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

Chien-Heng Lin [a, *], Chien-Min Chen [b]

[a] Department of Early Childhood Education, National Dong Hwa University, Taiwan
[b] Department of Foreign Languages and Literature, Asia University, Taiwan

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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

* Corresponding author.
E-mail addresses: chienlin@mail.ndhu.edu.tw (C.-H. Lin), cmchen@asia.edu.tw (C.-M. Chen).

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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 or transposition.

By examining the various test tools, the users may also gain further understanding of the implications of this ability; for example, French, Ekstrom, and Price (1963) applied the Paper Folding Test to the examinee who had to imagine the folding and unfolding of a piece of paper which, as folded, was to be perforated one or more times. In the Purdue Spatial Visualization Test–the visualization of rotations, which is a highly constructed validity test, the examinee has to rotate in two or three dimensions so as to match another spatial form. The paper-formed board is adopted to examine how the examinee can identify the shapes in the combination of different pieces of shapes. These tests aim for examining spatial visualization ability, and the common feature of these tests is to check how the examinees, by way of their inner visual inspection, do combine, decomposition, or rotate and convert shapes.

Mental rotation is the ability to rotate two or three-dimensional objects rapidly and accurately in the mind (Linn & Petersen, 1985). In other words, by way of rotating objects mentally and thereby solving problems related to space, this test includes the limit of reaction time and the rotation angle, both of which are mutually related to the degree of difficulty. In numerous studies of the inspection of the mental rotation, the focus is on the test of the examinee's mental ability to rotate 2D or 3D objects to manipulate the exact position and angle of the inspected object in the limited period of time (Peters et al., 1995; Vandenberg & Kuse, 1978). Quaiser-Pohl (2003) adopted different features of stimuli for young children to do the rotation test. The larger the change in the rotation angle of the object, or the shorter the time limit, the higher degree of difficulty the test indicates.

According to the findings of Piaget's research, young children develop mental rotation ability after the age of seven because the children under the age of seven can only remember the initial and the final states of an object in motion and are unable to recognize or reproduce the intermediate states (Estes, 1998; Kerr, Corbitt, & Jurkovic, 1980). In other word, for children under the age of seven, their development of mental rotation is not yet full-grown; therefore, the subjects of the related research topics are limited to children who are less than seven years old. Although recent studies have pointed out that the children under the age of seven have already been capable of the mental rotation (Estes, 1998), the researchers prefer, in this study, only to recruit children who are more than seven years old to be the study participants.

This study provides the game design that specifically aims at the operating mechanism and the display mode of the two major spatial capabilities so that game design can lead the player to apply the above-mentioned two capabilities to manipulating the game.

1.4. Research purpose

Numerous researchers have agreed that spatial ability is the core capability of various subjects, such as mathematics, science education, graphics, and physical education. The importance of spatial ability is highly emphasized in certain professional fields which require the visual spatial ability, such as engineers, architects, pilots, technology educators, and others (Rafi et al., 2005). Spatial visualization and mental rotation are two valuable sub-items of spatial ability. However, the digital games purposefully designed to enhance spatial ability are very rare, and the digital games that are particularly focused on each sub-item of spatial ability, such as spatial visualization and mental rotation, are even more scarce. This study sets as its primary goal how to illustrate and design a domain-specific (i.e., spatial visualization and mental rotation) and theory-based digital game and explore its effects on spatial ability learning. Therefore, this study contains two specific research purposes: (1) firstly, to explore whether spatial ability can be combined with the correlated spatial theory and together serves as the design foundation of a digital jigsaw puzzle that corresponds to the related ability, and (2) secondly, to evaluate the effects of the theory-based puzzle game on improving the students' abilities of spatial visualization and mental rotation.

