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THE INFLUENCE OF BOARD GAMES ON MATHEMATICAL SPATIAL ABILITY OF GRADE 9 STUDENTS IN JUNIOR HIGH SCHOOL

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Abstract

The main purpose of this study is to investigate the influence of board games on mathematical spatial ability of grade 9 students. This study used quasi-experimental design to enroll 2 classes *of grade 9 students in a certain junior high school in the southern Taiwan as the research subjects. The subjects were divided into experimental group (28 subjects) and control group (29 subjects). This study performed the pretest, posttest, and experimental teaching for 7 times (once every 2 weeks; 2 classes each time). In the teaching experiment, this study used the implementation/non-implementation of board game activity teaching as the independent variable to investigate the influence of application of board games on mathematical spatial ability of grade 9 students in junior high school. Before the implementation of the experiment, this study used spatial ability scale to perform the pretest. After the implementation of the experiment, this study used spatial activity scale to perform the posttest. In the end, this study performed relevant statistical analyses, and collected students' feedback slips and teachers' teaching reflection. The research results showed that: (1) board game teaching improves students' learning effectiveness of spatial ability; (2) board game teaching improves students' learning interest in spatial ability; (3) after receiving board game teaching, the posttest showed that the mathematical spatial ability of students with more experiences in playing 3D animation games is significantly higher than that of those with less experiences in playing them; (4) the spatial perception, spatial identification, spatial rotation, and total score of mathematical spatial ability of the experimental group are significantly higher than those of the control group. According to the research results, this study proposed board game course of spatial ability for junior high school, and use computer network in combination with board game as reference for spatial ability teaching and subsequent studies.*

Keywords

Board Game, Game-Based Learning, Spatial Ability, Junior High School

1. Introduction

In the mathematics course of Curriculum Guideline in 2008 in Taiwan, regardless of the level of difficulty of teaching materials, researchers observed the following phenomena in the teaching scene: with the increase of age, the proportion of students who were willing to learn mathematics decreased from 2/3 and 1/3 to less than 1/3. Some of the students only guessed the answers of multiple choice questions when completing mathematics examination paper, and left blank other questions. Therefore, the poor performance of mathematics was apparent. Students' willingness to go to class and learning attitude also affect teachers' teaching enthusiasm.

Therefore, education scholars should attach importance to how to improve students' self-confidence and positive attitude towards mathematics learning (Huang, Tsai, Diez & Lou, 2014; Robelen, 2012).

At the transition from 2D to geometric 3D space in mathematics learning, students always encounter excessively abstract and incomprehensible questions (Pittalis & Christou, 2010). Therefore, the research hoped to increase students' hand-on operation and practice to improve their learning wiliness and effectiveness. Nickson (2000) mentioned that, at early school stage, children's failure to learn well spatial skills and concepts may affect their future learning career. The spatial ability of image operation and conversion is indispensable in mathematics learning. Therefore, this study used operational learning to help students develop mathematical spatial concepts, and used spatial ability-related board games to enable students to play by doing and learn by playing to further improve their mathematical spatial ability.

The existing spatial geometry teaching is the provision of cardboards attached to textbook for students to actually operate them. However, the learning of cubes is time-consuming. Once a model is adhered, it is fixed and cannot be opened and changed again. Although textbook suppliers provide more intricate plastic cube teaching materials that can be repeatedly operated, the quantity is limited. Limited teaching materials can only be used by teachers for demonstration or group-based operation. Most students can only passively observe operation, and it is difficult for them to develop the learning experiences of hand-on operation (Kirikkaya, Iseri & Vurkaya, 2010).

This study used board games of plane and three-dimensional designs available on the market to trigger students' interest, help them successfully convert from 2D to 3D spatial concepts, increase the spatial ability of various aspects, and strengthen the integrity of teaching materials to improve students' learning of spatial ability of higher difficulty. The research purposes as following,

(1) To investigate the influence of board games on students' mathematical spatial ability.

(2) To investigate the difference in mathematical spatial ability of students of different background variables after playing board game.

(3) To compare the difference in mathematical spatial ability between students who participate in board game activities and those who do not participate in them.

2. Literature review

2.1 Game-based Learning

Game-based learning is the integration of game with education to enable students to learn in game-based context, increase their learning interest, and absorb required concepts and knowledge progressively. The difference between game-based learning and school course is: in a game, players "witness and predict outcomes and then start to learn (Hsieh, Lin & Hou, 2015)." School course starts from fundamental materials (definitions and theories), and constantly postpones the effectiveness (system and application). Therefore, in a game, players face "top-down learning" (Gee, 2005). The feature of game-based learning is the integration of teaching content with game. Students cannot generate feedbacks until teaching materials trigger their motivation. Garris and Driskell (2002) suggested that, once teaching content matches up characteristics of a game, a game can be used to attract users to enable learners to spontaneously and repeatedly engage in learning to further achieve teaching objectives. In terms of introduction of game to teaching, teachers play an important role and affect students' learning, namely, teachers guide students to enter game system to engage in learning (Yien, Hung, Hwang & Lin, 2011). Therefore, good game-based teaching should be designed by teachers and integrated with proper course, which enables students to obtain meaningful learning. Hwang and Wu (2012) suggested that the introduction of game to teaching should include characteristics, such as challenge, competition or collaboration, opportunity or joyfulness, and education.

