Learning Geometry with Augmented Reality to Enhance Spatial Ability

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Abstract— **Spatial ability is considered essential in learning many disciplines. Studies have shown that providing students with geometry learning activities would help them develop spatial ability. Augmented Reality (AR) provides a combination of real and virtual worlds and allows students to view the spatial relationship of real world objects that is impossible to be implemented in traditional textbooks. This study have two purposes: (1) to develop an augmented reality system to assist students solve the Rubik's cube and learn the geometry concepts of volume and surface area; and (2) to examine the effects of using the system in terms of students' improvement on spatial ability, geometry achievement, and attitudes toward learning. The system is still under development and the evaluation is yet to be done.**

Keywords— spatial ability; augmented reality; geometry; Rubik's cube

I. INTRODUCTION

Spatial ability is the ability of manipulating visual patterns. It is considered as an important component of human intelligence. It offers ways to interpret and reflect on our physical world and has an robust influence on STEM (Science, Technology, Engineering, and Mathematics) domains [1]. Although spatial ability is one of the essential human abilities, it is never an easy task to develop. Many studies indicated that childhood spatial activities were a significant predictor of adult performance on math grades [2]. Studies also showed that there is a significant effect on learning geometry on students' performance in spatial ability tasks [3]. It is obvious that providing young students with geometry learning activities would help them develop spatial ability. However, learning geometry usually requires students to generate and manipulate three-dimensional (3-D) mental images from two-dimensional (2-D) objects, and it may cause cognitive overload and learning difficulties for some students. Thus, an important research direction of the field is to develop effective tools and strategies to help students generate and manipulate 3-D mental images when in learning geometry concepts, and in turn to develop their spatial ability.

Technology has been played an important role in teaching and learning geometry in last decade. Augmented reality, with the ability to overlay computer graphics onto the real world objects, could serve as an effective tool to learn the spatial concepts of geometry [4]. This study focuses on developing an augmented reality learning system to assist students in developing spatial abilities through learning geometry concepts and playing Rubik's cube.

II. USING TECHNOLOGY TO DEVELOP SPATIAL ABILITY

Several studies suggested that it was possible to improve students' spatial abilities through proper and specific training. Various training methods have been employed in training to improve spatial ability that focused on using emerging technology.

Several studies introduced simulation software to assist student learning geometry and had positive effects on both students' performance and their attitudes toward learning [5], [6]. Other research also found that spatial visualization and mental rotation accuracy could be trained by animations, because through the externalization of the internal mental operations in the visual and dynamic form can effectively lessen the cognitive load [7]. Apart from the virtual reality (VR) methods used in the above studies, augmented reality is considered as a better solution to afford spatial ability training, especially for those focus on the presentation of 3-D space [8]. Unlike simulation software allows students to virtually see the geometric figures or objects in the computer screen, augmented reality enables users to see the real object at the same time as virtual imagery attached to real locations and objects. It allows students to view the spatial relationship of real world objects that is impossible to be implemented in traditional textbooks. It also provides students a more intuitive way to manipulate virtual objects.

III. THE AUGMENTED REALITY SYSTEM

We intend to develop an AR system to help students learn geometry concepts, and, as a result, enhance their spatial ability. The augmented reality system consists of three main functions: Cubic Nets, Three-Dimensional View, and Spatial Cube. The prototypes of the first two functions were designed and reported in [9]. This study will focus on the third function. The three functions of the system are described below.

A. Cubic Nets

The function enable students to visualize all eleven possible cubic nets of how the net can be folded into a cube. By using a

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tablet to scan the six markers (representing a cubic net) placed on a cardboard, the system will then activate the animation which shows the process of folding a net into a cube if the markers are oriented correctly. This function enables students to visualize the process of folding a virtual net into a cube. And the augmented letters on the surface could help students to recognize the relationship among the different surfaces when being folded into a cube.

B. Three-Dimensional View

This function allows students to use a tablet to scan an object (assembled with piled cubes) from specified viewing degrees and to subsequently display a three-dimensional view of the object on a screen. Up to twenty-seven cubes can be placed on a cardboard with 3 X 3 X 3 matrix positions. By using a tablet, students can visualize the three-dimensional views of the composed object from different viewing angles.

C. Spatial Cube

This function is still under development. We expect that the AR function enables students to visualize the process clues while solving a Rubik's cube. A series of process steps will be provided to students when using this function. Additionally, the function also aims to help students learn the concepts of volume and surface area. With the AR function, students can use a tablet to scan an object (assembled with piled cubes) to visualize the hidden part of the object, or to see the added colored surface areas resulting from removing a cube from the object (Fig. 1). The system will attach the important hidden information on the real object which are critical hints to help students solve geometry problems (Fig. 2) and the Rubik's cube. Through the augmented hints might support students to build the correct mental images and lessen the cognitive load during their training.

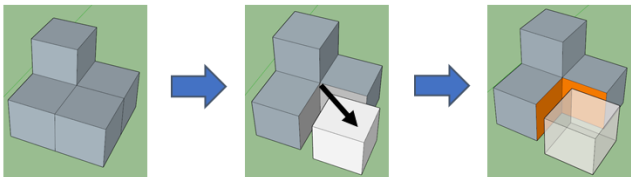

Fig. 1, AR to color on the originally non-existed surface areas

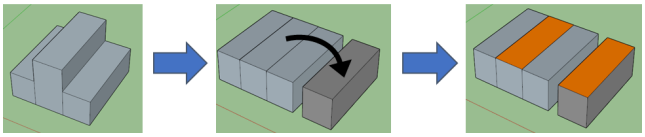

Fig. 2, AR to magnify the changed volume and surface areas with overlaid colors

IV. Research Method

Our system uses Unity3D with Vuforia AR extension as the development platform to construct the 3D objects and uses Java script to design the interactive behaviors of the augmented objects.

To evaluate the effectiveness of the augmented reality system, a quasi-experimental pretest/posttest research design will be applied to examine students' performance on geometry and spatial ability. The semi-structured interview and an attitude questionnaire will also be employed to investigate students' perceptions of using the AR system and attitudes toward learning. The target participants in this research are four classes of seventh grade students chosen from a middle school. Two classes of students will serve as the experimental group using AR tools, while as the others will serve as the control group using traditional learning methods.

The expected research results are students in the experimental group will have better spatial ability attainment and geometry achievements and more positive attitudes toward learning than the control group.

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