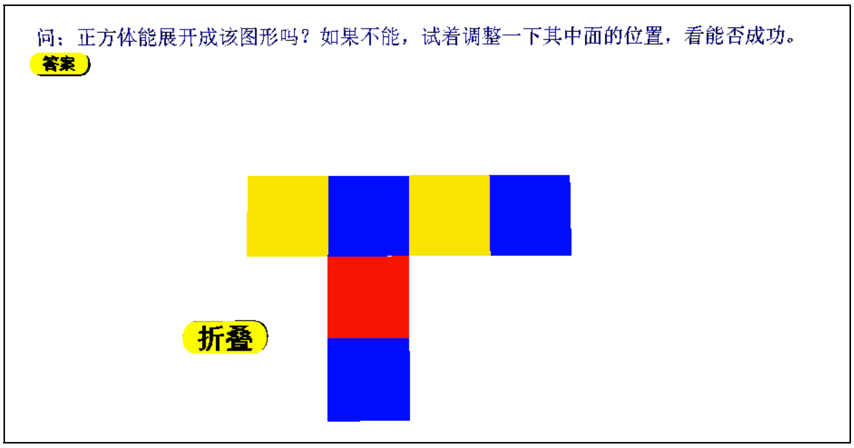

Figure 1. A sample segment of animations with hints.

3.3 *Measures and instruments*

A pretest and a posttest were developed to evaluate the learning effectiveness of the students. A pretest was composed of six choice items and fill-in-the-blank items about folding and unfolding cubes to measure participants' prior knowledge about spatial ability. Each of questions was 2 points, and the total points in the pretest was 12. The pretest aimed to detect that the two groups had the equivalent spatial ability. A posttest was conducted to measure the effect of participants' solving folding and unfolding questions after instruction. The posttest was composed of ten choice items and ten fill-in-the-blank items, which is different from pretest, but the level of the difficulty was similar. The total points in the posttest was 20. The sample question of the posttest is followed as Fig.2.

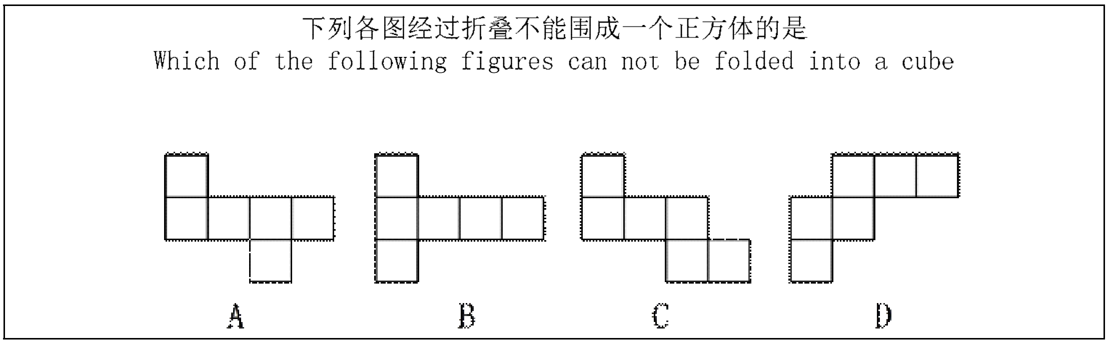

Figure 2. A sample question of the posttest.

In addition, a questionnaire with Likert-5-point was designed to measure students' intrinsic motivation. "1" was labeled as "not at all true", and "5" was labeled as "very true". There were total 10 statements, adapted from Ryan's study(Ryan, 1982), measuring intrinsic motivation with five subscales—interest, competence, pressure, value and effort (see Table 1).

Table 1: Intrinsic motivation items.

Item	Subscale
1. I spent a lot of effort to do this activity.	Effort
2. I feel these problems interest.	Interest
3. I think I was suitable to learn with this system	Competence
4. It was useful to study folding and unfolding problems.	Value
5. I didn't try very hard to do well at this activity.	Effort
6. I didn't feel nervous during learning.	Pressure
7. It was useful for me to learn these content.	Value
8. I was afraid to not do well at this activity	Pressure
9. I thought it was boring to do this activity.	Interest
10. I was not content with what I did at this activity.	Competence

Furthermore, a questionnaire with Likert-5-point was designed to measure students' cognitive load. "1" was labeled as "not at all true", and "5" was labeled as "very true". Three items about cognitive load (i.e., intrinsic load, extrinsic load and germane load) was conducted to measure the students' cognitive load (see Table 2). There were three statements to measure students' cognitive load adapted from NASA-TLX(Hart & Staveland, 1988) and were described in studies conducted by Gerjets, Scheiter, and Catrambone (2004).

Table 2: Cognitive measurement.