2. Design of the digital puzzle game

2.1. Design rationale

The content of the game to be designed should focus on the two main aspects of spatial visualization and mental rotation. In other words, this game is to be so designed that it allows the students to learn and practice the above-mentioned two capabilities, and in order to present its advantages and special features in the design, the designer has to integrate the characteristics of the game into the plan, with a view to have this game software bring forth the learning effects which are based on the structure and concept of a game. This allows the students to be completely involved in the mentality of game play, and the game's plot is so designed that they can naturally join in the context. When the students pass each level, their training and drill of spatial visualization and mental rotation are thus completed.

2.2. The strategy of the game design

This game is mainly based on the idea of a puzzle game as its strategy is so that the game can enhance the students' spatial abilities, and by the plot of the game's various strategic passes, it stimulates the students' challenge of this game and thus lifts their motivation to learn. This study has designed two kinds of jigsaw puzzle: one is the traditional flat puzzles, and the other the new design is of a three-dimensional jigsaw puzzle package.

The former puzzle game mainly takes the form of a traditional puzzle design, as shown in Fig. 1. Use a graphical reference picture and place it at the top right. Then use this little picture as a basic pattern, cut it into several small pieces of puzzle blocks, and randomly disperse them in the designed scene. Then the player rotates each puzzle block by 90, 180, 270, 360°, that is, by different angles, and s/he has to move each piece to the correct position. When the puzzle game is correctly completed, this hurdle is successfully passed. In addition, there is the timing device. Beside the rectangular pieces of the puzzle, the player may also come into contact with some triangular and fan-shaped puzzle pieces, and the difficulty increases depending on the number of its puzzle blocks.

The latter puzzle game is the jigsaw puzzle package. This is based on the relevant theories of mental rotation and spatial visualization with the purpose of enhancing these two abilities. As shown in Fig. 2, in the upper right corner of the scene, there is a three-dimensional block diagram for reference. Each side of this diagram has a picture. The four-direction buttons beneath allow the player to rotate this three-dimensional block and to clearly see the pictures wrapping up the block. People can imagine that when they put this block in the puzzle grid, within a limited period of time, they have to set the puzzle pieces to the appropriate grid. If the places for the puzzle pieces are correct, the entire grid can be wrapped up, and this means that the player has passed the hurdle. Then s/he can go to the next checkpoint. The whole structure of the game is designed from the simple to the complex. It allows the learners to be progressively inspired and thereby develop their spatial abilities and the learners do not feel frustrated easily and thus give up such game exercises.

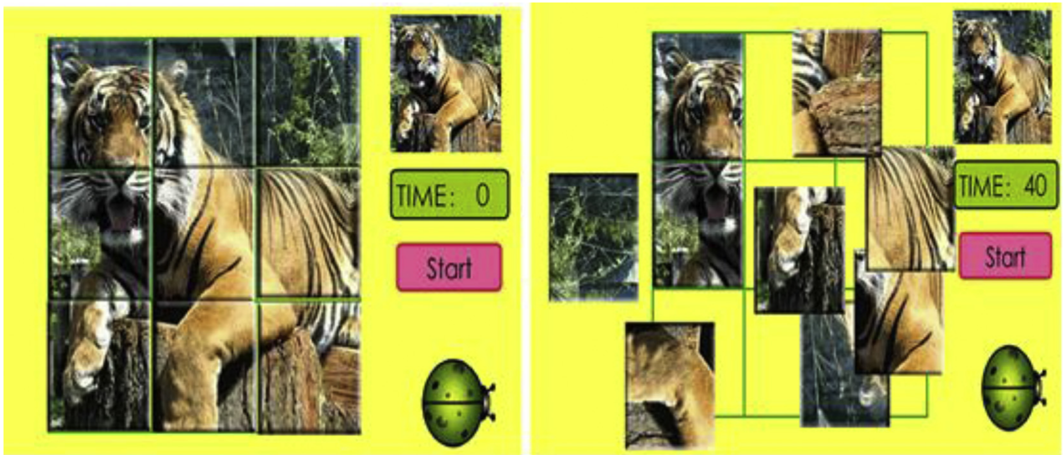

Fig. 1. A screenshot of the traditional jigsaw puzzle game.

