A Study of Effects on Cognitive Load and Learning Achievement with Different Spatial Ability Using Synchronized Multi-Display

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Abstract

In recent years, Augmented Reality (AR) has been widely applied in the educational field. Nevertheless, Sweller, Merriënboer, and Paas (1998) raised the Cognitive Load Theory, which concentrated on the development of instructional methods: the presentation mode of different teaching materials may affect learner's cognitive load; therefore, the cognitive load resulted from the change of teaching materials and methods was worthy of attention. This research is based on the teaching materials of phases of the moon and tidal, with the reference of features of teaching content and the AR, and also view each learner's spatial ability as one of the factors for consideration.

An AR model was used in the research, which can illustrate synchronously the relationship between the moon's rotation and the tidal effect. This research focuses on determining whether the presentation mode would affect learner's learning effectiveness and cognitive load, through the comparison between groups of learners using the single-image and multi-image method. In the end, the result shows that the presentation mode has no significant effect on the learner's cognitive load, but it does lay a significant effect on the learning effectiveness.

Keywords: augmented reality, Synchronized multi-display, cognitive load, phases of moon, e-learning

Introduction

Teaching materials have transformed from papers and whiteboards into various multimedia formats which are often presented on projection screens (Cheng, Lu and Yang, 2015). The development of technology makes learning more efficient and allows Augmented Reality(AR) to be applied in teaching, and moreover AR has been proved effective in increasing both the learning and teaching effectiveness. Billinghurst (2002) indicated that the ARs were proved beneficial in the educational field: For instance, students can gain knowledge through fine interacting learning and at the same time develop new learning strategies. In addition, students are immersed in the dynamic learning contents.

Although research has revealed that applications of augmented reality are considered useful in the education field, more investigations on the effects of interactive media learning to cognitive load are necessary. Miller (1956) believed that the human beings' cognitive resources in processing messages was limited. Soloway, Gudial and Hay (1994) came up with a "Learner-Centered" interface design research; They suggested that an interactive learning system should allow learners to experience better interactions as the system put no burden on learners. By probing learners' cognitive load in machinery systems, we can determine whether the new learning system would put extra burden on learners.

According to the Cognitive Load Theory, different modes of message presentation would affect the learner's cognitive load and information processing. Sweller, et al. (1994) suggested that the pattern of teaching materials would affect the cognitive load of learners; They listed seven principles that could affect the cognitive load, and pointed out the effect on learners of different modes of presentation. Kirschner(2002) listed three media effects that may affect cognitive load, which are the attention effect, the repetition effect and the form effect. How these media effects affect the cognitive load is worthy of more in-depth explorations. This research also inquires the effect of math study on learners.

Purpose of the study

Most instructional ARs developed so far can only dub a single interactive AR image onto a single object. In this research, we used a synchronized multi-display AR system; its difference lays can combine two or more conceptions in order to teach through an interrelated manner. These images coordinately and interactively show the features of interaction between virtual reality and concrete reality. The correlations among the revolution and the phase of the moon and tidal effect on earth are multiple correlated concepts, and therefore were selected as the instructional content in this research. Moreover, this research also probed the different outcome between the teaching methods using single-image and multi-image displays, and each learner's spatial ability that may affect cognitive load was also examined.

During the experiment, learners were randomly divided into three groups, and each group used traditional teaching tools, single-image AR, or multi-image AR respectively as their instructional media. Learners' learning outcomes and cognitive load were evaluated by pre- test and post-test gains, which are designed by the researchers, and cognitive load scale, modified from Cheng, et al. (2015).