Item	Indication of
1. I thought these problems were very difficult.	Intrinsic load
2. I thought this system was helpful to learn these problems.	Extraneous load
3. I spent lots of effort to do this activity	Germane load

3.4 Procedure

The experiment was conducted in a laboratory setting. At the beginning of the experiment, a pretest with paper-and-pencil was made in order to measure whether the two groups had the similar level of spatial skill. Then students studied with the multimedia learning system in thirty minutes. Post-test was conducted to measure the effect of the spatial skill with animations or non-animations after instruction. Finally, the questionnaire was followed.

4. Results

4.1 Prior knowledge

The mean and standard deviation of the pretest were 9.12 and 1.45 for the experimental group, and 8.75 and 2.21 for the control group. An independent-samples *t*-test was conducted in order to examine whether animation group and non-animation group had different prior knowledge of spatial skill. The results revealed that there was no significant difference between the two groups ($t = .673$, $p = .505$), indicating that the participants in experimental group and control group had the equivalent abilities before learning.

4.2 Learning outcomes

An analysis of covariance (ANCOVA) was conducted to evaluate the effects of animation on students' performance. The percentage correct score on the pretest was used as a covariate. The result revealed a significant difference between the animation conditions and non-animation conditions ($F = 17.81$, $p<.01$), as shown in Table 3. The mean score of the experimental group is 15.82, higher than of the control group, 13.06. Furthermore, the effect size was computed to measure the strength of the *t*-test result. The *d* value 1 implied that the animation is very helpful to improve students' learning achievements.

Table 3: Descriptive data and ANCOVA of the posttest results.

Variable		N	Mean	S.D.	Std. error.	*F* value	*d*
Posttest	Experimental group	24	15.82	1.92	.44	17.81	1
	Control group	20	13.06	2.49	.48		

4.3 Intrinsic motivation

There were two items of each subscales of intrinsic motivation. So we add these two items of the subscale (effort, pressure, interest, value and competence) to compare students' intrinsic motivation of the two groups. *T*-test was conducted, and the results shows that the subscale of effort, pressure, interest and value had no significant difference between the two groups. But "competence" had significant difference between the two groups (t = .35) (See Table 4). That is , the animations improved students' competence of solving folding and unfolding problems.

Table 4: The t-test result of the post-questionnaire scores of the two groups.

Dimension	Group	N	Mean	S.D.	*T*
Effort	Experiment group	24	7.38	1.93	1.57
	Control group	20	6.40	2.19	
Pressure	Experiment group	24	5.96	1.27	.28
	Control group	20	5.85	1.27	
Interest	Experiment group	24	8.25	1.91	.24
	Control group	20	8.10	2.27	
Value	Experiment group	24	7.79	2.23	1.05
	Control group	20	7.10	2.12	
Competence	Experiment group	24	7.83	2.55	.35*
	Control group	20	7.60	1.85	

*p<.05

4.4 Cognitive load

Three ANCOVAs were conducted to evaluate the effects of animation on learners' intrinsic load, extraneous load and germane load respectively. The covariate was pretest score so that participants' prior knowledge was statistically controlled. There were no significant difference between the two groups with respect to intrinsic load(F = .44, p>.05), extraneous load (F = .22, p>.05) and germane load (F = .45, p>.05).

Furthermore, correlation analysis were conducted to measure the strength of relationship between intrinsic load or intrinsic motivation and difference between posttest scores and pretest scores. We assume that students' intrinsic motivation and cognitive load would impact the posttest scores. The results show that intrinsic load (r = -.365, p<.05)and interest of intrinsic motivation (r = -.415, p<.05) relate to difference between posttest scores and pretest scores. So a univariate ANCOVA was conducted to measure the effect of intrinsic load and interest on the difference between posttest scores and pretest scores. The covariate was interest and the difference between posttest scores and pretest scores. The result is F (1,43) = 3.20, p=.08, Partial Eta Squared = .078. That means the significant difference between experimental group and control group is related to animations, but not to interest to mathematics and intrinsic load.

5. Discussion

The purpose of this paper is to explore the effect of 3D animations which simulating the transforming process between two-dimension figures and three-dimension figures on students' performance of solving folding and unfolding problems. According to previous studies, 3D animation have been recognized as effective method to improve students' spatial ability.

In this study, a multimedia system with 3D animations is developed. Students solve folding and unfolding problems in this system, and they can get feedback immediately with 3D animation or not. These 3D animations simulate the transforming process between two-dimension figures and three-dimension figures. In order to eliminate the factors that may influence the folding and unfolding scores, the two group students' level of intrinsic motivation and cognitive load have measure by the questionnaire. The results show that the posttest score significant difference between the experimental group and control group is due to watching animation or not. This study proves that 3D animation is helpful to students in improving students' ability of spatial image about transforming between two-dimension figures and three-dimension figures.

Furthermore, there are some limitations in this study. The sample size is small, this directly leads to some results un-significant. The result may be kind of different if the sample size is large enough.

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