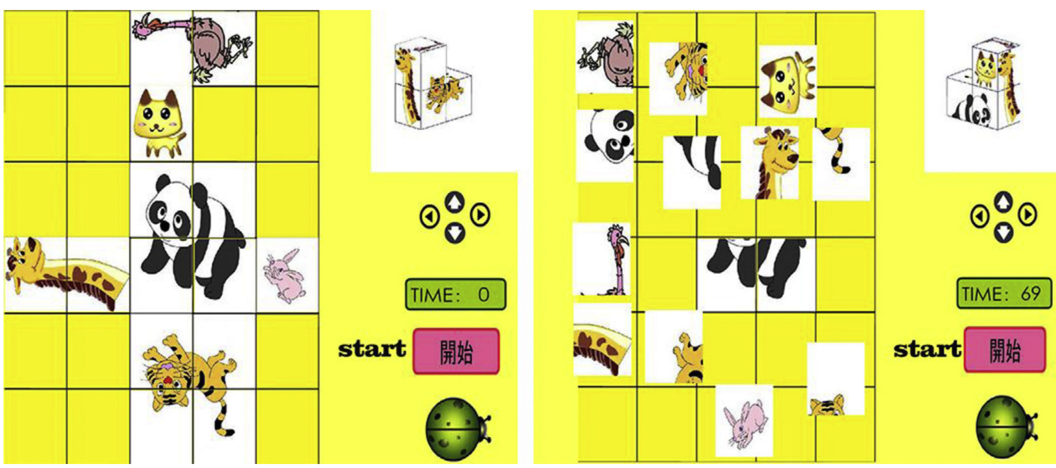

Fig. 2. A screenshot of the designed package jigsaw puzzle game.

2.3. Learning the ability of mental rotation

As previously discussed, mental rotation is the ability to rotate 2D or 3D objects and manipulate the inspected objects to be moved to the exact position and the right angle. Therefore, both jigsaw puzzle designs contain the function that rotates a different angle of a puzzle piece into the correct one and places it in the correct place. By clicking with a mouse, each puzzle piece is rotated to the exact angle and moved to the right place. Through the practice of these rotating activities, we preview children can enhance the ability of mental rotation.

2.4. Learning the ability of spatial visualization

Particularly for enhancing the spatial visualization ability, the researchers design a "package jigsaw puzzle game" which is different from the game of traditional puzzle design. The main idea behind the game design is basically to stimulate the traditional puzzle position-locating and the rotation angle-finding, and most important of all, the players have to visualize in their mind how to arrange the puzzle piece and how to fold it before they could actually have the cube wrapped up. In the process of the game, the learners practice to manipulate in their mind the complex spatial information that involves configuration of shapes, and such ability is scholarly defined as spatial visualization.

3. Method

To reach the aim of our research purposes, an empirical study is conducted essentially with a quantitative approach. This study employs an experimental design with the process of pre-test, intervention, and post-test.

3.1. Participants

This study involves a total of 79 student volunteer participants, who are the third-grade students of a public elementary school in Taichung, Taiwan, at the age of nine or ten. Because males and females have differences in spatial ability, the number of boys and girls are controlled in a state of balance, i.e., balanced sample. This is to avoid the experimental interference; therefore, 40 boys and 39 girls are accepted. Participants are randomized to the experimental group and the control group. During the period of experiment, four persons have failed to fully participate, so the actual number of participants is 75. There are two treatment groups with a total 50 persons and the control consisted of 25 persons. The first treatment group are trained with traditional jigsaw puzzle game, and the second treatment group with the designed package jigsaw puzzle game.

3.2. Instructional materials

The teaching tool used in this experiment is the jigsaw puzzle designed by the author with CS6 Adobe Flash 2D animation software and Actionscript 2.0 programming language. As to the jigsaw puzzle designs, there are two kinds: the traditional jigsaw puzzle and the newly designed package one. Each game is divided into five levels, beginning with the easier puzzle to the more difficult and intricate ones. Each level has two options with the same difficulty in each game, and the player has to pass the elementary level before they can enter the higher level. The design of this jigsaw puzzle is mainly made for the training of the two capabilities, spatial visualization and mental rotation utilizing the relevant theories and the assessment methods.