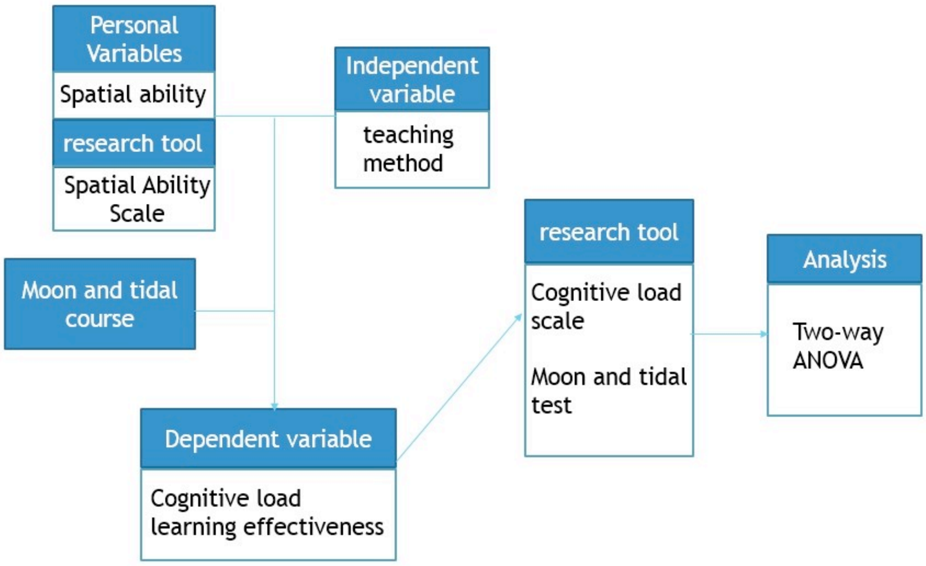

Figure 1. Research framework

Research tools

A. Spatial ability scale

The teaching content of this research are the phases of the Moon and Tidal. The waxing and waning of the moon are related with the relative location of the sun and the moon. Learners shall transform their thoughts between the metric moon changes and the three-dimensional moving model of sun and moon.

Hays (1996) believed that learners with lower spatial ability are in lack of the ability to construct effective comprehension and concept, so they tend to establish their mental models through visualization; therefore, in this research we took the spatial ability as one of factors. In addition, the "spatial ability mode pattern" proposed by Pellegrino and Kail (1982) was used as the guideline of spatial ability scale in this research; It divided the scale into two themes: rotation and vision, in the purpose of making the spatial ability scale more suitable for fifth graders.

B. Cognitive load scale

A measuring method is necessary to deter whether teaching materials would increase learners' cognitive load; however, there is no standard measuring method of cognitive load. Paas and Van Merriënboer (1994) divided cognitive load into two dimensions: the task-based dimension (mental load) and the learner-based dimension (mental effort), which can both improve learning effectiveness.

The task-based dimension is that the learners can reflect on the difficulty level of textbook content after carrying out the task, and the learner-based dimension is that learners can reflect on the cognitive ability or resource after carrying out the task. Therefore, the dimensionality of distinguishing cognitive load by Paas was referred as the reference, and he also adopted Likert's four points scale to measure the cognitive load, so that learners can self-evaluate their cognitive load in the learning process.

The scale was then subdivided into Mental load, Performance, Frustration Tolerance, Information absorption, Temporal Load, and Effort.

C. Phase of Moon and Tidal test paper

The experimental subjects of this research are fifth graders in Taiwan. Coordinated with the teaching schedule of “nature and science” fields, two test papers were given by the exports in the phase of pre-test and post-test. The number of questions and the testing concept were all the same in these two test papers.

The synchronized multi-display Augmented Reality system

The synchronized multi-display Augmented Reality system used in our experiment consists of three components: an earth/moon relation turntable, a computer with screen, and a webcam that captures a bird-eye-view of the turntable. This system is able to display a map of earth-moon relation, synchronizing with an animated version of phases of the moon and the related tidal effects.

The synchronized multi-display Augmented Reality system (Figure 2) could be stroked by the turntable showing the relationship between the moon and the earth, and this system shows the corresponding four images on the screen, including the image directly from the internet camera, the phase position of the moon, the relation schema of the earth and the moon, and the tidal effect (Figure 3). In the multi-image group, the screen is divided into four parts to show different images, and these four images could be shown at the same time, with their positions changing according to the relative time in the turntable. The single-image group, on the contrary, showed just one image once, and the displaying sequence is planned by teachers according to the course schedule. By comparing these two groups, we can discuss whether the presentation methods of teaching materials would affect the cognitive load of learners or not.

