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Developing spatial visualization and mental rotation with a digital puzzle game at primary school level

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ABSTRACT

Spatial ability has been recognized as a significant human skill involving the retrieval, retention, and transformation of visual information in a special context. The enhancement of the spatial ability and the effective method of training are rarely considered as an area of study in the education field. This study focuses on the enhancement of spatial visualization and mental rotation, which are two major components of spatial ability, through the practice of puzzle games. This study adopts an experimental approach to test whether the game is effective in facilitating student's development of spatial visualization and mental rotation. 79 primary school students in Taiwan are included to be volunteer participants. Two instruments are adopted to measure the participants' performance of spatial visualization and mental rotation. The research findings show that the designed puzzle games effectively improve the participants' abilities in spatial visualization and mental rotation and that the traditional puzzle games can only enhance participants' mental rotation. This study suggests that the theory-based design of multimedia games can offer a more effective learning environment for developing and improving cognitive skills.

1. Introduction

Spatial ability has been recognized as a significant human skill involving the retrieval, retention, and transformation of visual information in a special context (Rafi & Samsudin, 2009). Many studies have shown that spatial ability and the ability of certain disciplines, such as mathematics, graphics, engineering drawing, science education, and physical education, are closely related in a positive way. In some occupations, such as engineers, architects, pilots, and technical educators, it is the related capabilities of visuospatial specialties that are highly needed (Rafi, Anuar, Samad, Hayati, & Mahadzir, 2005). Some studies have further pointed out that the effectiveness in learning engineering drawings and other courses is to be decided by the role of spatial ability (Rafi & Khairulanuar, 2007). Samsudin, Rafi, and Hanif (2011) also pointed out that students in certain disciplines, who needed to represent a three-dimensional object onto a two-dimensional plane surface or create three-dimensional perspectives by working from the two-dimensional representation of the object, are required to have a high level of spatial ability. The enhancement of the spatial ability and the effective method of training has been a significant concern of educators.

While the importance of spatial ability is beyond doubt, the approach to enhance such an ability is very ambiguous. Due to the nature of spatial capability that requires space and time enough to implement its training, general classroom curriculum finds it difficult to enhance this capability. Therefore, a great deal of research in computer games or virtual environment enhancing this ability has uncovered certain valuable results. As an example, the research of Samsudin et al. (2011) developed a spatial trainer that is based on a virtual environment and this in fact, does improve space capability. Furthermore, there was additional research in computer games that train and enhance the spatial capacity, such as David's (2012) research in Block-out 3D-Blocks and Cram jam and other games that improve spatial abilities of high school students, Kadam, Sahasrabudhe, & Iyer's (2012) research in Blender 3-D animation software that enhances the students' ability of spatial rotation, and Yang & Chen's (2010) research involved using a digital pentominoes game to train the elementary school students and promote their spatial capability. However, all these studies adopted

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the current games or animation software and neglected the approach of aiming at a particular space capability and specifically designing a game that enhances the training. Therefore, these digital games may not be sufficient or specific enough to meet the needs of learners in various domains and types of content. Therefore, when the corresponding spatial theory and the practical space-based operation mechanism can be applied to designing a computer game of space, the learners will acquire the necessary spatial skills and thus, have a much effective learning environment. By targeting spatial ability for a particular mental rotation and for spatial visualization, this study has designed digital games that can effectively enhance their learning ability and can be a useful tool in assessing their learning achievement.

1.1. Gamed based learning approach

Many educators have advocated for years that if students are allowed to play the games and thus learn, this method will result in a definite and effective improvement in the quality of education (Clements & Mcmillen, 1996; Lin & Liu, 2009; Papastergiou, 2009). Computer games with various sorts of digital elements, i.e., sound, light, images, and animation, provide an immersion environment to inspire the students through their engagement in a competitive scenario. According to the argument in Lin & Liu's research (2009), when the teaching content can be conveyed in the form of game, this attracts more of the learners' attention and helps to increase their learning motivation.

The game-based learning builds itself mainly on the concept of participation, for a competitive gaming environment requires the learners to be actively involved and thus increases their desire to learn more. Furthermore, games are capable of simulating the world as it is perceived by children, which increases their willingness to be engaged in participating. As Hung, Hwang, Lee, and Su (2012) have argued, the computer games provide virtual and beneficial visuality as the concrete models do, and this makes it possible for the games to provide promising opportunities for a new type of cognitive learning experience. Therefore, the design of this study draws on the advantages of game, and based on the concept of games, it is expected to design a tool that is capable of enhancing the learners' cognitive ability.

