Learning with Augmented Reality: Effects toward Student with Different Spatial Abilities

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The purpose of this study is to investigate the learning effectiveness of Augmented Reality (AR)-based learning environment and to examine its effects on learners with different spatial abilities with regard to their learning gains. Thirty-four fifth grade students participated in this study. A quantitative approach with pre-experimental design of one group pre-test post-test type was employed in the present study. The findings of this study indicate that students’ learning performance levels benefited with the AR-based learning environment where the students showed better achievement in their post-test. Further analysis showed a significant difference in the learning gains of learners with different spatial abilities and AR-based learning environment has relatively larger influence on low-spatial-ability students.

Keywords: Augmented Reality, Spatial Ability, Science Learning

1. INTRODUCTION

Learning science may be crucial in early childhood, serving not only to afford opportunities for children to develop a better understanding of the world around them but also to build important skills and attitudes for learning. Unfortunately, when introduced to science learning in school, many children have difficulty in understanding science concepts\(^1\).\(^2\). This may cause their losing interest in the subject, which would later render their negative attitude towards learning.

This issue necessitates improvement in the learning methods and tools used in science learning. Thus there are concerns over the use of emergent technologies as a tool to facilitate students to obtain a better understanding of science.

One visualization technology that has emerged and gained attention in every field is augmented reality (AR). Annual Horizons Report 2011, AR is one of the key emerging technologies that will be used extensively in education in the future\(^3\).

Recent studies have elaborated on the educational affordances that AR experiences have garnered for science learners in the recent decade. However, the findings are mixed in terms of the effectiveness of AR-based learning. A number of studies have reported the positive outcomes with AR-based learning such as better performance in spatial structure related content\(^4\), improved language learning\(^5\), enhanced spatial abilities\(^6\), and improved practical skills\(^7\). On the other hand, author\(^8\) found no difference in understanding physics knowledge among secondary school students who used AR. Similarly,
in the study of author\textsuperscript{9}, a between-group comparison failed to attest the benefits of AR as a spatial ability learning tool in engineering domain.

Hence, AR might not work for all learners. Individual differences can cause differences in learning and has impact on the understanding of 3D computer visualization\textsuperscript{10}. Thus individual differences in AR learning environments may have effect towards learning outcome. Only a few studies have focused on the issues of individual differences such as spatial ability with the use of AR technology\textsuperscript{11}; in fact, the implementation of AR in education is also in its developing stage.

Therefore in this study, we intend to develop an AR-based learning environment in science education and examine the effect of the AR-based environment on students’ learning performance, as well as to compare the effects of the environment on learners with different spatial abilities with regard to their learning gains.

2. LITERATURE REVIEW

2.1 Augmented Reality

The term \textit{augmented reality} refers to a technology that fulfills three basic characteristics: (a) the integration of virtual objects and real world; (b) users being able to interact with virtual object in real time; and (c) being registered in three dimensions\textsuperscript{12}. Unlike virtual reality (VR), which separates users from the real world (fully immersive), augmented reality allows users to see the real world environment with the virtual objects overlaid upon it.

Presently, AR has been recognized and designed for science learning as it has the potential to improve learning outcomes\textsuperscript{11}. AR is useful when applied to activities that cannot be easily seen in real world because the concept requires a strong visual spatial ability. For instance, lab experiments\textsuperscript{13}, chemistry\textsuperscript{14}, architecture\textsuperscript{12,15} and ecology\textsuperscript{15}.

2.2 Spatial Ability

The term \textit{spatial ability} has been defined as the ability to generate, retain, retrieve, and transform well-structured visual images. Spatial ability can be categorized into five types: spatial relations, spatial perception, spatial visualization, closure speed, flexibility of closure, and perceptual speed\textsuperscript{16}.

Previous studies argue that this ability is a prerequisite for learning\textsuperscript{17} and a part of human intelligence. One of the benefits of improving spatial abilities is the improvement of academic achievement in mathematics and science. Previous studies have reported that spatial abilities can be improved through practice especially by using a computer technology. This is because spatial tasks require manipulation of two or three dimensional objects, which can be found in many computer technologies\textsuperscript{18}. Spatial ability is crucial in solving problems in science learning as it involves visuo-spatial information.

3. METHODOLOGY

3.1 Research Design

A quantitative approach with pre-experimental design of one group pre-test post-test design was employed in the present study.