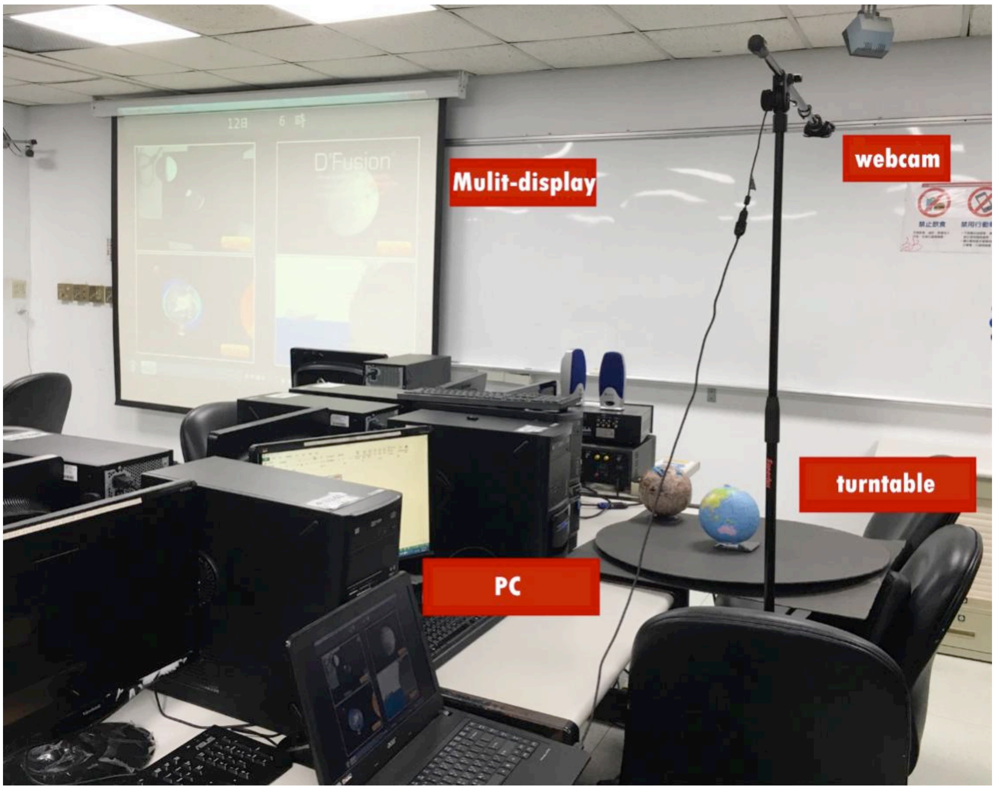

Figure 2 The synchronized multi-display Augmented Reality system

Figure 3 Synchronized multi-display of phase of the moon and tidal effect.

Implementation

The implementation process of this research differed during the experiment due to various kinds of teaching method, but the teaching content and the total teaching timespan are the same. A pilot test was done to gather user information for necessary modification: we chose 25 reliable test objects to test the reliability of the size chart, and then modified the teaching process based on the result.

The formal experiment was carried out in an elementary school in Taiwan. We chose three classes with 76 students in total as the experimental subjects, and they were divided into three groups based on their original class: one was the traditional teaching group in which we used the slides, another was the synchronized single-image AR group, and the other was the synchronized multi-display AR system group.

Students of each group were divided into sub-groups with 7-8 students each. The teaching content was the relationship between moon and tide, and was kept the same as we used the same learning sheets. The whole experiment was carried out sticking to the teaching process.

Figure 4 shows a real scene of implementation in the classroom.

Figure 4 Classroom implementation

Findings

Table 1 shows the measure results of different teaching methods in pre-test and post-test.