Based on the above, game-based learning provides teachers and learners with the site where game content and task can facilitate learning. Knowledge is developed through game content, and skills are also the results of game experiences (McFarlane, Sparrowhawk & Heald, 2002), indicating that game and enhancement of knowledge and ability are mutually influential.

2.2 Board Game

A board game, a.k.a. an unplugged game, is a game of cards (including collection and exchange of cards), plate, dice, and others played on table or any plane. A board game is originated from parent-child interactive leisure activities in the Europe and the U.S., and has been developed for nearly a century. In Taiwan, players started to import board games from abroad in 2000, and translated the rules. However, they only played them with friends around them. Therefore, board games are a niche market. In 2007, relevant promotion units, stores, exhibitions, and gatherings started to rise. In October 2009, Board Game Association, Republic of China was established to hold "Board Game Professional Teacher Training Course." Members completing the training course formed a teaching group to offer board game courses in elementary schools, junior high schools, and senior high schools in the northern Taiwan. They used social media to guide one another, design teaching programs, and engage in class observation to enhance professional ability. As a result, board games in Taiwan are stepping towards organization and teaching professionalization (Liu & Liu, 2010).

Hinebaugh (2009) suggested that a board game is a learning catalyst. Parents and teachers can understand students' learning process, improve their cognitive learning, and trigger their curiosity about knowledge and discussion. If the game content covers the knowledge of a certain field or the emphasis on problem-solving, the game will help players learn knowledge and develop the ability of problem-solving under high motivation. Gamlath (2007) pointed out that, board games are featured by group participation, easy and vivid game rules, full participation, unlikely formation of attack and opposition, luck, strategies and choices, and emphasis on creativity and aesthetic sense. Liu and Liu (2010), who is devoted to board game even indicated that, players can acquire the abilities of social learning, skill assessment, social skills, and community sharing from board games. Gee (2003) suggested that, if students can grasp game content and rules, their vision and abilities can be expanded. Once learners are familiar with the strategies and design methods of a game, it is more likely to adjust game rules according to their level to achieve the teaching objectives of adaptability. Lantz, Nelson and Lotfin (2004) suggested that board games have a significant impact on improving children's perception, social abilities, language, motor ability, and emotional development. Games can be used to explore a variety of social roles and interactions to help children build self-confidence and social abilities. Well-designed board games not only create attractive game atmosphere, but also increase learners' social interaction skills, teamwork ability, investigative ability, decision-making ability, and information assessment ability. Healthy competitions enable learners to develop a positive attitude towards success/failure. Losers can review the reasons of failure during the game process and reflect on how to rectify mistakes (Mayer & Harris, 2010; Treher, 2011). Therefore, board games enable students to learn various abilities from game, and are good teaching aids.

In recent years, the wave of flipped education has been set off on campus. Hui-tse Hou promoted "micro-flipped learning," namely, use of board game flipped learning to overcome the gap of learning and playing. In addition to engaging in R&D, his team also promoted historythemed board game "Passing through the History of Taiwan" in 2014 (Hou, Li, & Wang, 2015). Hui-lung Liu even introduced board game into grade 7 and grade 8 gifted classes to lead students to engage in exploration, reflection, and discussion, which achieved great teaching effectiveness (Kang, Liang, & Chai, 2014). Therefore, board games are innovative teaching tool of great potential.

According to the literature review, game-based learning and application of board games to teaching have a significant influence on improving students' learning achievement, learning motivation, learning attitude (Kang, Liang & Chai, 2014), as well as increasing their active learning and ability of cooperation and communication. However, most of the studies focused on special education and elementary school students, and seldom investigated junior high school, let alone spatial ability. Therefore, this study intends to investigate the influence of board game teaching on mathematical spatial ability of junior high school students.