3.3. Instrument

For spatial visualization tests, the researchers use Zuo and Liang's (2001) test design to approach spatial visualization (with internal reliability coefficient 0.77), as shown in Fig. 3. This test has 15 questions, and it takes 10 min to complete. All answers being correct, the participant gets 15 points, with 1 point for each correct answer. For each question, there is a cubic grid, and on the cubic grid, there are one or several tokens of numbers. Participants have to using mental acuity skills and open the checkered grid and select from the four possible options the correct picture spread at the corresponding position. Particularly for the mental rotation, the researchers used Chay's (2000) online Mental Rotation Test, as shown in Fig. 4. The reliability coefficient of Chay's Online Mental Rotation Test ranges from 0.72 to 0.88 (Samsudin et al., 2011). This test is comprised of 30 items, with each item showing both a target object and a comparison object. Participants are required to determine whether the two objects are congruent or incongruent. There is 1 point for one correct answer, and 30 points in total for all correct ones. In addition to the requirement of correctness, the speed is also considered a very important factor; therefore, the time consumed to complete the test is recorded as well.

3.4. Procedure

This research adopts a twin pre-test and post-test design to measure the game's effect on the students. In addition to the game's effect on the experimental team, its effect on the control team was measured. This was designed to reduce any possible inaccuracy that might have been caused by the pre-test and post-test. The research design is comprised of two independent variables, namely training game and group. The dependent variables in the study are the spatial visualization and mental rotation mean scores that provide both the pre-test and post-test measures.

In each performance, four or five participants formed a team. Each participant operated a computer independently and maintained a certain distance from the other subjects so as to avoid any possible disturbance. A description of the entire process is as follows.

All participants were pre-tested with the Spatial Visualization Test and the Mental Rotation Test. After a 5-min break, the game began. Once they entered the game, all participants started from the first pass and moved on to solve each pass until all were solved (about 45–55 min).

When certain participants cannot complete the pass of a checkpoint in a timely manner, the researchers will provide more time for them to operate till the completion, or press the start button for them to restart the game. As to the other participants who have already finished, they will be led by other researchers to join the next program. Although the game has a timing function, this timekeeping is meant only to enhance the game itself as being competitive and interesting, but never to add to their checkpoints passing difficulties. All checkpoints are based on how to correctly complete the puzzle. Should there be any participant who, after a long attempt, is still unable to complete the game, this case will be withdrawn.

The participants were required to wear headsets and not allowed to have conversations with others during their participation. After the experiment was completed, they had a 10-min break, and then the post-test with the same instruments was conducted.

3.5. Data analyses

All the data collected from the pre-test and the post-test of the Spatial Visualization Test and the Mental Rotation Test are coded for quantitative analyses. All the analyses are conducted with the analytic software SPSS. The pre-test and post-test scores of the two exams are analyzed with descriptive statistics, including mean and standard deviation.

In order to check whether the differences between the pre-test and the post-test scores are significant and to exclude certain moderating variables, this research adopts the method of analysis of covariance (ANCOVA).

4. Findings

4.1. Mental rotation

The test of mental rotation is recorded in two parts: the mental rotation accuracy (MRA) and the mental rotation speed (MRS). Prior to the treatment training, the researchers examine the participants' levels of MRA and MRS. The scores of MRA and MRS are measured by the number of correct responses and the time taken to complete the test in seconds respectively. In order to check whether the differences between the pre-test and the post-test scores are significant and to exclude certain moderating variables, the researchers conduct a 3 (treatment groups) by 2 (the pre-test and post-test) two-way mixed design analysis of covariance (ANCOVA) on the scores.