3.2 Participant

The study involves 34 fifth-grade elementary school students in East Malaysia including 11 males and 23 females. These participants were selected because they were within the targeted population, that is, they have just begun to learn astronomical concepts.

3.3 AR Application

In this study, the developed AR-based learning environment is an interactive book format created to introduce and enhance concepts about astronomy by using the AR technology. Unity3D has been used to develop and create an interactive AR environment, and this application requires a laptop/desktop, a marker, and a web camera to operate. Figure 1 shows the setup of the AR application.

The application is composed of three units: (1) the movement of the earth, the moon, and the sun, (2) day and night occurrence, and (3) the phases of the moon. The subject content was based on the science syllabus of grade 5 elementary studies in Malaysia. For each unit, there is a text description, pictures, and a printed marker that represents the corresponding AR models. Some instructions were listed below the text description box to help participants interact with the AR objects.

In addition, the AR marker in this book could be removed so that the participants could manipulate a 3D virtual object from different perspectives by using their tactile sensory inputs. The participants would see themselves manipulating a marker with a virtual object on top of it (refer Fig.2). The virtual object would behave as would the physical object, such as if the participants bring the marker closer to the camera, the virtual object will get larger and smaller when the marker is moved away from the camera. The participants could also physically rotate and tilt the marker and the virtual object on the monitor screen would correspondingly behave to that manipulation.

Fig.1. The setup of AR  
Fig.2. Virtual objects
3.4 Instruments

Two instruments were employed in this study: a Mental Rotation Test (MRT) for assessing spatial ability, and a performance test for measuring astronomy content knowledge.

The Mental Rotation Test, which was employed to examine spatial ability, is one of the commonly used instruments to assess spatial ability. The test required the participants to determine a match between a target figure on the left and two out of four figures rotated in different positions on the right. In order to avoid floor effect in fifth grade students, some modification was made as suggested by author. The alternative figures were reduced from four to three. The author reported the Kuder-Richardson 20 coefficient of this test as .88, indicating that the reliability of the test was satisfactory. In the present study, the Cronbach's alpha was .86.

To assess the students’ knowledge about astronomy, a performance test was designed based on the astronomy modules covered in this study. The content for both pre-test and post-test were similar but the order of the items of the questions was different in order to avoid set response effect. The enquiries consisted of multiple-choice questions, labeling, and drawing sentence completion that were pertinent to the subject matter. Two subject matter experts were requested to determine the content validity of this test. A pilot study was also conducted with 20 randomly selected grade 5 students in an elementary school to attain the internal consistency measure. The final editions of the performance test for both pre-test and post-test have 23 items with the Cronbach’s α of .81.

3.5 Procedures

This study went through several stages. During the pre-assessment stage on week 1, the procedure began with the participants having to sit for an MRT test to determine their spatial abilities. Ten minutes were allotted for the test. After that, the students were tested on their astronomy knowledge using a performance test, which took about 30 minutes. On week 2, the participants were gathered in a computer laboratory for a brief training session to minimize their confusion when using AR. The training session consisted of a marker representing the earth and the sun and an instruction sheet to guide the students in manipulating and holding the marker.

To assist the students in interacting more with the AR, we designed a learning task in which the students were required to discuss and use the AR tool in order to answer and complete the task given.

Week 3 is the stage in which the first unit was given to the participants. The students were divided into two groups to collaboratively work on the tasks in pairs and learn in an AR environment. During the first unit, the participants would learn about the movement of the earth, the moon, and the sun by using an AR instructional treatment. AR application was used to show the virtual 3D animation of these topics by directly augmenting the models of the earth, the moon, and the sun on top of the marker.

The second unit was conducted during week 4 in which the content was based on the day and night occurrences and was presented by using the AR application. Two markers were provided to represent the virtual model of the earth and the sun. The participants were required to use these markers to view and understand the phenomena of day and night occurrence. During week 5 of the research, the third unit required the participants to learn about the phases of the moon by manipulating the AR markers to observe and understand this phenomenon. Finally, on week 6, the final stage required each participant to fill out the post-test to assess their learning performance after the treatment.

4. DATA ANALYSIS AND FINDINGS

4.1 Student Performance

To analyse the effect of the AR treatment towards the students’ performance in science, we conducted a paired samples t-test for the pre-test and post-test score variables. As Table 1 shows, the p-value (two-tailed) of the mean is close to zero (t = 24.8, p-value = 0.000).