2.3 Spatial Ability

For the definition of spatial ability, Guzel and Sener (2009) proposed the concepts concerning individuals' techniques of rotation, maintenance, and conversion of visual information of spatial events. Newcombe and Frick (2010) suggested that, if one can identify the shape of an object, understand its states of zooming in and zooming out, and understands its spatial relationship, he/she can still fully understand the mutual relationships of this object. Dean and Morris (2003) defined spatial ability as individuals' perception, conjecture or image and object in thinking space, as well as the ability of abstract reasoning, such as recalling, extracting, rotating, moving, changing direction and position, expanding, combining, and thinking in mind according to perception, memory or conjectured image or object. Dai et al. provided a more circumspect definition, and this study adopted this definition, as well as spatial ability defined by Lai (2010). Therefore, this study defines spatial ability as students' ability to identify, observe, analyze and compare image or graphics of objects. In addition, such graphics can be freely moved, flipped, rotated, manipulated, and compared in mental imagery. Besides, students can also perform logical reasoning on images (Harle & Towns, 2011; Kell, Lubinski, Benbow & Steiger, 2013).

Many foreign studies investigated the meanings of spatial ability. However, in Taiwan, only Kang, Chien, Chung, Jan and Lu (2006) and Tai, Yu, Lai and Lin (2003) conducted a comprehensive study. According to the research results of Tai, Yu, Lai and Lin (2003) developed the "spatial ability scale" where spatial perception, spatial identification, spatial rotation, spatial organization, and spatial reasoning are included. This study used the spatial ability scale developed by Lai (2010) as the tool for measuring mathematical spatial ability of grade 9 students. Past studies found that, there is a close relationship between spatial ability and game-based learning. Most of the past studies enrolled elementary school students as the research subjects, and focused on designing various types of teaching activities to improve spatial ability, including Rubik's cube, pentomino, 2D3D-tangram, and LEGO. However, they seldom investigated the influence of board game on spatial ability. As a result, this study intends to enroll junior high school students as the subjects and use spatial ability as the research direction to investigate the influence of board game on mathematical spatial ability (Nilges & Usnick, 2000).

The mathematics field of Grade 1-9 Curriculum in Taiwan includes number and quantity, geometry, algebra, statistics, probability and links. "Geometry" includes identification of appearance of shape, construction and conversion of plane graphics and three-dimensional shapes, constituent elements of shape and relationship investigation, investigation of nature of shape and application of such nature to reason problem-solving and spatial orientation. The stage of elementary school focused on life-based geometry learning, and advanced objective is to use the expansion and combination of three-dimensional shape to develop the visualization and reasoning ability of spatial ability. There is a lack of learning of mental imagery rotation, spatial visualization, and reasoning ability in teaching materials of junior high school for students. The learning of three-dimensional graphics of grade 9 students is merely hand-on fold and unfold of cardboards to understand three-dimensional graphics or the calculation surface area and volume. Because there are only few introductions to three-dimensional graphics in junior high school course, this study used board game integrated with plane and three-dimensional geometry teaching and square and cube as components to design teaching activities to enable students to learn from operation and develop spatial ability.

3. Methodology

3.1 Research Structure

The main purpose of this study is to investigate the influence of board game teaching on junior high school students' spatial ability. The research framework is shown in Figure 1. This study processed both quantitative and qualitative data. For quantitative data, this study used descriptive statistics, paired sample t-test and ANCOVA, etc. For qualitative data, this study used students' feedback slip and teachers' teaching reflection. This study compared quantitative data with qualitative data to understand the influence of board game on junior high school students' spatial ability.

(1) Independent variable was different teaching methods. Experimental group participated in the board game activities, while control group did not participate in the board game activities.

(2) Personal background variables: this study investigated students' experiences of playing LEGO, Rubik's cube, and 3D computer animation games before the experiment.

(3) Dependent variables: including spatial perception, spatial identification, and spatial rotation. Each dimension included 15 items in order from the simplest to the most difficult, with a total score of 45 points.