The mean scores of the MRA for three groups are summarized in Table 1. Before initiating the application of ANCOVA, the researchers need to be supported by testing the assumption for homogeneity of regression, which is non-significant (data of $a^{*}x$):

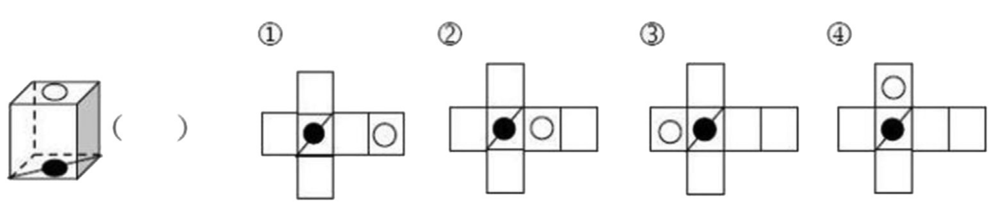

Fig. 3. Screenshot of the spatial visualization test.

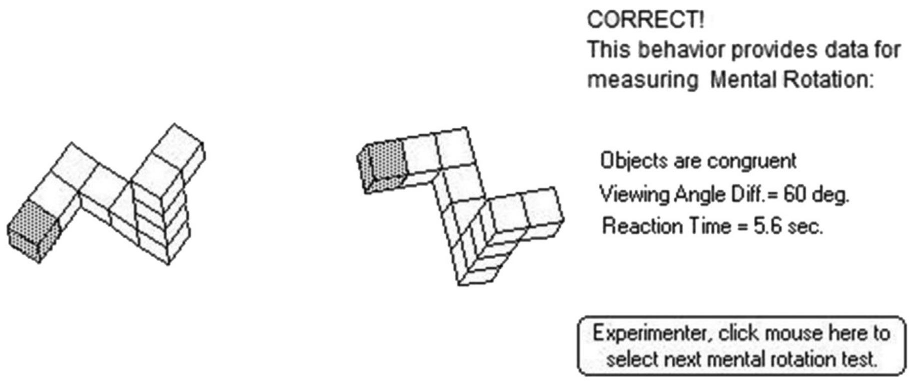

Fig. 4. Screenshot of the online Mental Rotation Test.

Table 1
Scores of pre- and post-tests in the Mental Rotation Test (MRA and MRS).

	Group	N	MRA		MRS	
			Mean (SD)	Adjusted mean	Mean (SD)	Adjusted mean
Pre-test	Control		23.08 (1.80)		170.77 (33.45)	
	Treatment-1	25	22.16(1.86)		173.24 (26.33)	
	Treatment-2	25	21.88 (2.00)		183.12 (28.46)	
Post-test	Control	25	23.40 (1.68)	23.02 (a)	164.28 (34.03)	168.94 (a)
	Treatment-1	25	25.76 (1.45)	25.87 (a)	162. 48(23.30)	164.81 (a)
	Treatment-2	25	24.70 (1.86)	25.22 (a)	172.20 (27.24)	165.19 (a)

$F(2,69) = 2.014$; $p = 0.141 > 0.05$. This shows that the slope of the regression line in the three groups remains the same. Therefore, the analysis of covariance can be further conducted. The result of the ANCOVA is significant ($F(2,71) = 34.096$, Eta Squared $\eta^2 = 0.466$, $p = 0.00 < 0.05$), and it indicates certain significant differences existing between the treatment groups and the control group in their post-test scores under MRA.

This suggests that training in different puzzle games can produce a differential MRA performance. The adjusted post-test average scores of MRA are shown in Table 1. The mean difference of the MRA scores between the treatment-1 group and the control group is 2.853 at the significance level of 0.00. Similarly, the mean difference between the treatment-2 group and the control group is 2.20 at the significance level of 0.00. However, no significant difference is shown between the two treatment groups (Mean difference = 0.65, $P = 0.069 > 0.05$). The results indicate that both puzzle games can improve the participants' mental rotation of accuracy.