Among these three different teaching methods, the posttest mean for single image exhibits a higher score than that of the traditional group and multi-image group.

Table 1 Descriptive data of learning achievement

Group	Pre-test mean	Post-test mean	Post-Pretest gain	Number of subjects
Traditional	41.23	58.04	16.808	26
Single-image	37.56	68.48	30.92	25
Multi-image	39.72	56.72	17	25

Next, we used two-way ANOVA to analyze the effects of spatial ability and displaying methods on learning achievement, both exhibited significant results (F=6.380. p=.003, F=4.314, p=.017, respectively, see Table 2). However, displaying method (group) have no obvious interaction effects on spatial ability and learning achievement. but in this research, we still compared the effects of teaching methods on different level of spatial ability, which means that we examined the difference of learning performances of learners with high, medium and low level of spatial ability in different groups. What we discovered was that learning performances of students in the single image group were better than the other two groups for learners with medium or high level of spatial ability. As for learners with lower level of spatial ability, there was no obvious difference between students in the single image group and the traditional teaching group, however their performances were all better those in the multi-image group(see Table3&4).

Table 2 Two-Way ANOVA on learning achievement

Source	SS	df	MS	*F*	*p*
group(A)	3691.938	2	1845.969	6.380	.003
spatial ability(B)	2496.240	2	1248.120	4.314	.017
A*B	1150.931	4	287.733	.995	.417
error	19094.960	66	289.318		

Table 3 Simple main effects

Traditional	**Adj. Mean**	**SD**	**Case**
high level	70.14	13.031	7
medium level	51.53	21.344	15
low level	61.25	12.285	4
Single-image			
high level	76.00	14.394	6
medium level	74.00	17.288	10
low level	57.33	18.214	9
Multi-image			
high level	64.36	23.484	14
medium level	52.13	15.385	8
low level	33.33	26.502	3

Table 4 post hoc

(A)Group	**(B)Group**	**Mean Difference (A-B)**	**SD**	***p***
Multi-image	Single-image	-13.130	5.117	.012
	Traditional	-.360	5.063	.944
Single-image	Multi-image	13.130	5.117	.012
	Traditional	12.770	5.084	.014
Traditional	Multi-image	.360	5.063	.944
	Single-image	-12.770	5.084	.014

We also used Two-Way ANOVA to analyze how learners' spatial ability and teachers' teaching methods affect the cognitive load, with the covariant being the scores learners gained from the cognitive load scale. The results are shown in Table 3: The teaching methods and spatial ability have no obvious interaction effect, and both displaying method and spatial ability have no significant effect on cognitive load. Therefore in this research we believed that different teaching methods have no obvious effects on the cognitive load of students with different level of spatial ability.

Table 5 Two-Way ANOVA on cognitive load

Source	**SS**	**df**	**MS**	***F***	***p***
group(A)	137.386	2	68.693	1.692	.192
spatial ability(B)	166.433	2	83.216	2.050	.137
A*B	142.696	4	35.674	.879	.481
error	2719.825	67	40.594		

Conclusion

Based on the statistic results, we concluded that generally speaking, the learning performances of leaners in the single image group is better than those in the other two groups; as for learners with different level of spatial ability, those with medium or high level have good performances in the single-image group, but for those with low level, probably due to spatial ability restraint, only some of them are suitable with the single-image teaching method, and the rest still have better performances when under the traditional teaching mothod.

In terms of the difference of learning performances, the possible reason could be that the synchronized multi-display AR system shows multiple images simultaneously, which might confuse elementary students; for the single image group, on the contrary, students are able to concentrate on the single information with teachers filtering the images shown according to the teaching progress, so they can learn more efficiently. As for cognitive load, there is no obvious difference between three groups; It could be that elementary students are too young to correctly respond to the cognitive load inventory.

After this research, we accordingly suggested that the effects on elder learners, e.g. junior high school students, should also be investigated on further studies.

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