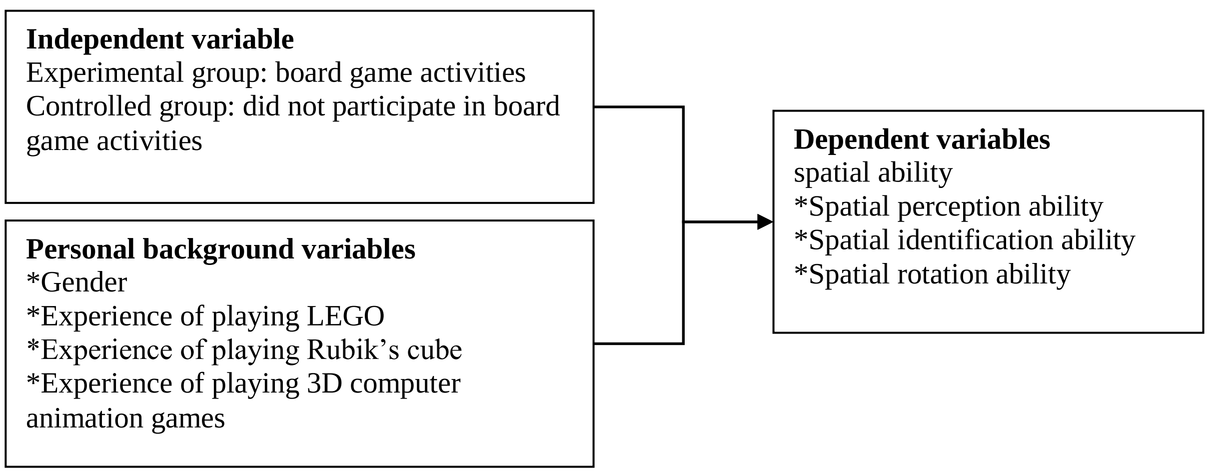

Figure 1: *Research framework*

3.2 Research Subjects

This study enrolled grade 9 students in a certain junior high school in the southern Taiwan as the research subjects. This study selected a class taught by the researcher as the experimental group (15 male students and 13 female students), and selected another class as the control group (15 male students and 14 female students).

3.3 Research Design

This study mainly used nonequivalent quasi-experimental research method as the research design. The teaching method was independent variable. Experimental group participated in the board game activities, while the control group did not participate in the board game activities. The dependent variable was spatial ability. The two groups both received the pretest and posttest of "junior high school students' spatial ability scale" before and after the experiment. This study used class meetings and club activities to implement board game teaching, and divided the subjects into 7 groups to implement board game teaching 2 classes each time for 7 weeks, with 14 classes totally.

3.4 Research Tools

3.4.1 Spatial ability-related board games

1) Blokus: a.k.a. German's go. Although it looks similar to Rubik's cube, actually it resembles the territory of go. Players have to use cubes to expand their own territory, prevent opponents from invading territory, and slowly use up the cubes at hand. Blokus won the Best Intellectual Game Mensa Select in 20013, and is often used as the teaching aid of intellectual enlightenment. In terms of the development of spatial ability, 21 pieces of cubes of the same color form different patterns to develop students' ability to identify, observe, analyze and compare the images or graphics of objects.

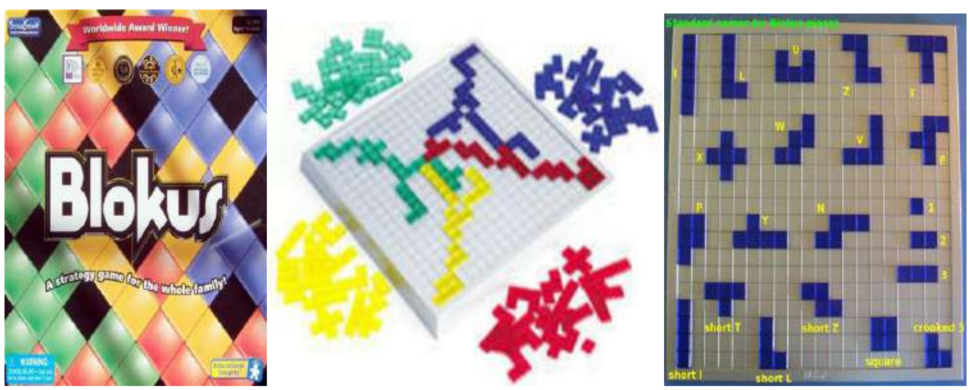

Figure 2: *Blokus Board Game*

2) Ubongo: a game to train and develop spatial concept. It is similar to ancient game Rubik's cube where players have to use designated plates to form the shape required by the items. In terms of the development of spatial ability, it tests players' ability to observe and form shapes. Therefore, it develops students' logical reasoning ability to identify and observe shapes, as well as freely move, rotate, manipulate, and compare them.

Figure 3: *Ubongo Board Game*

3) SOMA Cube: use of construction and observation of objects to learn to analyze structures. SOMA cubes reflect different appearances to enable students to develop the preliminary concept of spatial observation, observe the formed shapes from different perspectives to understand relative spatial positions. In terms of the development of spatial ability, four cubes of the same size connect each another with surfaces can form a larger cube. Therefore, SOMA cubes develops students' ability to observe, analyze, and compare shapes, as well as the logical reasoning ability to freely flip, rotate, manipulate, and compare them.