The mean scores of the MRS for three groups are shown in Table 1. The test of the assumption for homogeneity of regression shows non-significant data (of a^*x): $F(2,69) = 2.588$; $p = 0.082 > 0.05$. The analysis of covariance on MRS can be further conducted. The result of the analysis of ANCOVA is significant ($F(2,71) = 3.776$, Eta Squared $\eta^2 = 0.096$, $p = 0.028 < 0.05$). Although the effect size is limited, the research still shows significant differences among the three groups in the post-test scores under MRS. The adjusted post-test average scores of MRS are shown in Table 1. The mean difference of MRS scores between the treatment-1 group and the control group is 4.12 at the significance level of 0.015. The mean difference between the treatment-2 group and the control group is 3.74 at the significance level of 0.028, but no significant difference is shown between the treatment-1 group and the treatment-2 group (Mean difference = 0.382, $P = 0.819 > 0.05$). This indicates that both the traditional puzzle games and the package puzzle games can improve the participants' mental rotation in speed.

4.2. Spatial visualization

The participants' scores in spatial visualization are shown in Table 2. Before the application of ANCOVA, a test of the assumption for homogeneity of regression was conducted, which is non-significant (data of a^*x): $F(2,69) = 0.603$; $p = 0.550 > 0.05$. This indicates that the assumption for homogeneity can be fulfilled, and the analysis of covariance on MRS can be conducted further. The result of the analysis of ANCOVA shows that the difference among the groups is significant ($F(2,71) = 36.76$, Eta Squared $\eta^2 = 0.668$, $p = 0.00 < 0.05$), as is revealed in the three groups in their post-test scores under SV. The adjusted post-test average scores of SV are shown in Table 2. The mean difference of SV scores between the treatment-1 group and the control group is 0.161 at the significance level of 0.523, which shows no difference between them. The mean difference between the treatment-2 group and the control group is 1.96 at the significance level of 0.00, which demonstrates a significant difference between two groups. The results indicate that the traditional puzzle games cannot improve the participants' spatial visualization, but the package puzzle games have positive effects on the participants' performance of spatial visualization.

Table 2
Scores of pre- and post-tests in the Spatial Visualization Test (SVT).

	Group	N	SVT	
			Mean (SD)	Adjusted mean
Pre-test	Control	25	8.96(2.11)	
	Treatment-1	25	8.80(2.10)	
	Treatment-2	25	9.44(1.5)	
Post-test	Control	25	9.84 (1.70)	9.921 (a)
	Treatment-1	25	9.88(1.88)	10.08 (a)
	Treatment-2	25	12.16 (1.52)	11.88 (a)

5. Discussion

Previous studies have effectively increased spatial ability by the use of digital games (Pannese & Carlesi, 2007; Sung et al., 2008; Wilms, Petersen, & Vangkilde, 2013). Lin, Chen & Lou's (2014) studies further proved that the digital treasure hunting game could enhance the spatial memory and spatial orientation. Yang & Chen's (2010) designed the digital pentominoes game to improve the students' three types of spatial abilities: spatial perception, spatial visualization, and mental rotation.

In this study, the researchers try to design puzzle games that incorporate the theories of spatial visualization and mental rotation into the content so as to train and improve the students' spatial ability, which focusing primarily on spatial visualization and mental rotation. The findings show that the designed package puzzle game has effectively improved the participants' abilities in spatial visualization and mental rotation, but traditional puzzle games can only enhance the participants' mental rotation.

The test results of mental rotation showed that after the training of the two puzzle games, the participants' ability of mental rotation, either in the correctness or in the speed, had made a significant progress. In other words, either the traditional puzzle game or the newest package puzzle game can have significant effects on uplifting the capability of mental rotation. This is because both kinds of puzzle games allow the participants to directly practice their mental rotation in the game play.