The jigsaw puzzle is a favorite game for children, which can stimulate the growth of their ability in mathematics, geometry, and spatial sense. Orman's (1998) research indicated that jigsaw puzzle served as an appropriate way to enhance the ability in mathematics. Smith, Olkun, and Middleton's (2003) study also pointed out that the computer jigsaw puzzle could enhance the students' ability in learning geometry. In a puzzle game, the player has to move and rotate geometric shapes mentally and to visualize their proper location, so the game is suitable for the application of stimulating and exercising the spatial ability. For example, Yang & Chen's (2010) studies on developing a digital pentominoes game (a kind of puzzle game) to improve the spatial ability in primary school students shows that such a game can effectively enhance their spatial ability. According to Hung et al.'s (2012) study, it is also pointed out that online Tangram puzzle games could be an appropriate spatial learning tool for improving the spatial visualization. Therefore, this study adopts the game concept, and with the skeleton puzzle game as the frame, the researchers designed the computer game that is capable of enhancing the spatial ability.

1.2. Theoretic base of game design

Can all computer games have a positive learning effect? The answer is probably no. Computer games without any specific learning objectives attached are merely entertaining games. As argued by O'Neil, Wainess, and Baker (2005), games are not effective in learning unless they involve the instructional support. In other words, to have a game achieve the purpose of learning and teaching, the game should be designed in the appropriate ways that meet specific learning objectives. In the marketplace, it is easy for people to find a myriad of multimedia games that self-claim to be effective in enhancing the students' cognitive abilities; however, in terms of the overall planning and design, there are relatively few multimedia games whose designs are cognitive-theory-based. Besides, the design and planning rarely meet the specific target-oriented capabilities, or the domain-specific ones, and accordingly, the game design lacks a clear goal in the mainstream development, which indicates a lack of the development centered on the cognitive abilities. Therefore, the game design has to consider the objective and the theory, and the design with these concepts behind it, could be truly effective in enhancing the cognitive abilities.

The so-called theoretic-based games refer to the specific-targeted computer games that are designed on the basis of the review of current cognitive theories, related cognitive learning methods, and the related psychometric testing of the ability. This type of game design, with the specific-targeted cognitive and processing characteristics, adopts the game concept as the infrastructure to develop its teaching strategies and thereby allows the students to develop in the cognitive areas by learning or practicing directly. Many other studies have also pointed out that the theory-based design of computer games can be more effective in enhancing the students' cognitive abilities; for example, Sung, Chang, & Lee's (2008) study showed that the games with a theory-based design are, comparatively, more effective than any other games with non-theory-based design in terms of their power to enhance children's logic and classification capabilities. Bottino, Ferlino, Ott, and Tavella (2007)successfully used the digital mind games (e.g. puzzler) to foster strategic and reasoning abilities among the primary school students. By his research, they firmly believe that the well-structured and theory-based design of digital games brings better learning results.

In this study, the spatial ability in mental rotation and spatial visualization are our focus to help enhance cognitive abilities. Therefore, this game design is primarily based on the definition of the analysis of mental rotation and spatial visualization, the operating mechanism, and current theories and the related psychometric testing of the ability, as the coming discussion in the next section.

1.3. Spatial visualization and mental rotation

In the relevant research, spatial ability is defined as the composition of different aspects. Linn and Petersen's (1985) classification is the most accepted one, for they divided spatial ability into three sub-dimensions: mental rotation, spatial visualization, and spatial perception. This study specifically aims at two aspects of spatial ability, mental rotation and spatial visualization.

In many factorial study reports, spatial visualization is identified as a very important factor in spatial ability. Guilford and Zimmerman (1948) identified spatial visualization as a process of imagining movements, transformations, or other changes in visual objects. French (1951) described spatial visualization as the aptitude to comprehend imaginary movement in three-dimensional space. Linn and Petersen (1985) clarified that spatial visualization is the ability to manipulate complex spatial information involving configurations of shapes. In brief, such a capability is the ability to imagine spatial movements of objects and shapes (Hegarty & Waller, 2004), including the objects that are manipulated visually or in the mind, whether they are folded, synthesized, or in rotation