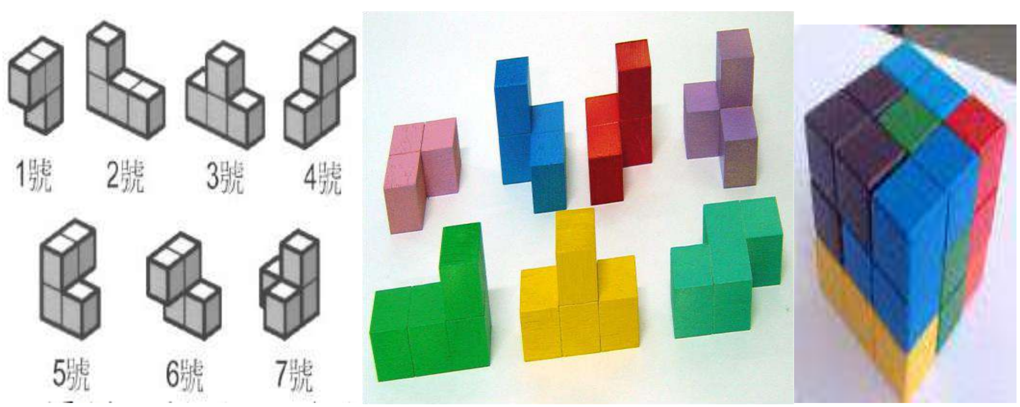

Figure 4: *SOMA Cube Board Game*

4) Rumis: designed according to the inspiration from Inca ruins, including pyramids, tall towers, steps, residences, and wall corners. When players think about how to circumvent opponents, Rumis can make players' spatial sense more sensitive. It is similar to 3D version of "Blokus," and some game vendors name it "Blokus 3D." In terms of the development of spatial ability,

the appearance of map varies with versions, which enables students to explore spatial concept and develop their ability to identify, observe, and compare the shapes, as well as freely flip, rotate, and manipulate them to improve spatial ability.

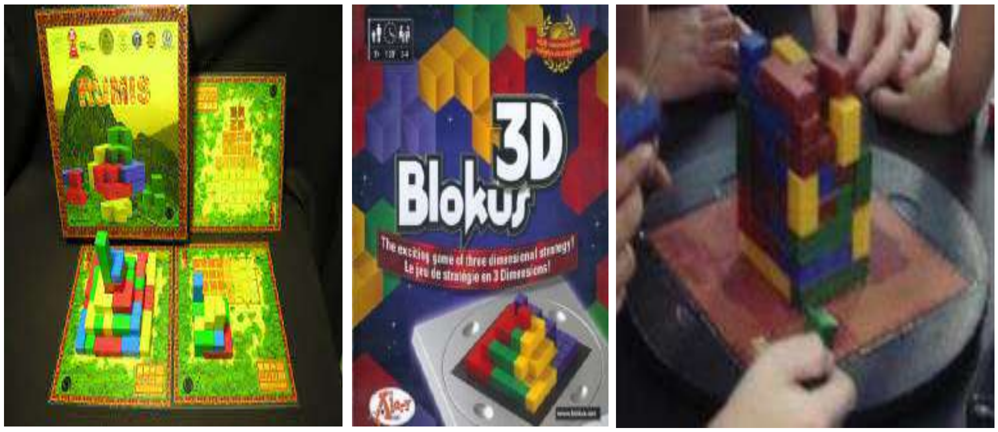

Figure 5: *Rumis (Boluk 3D Version)*

3.4.2 Spatial ability scale for junior high school students

This study modified the spatial ability scale for junior high school students developed by Lai (2010).The scale used in this study included 3 sub-scales: spatial perception, spatial identification, and spatial rotation, with 15 items in each scale. If the subjects offered the right answer, they would be given 1 point. If the subjects offered the wrong answer or did not offer any answer, no point would be given or deducted. In terms of validity, 17 experts in Taiwan completed the Delphi expert questionnaire, and they reached consensus on this scale. In terms of reliability, the total scale reliability (KR20) was 0.90. The reliability of each sub-scale was: spatial perception: 0.72; spatial identification: 0.87; spatial rotation: 0.71, suggesting that the reliability was quite high.

3.4.3 Students' feedback slip

Including "feedback slip for learning of spatial ability board game" and "questionnaire on spatial ability board game," which were both modified from the feedback slip of board game developed by He (2012). A 3-point scale was used for scoring. The highest score was 3 points, followed by 2 points, and the lowest one was 1 point. After the number of subjects was multiplied by the score of options, the higher the cumulative scores were, the better the perception of board game was. For the average score >70 points, the perception of board game was positive. For the average score=40-69 points, the perception of board game activities was appropriate. For the average score <40 points, the acceptance of board game was low. After the completion of teaching of each board game, the students completed "feedback slip for "spatial ability board game." The content of the feedback slip included the level of difficulty of game, rules of game, process of game, time of game, control of order, design of board game, perception of board game, and whether the game helps me develop geometry spatial concept. After the termination of four board games, the students completed "questionnaire on satisfaction with spatial ability board game," which included two parts: (1) perception and preference, selection of the game attracting the highest interest, most impressive game, and game from which the subjects learn most; (2) overall perception: the subjects completed personal perception and ideas according to activity performance, order & concentration, interaction with classmates, and whether the game is beneficial to the learning of spatial ability concept.