As discussed above, mental rotation is the ability to rotate 2D or 3D objects and manipulate each of the inspected ones to fit in the exact position and angle within a limited period of time (Peters et al., 1995; Vandenberg & Kuse, 1978). Purposed for the learners to enhance the ability of mental rotation, the researchers have both the designs of the jigsaw puzzle so programmed that the players can use the mechanism to rotate objects and the timing system to enhance their speed in play. In the game, the players have to mentally rotate each piece of the cutout picture in order to match the right location in the original picture until all the pieces of the puzzle have been rotated to the correct angle and moved to the correct position, and thus they pass. Both types of puzzle games supply a great amount of opportunities for the players to practice and self-train the ability of mental rotation. As a result, both the traditional puzzle games and the newly designed package puzzle games have positive effects on the learners' ability of mental rotation. This result corresponds to Yang & Chen's (2010) research, in which their findings showed that the digital pentominoes game (i.e., one type of puzzle game) can effectively enhance the student's ability of mental rotation.

The result of the Spatial Visualization Test shows that only the package puzzle games have the positive influence on improving the ability of spatial visualization. However, the training by the traditional puzzle games shows no significant effects on the improvement of spatial visualization. The main reason for such a difference is revealed in the concluding point that direct stimulation of spatial visualization is provided only in the package puzzle games.

As previously discussed, spatial visualization is the ability to imagine spatial movements of objects and shapes, manipulated either visually or in the mind (Hegarty & Waller, 2004). Aiming to train students' spatial visualization, the researchers design the package puzzle games in a specific way. By playing the package puzzle games, students are able to practice the operating mechanism of spatial visualization which involves the mentally visualizing how the puzzle is to be arranged, folded, synthesized, or transpositioned so that the cube may be correctly wrapped up. In the package puzzle games, the players have to rotate the pieces, but above all, they need to imagine the spatial movements of objects and shapes in order to cover the entire cubic block diagram. This mental mechanism manipulated in the mind can directly stimulate the learners' ability of spatial visualization. Therefore, this positive effect can be highly predicted. Comparatively, the design of the traditional puzzle games is more centered on the practice of mental rotation and significantly less on spatial visualization.

The result of this study illustrates that incorporating the theory of spatial ability into the multimedia games is functional in enhancing the students' acquisition of spatial visualization and mental rotation. The findings are consistent with the previous studies (Lin, et al., 2014; Sung et al., 2008) and support the notion that the theory-based design of multimedia games offers an effective learning environment for improving cognitive knowledge.

In sum, a few concluding points are presented to illustrate the theoretical value of this study. First, puzzle games have a very positive impact on the promotion of spatial abilities; second, the digital games designed on the basis of spatial cognition theory can effectively improve the spatial abilities; and third, spatial abilities, such as mental rotation and spatial visualization, show a very significant growth after a short span of time in the use of the digital games.

6. Conclusion

This study develops two types of digital puzzle games and examines the effects of two essential spatial abilities within these games, mental rotation and spatial visualization. The study's main findings include three parts: (a) although both the traditional digital puzzle games and the digital package puzzle games can improve student's ability of mental rotation effectively, (b) only the digital package puzzle game, specially designed for spatial visualization, can significantly enhance the students' ability of spatial visualization, and (c) the spatial cognitive theory-based design of digital game can effectively enhance the learners' spatial ability.

The study recommends that game design should be centered on the targeted capability. Not all kinds of digital games can be functional to the growth of spatial abilities, but only those which have included the design of the games so developed in an appropriate way that meets the specific learning objective can be useful (O'Neil et al., 2005). This study suggests that to be an effective learning game, the goal of design should be set up clearly, that is, the targeted ability to be developed should be defined precisely; and the analysis of the definitions, the operating mechanism, and the current theories, and the related psychometric testing of the targeted ability should be processed. In other words, when the details of the game design are more appropriate to the proposed target development of the learners' abilities and concepts, the achievements of their learning outcome will be greater as is resulted in the playing of the game. As argued by Sung et al. (2008) in the related research, the game design should be theory-based so that the game can be more effective in the learning procedure.

The findings of this research also demonstrate that digital jigsaw puzzle is not for entertainment only, but serves also as a functional way of education. If the game design process is to be added with the cognitive learning elements, the game does no longer remain just a game, but appears an effective learning tool. Playing a game is always children's favorite way of educational learning, and how to have the cognitive contents and the digital games well-integrated will be an important trend in the future direction of research.

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