These results suggest that the students’ performance in science after learning through the AR applications is significantly higher than their performance before the treatment. As a result, we can conclude that the AR-based learning tool has significantly improved the students’ performance scores. Figure 4 illustrates the comparison chart of the pre-test and post-test scores for each student.

4.2 Comparison of the learning gains of student with high and low spatial ability

In this study, we used median split to categorize participants into those who have high spatial ability and those with low spatial ability. Median split is a rough way to classify learners with different spatial abilities. Hence, there were 19 low-spatial-ability learners and 15 high-spatial-ability learners in this study. Table 2 shows the average learning gains of high- and low-spatial-ability learners.
Therefore, based on... learner to improve their perceptions. By bringing together a virtual
object and a real world,учитывая различия в обучении студентов с высокой и низкой способностью к пространственному мышлению, можно использовать интеллектуальные процессы для создания более эффективной работы короткого памяти. К тому же, AR позволяет студентам управлять своим рассмотрением виртуальных объектов, используя свои руки. Это позволяет студентам лучше понимать абстрактные научные концепции, такие как астрономия.

5. DISCUSSIONS

After conducting a statistical analysis on the pre-test and post-test scores, it was found that the participants who learned through AR have achieved significantly better post-test scores than their pre-test. These findings imply that the AR application has helped to improve the students’ academic performances.

A possible explanation for this might be that the AR has provided them with a real world annotation that could improve their perceptions. By bringing together a virtual object and a real world, cognitive load could be reduced then the bigger fraction of short term working memory can be used to operate the cognitive processes, leading them to a better understanding of the concept of astronomy.

Moreover, this finding also may be explained by the fact that AR involves physical action that can help the students learn spatial content. Author 24 reported that the amount of physical interaction contributed to the increasing differences in pre-test and post-test scores. As in this present study, the AR application allowed the students to pick up an object and easily inspect the virtual objects from many different angles; and they could enhance their understanding by simply moving the markers by using their bare hands. This kind of student control can lead to the improvement and recalling of the learning spatial content, such as astronomy.

The AR-based application in this study enabled the learning content to be viewed from 3D perspectives. Content like astronomy requires a high imaginative ability, and through the use of 3D imagery to represent the learning content, AR could enhance the students’ understanding by making the contents matter available to support learners in visualizing abstract science concepts that cannot be easily seen in a natural environment.

As for the second objective, the statistical analysis indicated that the AR application has resulted in more significant learning gains for student with low spatial ability than for those with high spatial ability students. These results are consistent with the study of author, 25 who found that low-spatialability learners achieved better performance in their study. This research indicates that AR has enabled the students control over the instructional material, which was very useful for the low-spatialability students. These students had their own control over the use of the markers to view the virtual objects and their control preferences can be vary. They could see what they wanted to see, when they wanted to see and how they wanted to see it. This ease of access is highly beneficial as is offers low-spatial-ability students independent control and personalized views over the learning content. In turn, these students would have full control over their investigation of the content, which may

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<td>Mean                      Std Deviation</td>
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| Table.2. Average Score for Students of High and Low Spatial Ability |
|-------------------------|--|--|--|---|---|---|
| Group                   | Pre-test average | Post-test average | Gain average |
| High spatial ability    | 41.96       | 79.97       | 38.01        |
| Low spatial ability     | 30.15       | 75.92       | 45.77        |

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reduce extraneous cognitive load, increase the germane cognitive load, and eventually may result in better performance.

Moreover, some of the pre-test scores of high-spatial-ability students were high so the space for improvement is quite limited. Compared to those with low spatial ability whose original scores were low, therefore the space for post-test increasing are high.

6. CONCLUSIONS

The quantitative results of this research study showed that the use of AR technology on learning environments is beneficial in terms of improving student’s performance in science. The students with low spatial ability gained benefits more when AR-based learning environment was used compared to high spatial ability students. The study has gone some way towards enhancing our understanding of learner characteristics which could be used to facilitate individualized learning. However, research about AR-based learning environment require further exploration because the researcher did not arrange control group and we must admit that the result in scores increases might not be solely rely on the AR application. Therefore, it would be interesting to assess the effect of AR by analyzing the difference of learning achievement between the control group and experimental group. Taken together, the finding that we have identified therefore assists in our understanding of the capability of AR technology in education and its effects toward spatial ability.

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