4. Research Results and Analysis

4.1 Sample description

In terms of the distribution of number of students with experience of playing LEGO, 0 students never played LEGO (0%), 37 students less frequently played LEGO (64.9%), and 20 students frequently played LEGO (35.1%). For the distribution of number of students with experience of playing Rubik's cube, 1 student never played Rubik's cube (1.8%), 41 students less frequently played Rubik's cube (71.9%), and 15 students frequently played Rubik's cube (26.3%). For the distribution of number of students with experience of playing 3D computer game, 7 students never played 3D computer game (12.3%), 33 students less frequently played 3D computer game, and 17 students frequently played 3D computer game (29.8%).

4.2 Analysis on the Differences in Spatial Ability

4.2.1 Within-group Comparison on Experimental Group's Spatial Ability

As shown in Table 1, this study performed pretest and posttest before/after the implementation of experimental teaching. The average score of pretest and posttest of the experimental group was 19.46 and 27.14, respectively. t value was -10.477(p=.021<.05), and the difference reached significance, suggesting that, after receiving the teaching of board game, students' spatial ability improved significantly.

Table 1: *Independent Sample t Test on Pretest and Posttest of Students' Spatial Ability Scale*

Items	Number	Mean	S	*t*	*p*
Pre-test Post-test	28 28	19.46 27.14	6.455 6.352	-10.477	.021

4.2.2 Analysis on the within-group differences in in spatial ability of the two groups

This study performed regression coefficient homogeneity test first to understand the within-group difference between experimental group and control group 在 spatial ability. The F value of the "within-group pretest" of subscales of spatial perception, spatial identification, spatial rotation was .005 (p=.943), 1.787 (p=.187), and 3.310(p=.075), respectively. The F values all failed to reach the significance of .05, suggesting that there was a consistent linear relationship between covariance and dependent variable in each group. Therefore, ANOVA could be performed. This study used the pretest score of "spatial ability scale" as the covariance, posttest score was the dependent variable, and group as the independent variable to perform one-way ANOVA. The explanations are given as follows according to the subscales:

(1) Spatial Perception

As shown in Table 2, the F value of the ANOVA on spatial perception was 9.316 (p=.04<.05), and reached a significant difference, suggesting that after the influence of pretest was excluded, the learning effectiveness of spatial perception in spatial ability between the two groups reached a significant difference. In addition, the adjusted average of the experimental group (M＝8.61) was significantly higher than that of control group (M＝6.73). Therefore, after the implementation of teaching of spatial ability-related board game course, the students in the experimental group developed the visual image ability to perceive spatial image and reflect on other directions. In other words, students' learning effectiveness of spatial perception was significantly improved.

(2) Spatial Identification

As shown in Table 2, the F value of the ANOVA on spatial identification was 17.280(p=.00<.05), and reached a significant difference, suggesting that after the influence of pretest was excluded, the learning effectiveness of spatial identification in spatial ability between the two groups reached a significant difference. In addition, the adjusted average of the experimental group (M＝11.71) was significantly higher than that of control group (M＝9.08). Therefore, after the implementation of teaching of spatial ability-related board game course, the students in the experimental group developed the ability to identify and extract graphics and form images. In other words, students' learning effectiveness of spatial identification was significantly improved.

(3) Spatial Rotation

As shown in Table 2, the F value of the ANOVA on spatial rotation was 4.958 (p=.03<.05), and reached a significant difference, suggesting that after the influence of pretest was excluded, the learning effectiveness of spatial rotation in spatial ability between the two groups reached a significant difference. In addition, the adjusted average of the experimental group (M＝7.63) was significantly higher than that of control group (M＝6.50). Therefore, after the implementation of teaching of spatial ability-related board game course, the students in the experimental group developed the ability to maintain the clearness of features of three-dimensional images after they are rotated. In other words, students' learning effectiveness of spatial identification was significantly improved.

Based on the above, after the implementation of experiment, the learning effectiveness of overall spatial ability of students in the experimental group was significantly higher than that of those in the control group. This experimental result is consistent with that of Kuo (2010), Pittalis and Christou (2010), Chen (2013) and Hsu (2015), suggesting that spatial ability can be improved through board game teaching.

Table 2: *Summary of ANOVA on Spatial Ability Scale of Students in the Experimental Group and Control Group*

	Source	Type I SS	df	MS	F	Significance	Net relevant Eta square
Spatial Perception	spatial perception*Pre-test	262.454	1	262.454	48.799	.00	.475
	Group	50.105	1	50.105	9.316	.04	.147
	Error	290.423	54	5.378			
Spatial Identification	Spatial Identification*Pre-test	448.435	1	448.435	74.777	.00	.518
	Group	103.626	1	103.626	17.280	.00	.242
	Error	323.83	5	5.997			

		4	4				
Spatial Rotation	Spatial Rotation *Pre-test	414.58 4	1	414.58 4	114.08 3	.00	.769
	Group	18.019	1	18.019	4.958	.03	.084
	Error	196.23 9	5 4	3.646			

4.2.3 Analysis on Between-group Difference in Spatial Ability of Students of Different Background Variables

In terms of the analysis on the difference in learning effectiveness of spatial ability of students of different backgrounds, this study analyzed background variables, such as gender, experience of playing LEGO, experience of playing Rubik's cube, and experience of playing 3D computer animation game. The F value of between-group regression coefficient homogeneity test was.589 (p=.446), .077 (p=.783), .386 (p=.537), and .430 (p=.446), respectively. The F values all did not reach significance, suggesting that there is a consistent linear relationship between covariance and dependent variables in each group, and one-way ANOVA could be performed. The explanations are as follows:

As shown in Table 3, the F value of between-group effect test in the analysis on background variables, such as "gender," "experience of playing LEGO," and experience of "playing Rubik's cube" was .071 (p=.898), 2.029 (p=.160), and .079 (p=.924), respectively, and did not reach significant difference. Therefore, the difference in gender, experience of playing LEGO, and experience of playing Rubik's cube did not have a significant influence on posttest of spatial ability of students receiving the teaching of board game. The difference in background variables, such as gender, experience of playing LEGO, and experience of playing Rubik's cube, did not have a significant influence on how the teaching of spatial ability-related board game improved students' learning effectiveness of spatial ability.

As shown in Table 3, the F value of between-group effect test in the analysis on background variables "experience of playing 3D computer animation game" was 3.446 (p=.039<.05), and reached a significant difference. Therefore, the difference in experience of playing 3D computer animation game had a significant influence on posttest of spatial ability of students receiving the teaching of board game. After receiving the teaching of spatial ability-related board game, the learning effectiveness of spatial ability of students who frequently played

3D computer animation game was significantly higher than that of those who less frequently played it.

Based on the said analyses, gender did not have a significant influence on the posttest of spatial ability. This result is consistent with that of the studies by Huang (2008) and Huang (2010) et al. The experience of playing LEGO and the experience of playing Rubik's cube did not have a significant influence on posttest of spatial ability of board game teaching, suggesting that the experiences of these two types of games did not have a significant influence on spatial ability. The posttest score of students who more frequently played 3D computer game was significantly higher than that of those who less frequently played it. The reason might be that playing 3D computer game involves the perception, identification, rotation, etc. of spatial ability. Therefore, it had a more significant influence on learning of spatial ability.

Table 3: *Summary of One-way ANOVA on Posttest of Spatial Ability of Students of Different Background Variables*

	Source	Type I SS	df	MS	F	Significance	Net relevant Eta square
Gender	Pre-test	2169.698	1	2169.698	125.154	.000	.699
	Gender	.286	1	.286	.017	.898	.000
	Error	936.156	54	17.336			
Experience of playing LEGO	Pre-test	2169.698	1	2169.698	129.816	.000	.706
	Experience of playing LEGO	33.905	1	33.905	2.029	.160	.036
	Error	902.537	54	16.714			
Experience of playing Rubik's cube	Pre-test	2169.698	1	2169.698	123.163	.000	.699
	Experience of playing Rubik's cube	2.773	2	1.386	.079	.924	.003
	Error	933.670	5	17.616			

			3				
Experience of playing 3D computer animation game	Pre-test	2169.698	1	2169.698	138.769	.000	.724
	Experience of playing 3D computer animation game	107.773	2	53.886	3.446	.039	.115
	Error	828.669	53	15.635			

4.3 Students' Feedback

Upon completion of each board game activity, 28 students in the experimental group were requested to complete the "feedback slip for learning of spatial ability board game" to understand their opinions on board game teaching. Moreover, upon completion of 4 board game activities, the students were requested to complete "questionnaire on satisfaction with spatial ability board game" to understand their overall perception and preference for board game. The explanations are given as follows:

4.3.1 Analysis on Students' Feedback for Learning of Spatial Ability Board Game

According to the statistical analysis on students' "feedback slip for learning of spatial ability board game," as shown in Table 4, the average score of feedback slips for Blokus, Ubongo, SOMA Cube and Rumis (Blokus 3D) was 68.63, 66.50, 65.38, and 66.00, respectively. The highest score was "Blokus," suggesting that students preferred this game most. The lowest score was "SOMA Cube." There was no significant difference in average score of four games, suggesting that the students' preference for four board games was close.

Table 4: *Statistics of Students' Feedback for Learning of Spatial Ability Board Game*

Item	Blokus	Ubongo	SOMA Cube	Blokus 3D
Level of difficulty of game	64	59	53	55
Rules of game	75	73	71	69
Process of game	71	74	60	62
Time of game	56	55	58	61
Control of order	61	64	69	65
Design of board game	71	66	69	70
Perception of game	78	72	71	73
The game enables me to	73	69	72	73

develop geometric space concept				
Average score	68.63	66.50	65.38	66.00

4.3.2 Analysis on Questionnaire on Students' Satisfaction with Spatial Ability Board Game

According to the "questionnaire on students' satisfaction with spatial ability board game," the explanations on perception, preference, and overall perception of spatial ability board game are given as follows:

(1) Perception and Preference

As shown in Table 5, the order of games that attracted the interest (from the highest to the lowest interest) of experimental group was: Rumis (Blokus 3D), Blokus, SOMA Cube, and Ubongo. The design of components of "Rumis (Blokus 3D)" was full of excitement and challenges, while "Ubongo" was only limited to flat-screen operation and was deficient in sense of excitement. Therefore, the students were less interested in "Ubongo." The order of games of impression (from the highest to the lowest impression) was: Blokus, Blokus3D, SOMA Cube, and Ubongo. The students were most impressed by "Blokus" because they found it simple, easy-to-learn, joyful, and could obtain a sense of accomplishment. The order of games from which the students learned (from the most to the least) was: Blokus, SOMA Cube, Blokus3D, and Ubongo.

Table 5: *Statistics of Students' Perception and Preference of Spatial Ability Board Game*

Items	Blokus	Ubongo	SOMA Cube	Blokus 3D
Game that attracted the highest interest of you	97 (points)	85(points)	87(points)	99(points)
Game that most impressed you	15 (students)	1(students)	2(students)	10(students)
Game from which you learned the most	12 (students)	2(students)	11(students)	3(students)

(2) Overall Perception

As shown in Table 6 - statistical analysis, the scores of activity performance, order & level of concentration, interactions with classmates, and being beneficial/unbeneficial to the learning of concept of spatial ability were 71, 48, 77, and 74, suggesting that the students could concentrate on board game activities without being interfered with. Order did not have a level of concentration. Most of the students suggested that order did not affect the level of concentration on playing games. During the board game activities, there were a lot of interactions with students. After the game, the students were divided into winner group and loser group for a rematch. There were a lot of interactions with students. The students suggested that board game was beneficial to their learning of concept of spatial ability.

According to the results of "feedback slip for learning of spatial ability board game" and "questionnaire on satisfaction with spatial ability board game," board games can improve mathematical spatial ability, activity performance, increase interest, and improve learning effectiveness. These results are consistent with those of the studies by Huang (2010) and Kuo (2010). Therefore, board games can be comprehensively applied to teaching units and themes to enable students to "learn by playing" and conform to game-based learning. In terms of peer interactions, the results of this study are consistent with those of the studies by Lantz and Lotfin (2004); Liu and Liu (2010); Mayer and Harris (2010); Treher (2011), suggesting that board game can improve learners' ability to engage in social activities and interactions, as well as teamwork.

Table 6: *Statistics of Students' Overall Perception of Spatial Ability Board Game*

Items	3 points	2 points	1 point	Score
Activity performance	Extremely concentrated (15 students)	Ordinarily concentrated (13 students)	Not concentrated (0 students)	71
Order & level of concentration	Completely not affected (1 student)	Mildly affected (18students)	Severely affected (9 students)	48
Interactions with classmates	Many interactions (21 students)	Ordinary interactions (7 students)	Few interactions (0 student)	77
Being beneficial/unbeneficial to the learning of concept of spatial ability	Extremely beneficial (18 students)	Somewhat beneficial (10 students)	Unbeneficial (0student)	74
Average score of overall perception: 67.50 points				

5. Conclusion and Suggestions

5.1 The teaching of board game course significantly improves students' spatial ability

The research analysis showed that, after the teaching of spatial ability-related board game course, in terms of overall learning effectiveness of spatial ability, the posttest score of spatial ability of students in the experimental group was significantly higher than pretest score.

Therefore, the teaching of spatial ability-related board game improves students' abilities of spatial perception, spatial identification, and spatial rotation.

5.2 The teaching of board game course increases students' learning interest in spatial ability

According to the statistical analysis of the "questionnaire on satisfaction with spatial ability board game," most of the students found board game activities very interesting and could trigger their learning interest, improve their concepts of mathematical spatial ability, and break small groups. In order to win the board game, team members would share strategies, which invisibly increased peer interactions and cooperation.

5.3 The spatial perception, spatial identification, and spatial rotation of spatial ability and total score of experimental group are significantly higher than those of control group

The research analysis showed that, after the teaching of spatial ability-related board game, the overall learning effectiveness of spatial ability of students in the experimental group was significantly higher than that of those in the control group. Therefore, spatial ability-related board game can significantly improve students' learning effectiveness of spatial ability. For example, the piling of LEGO and formation of SOMA Cube enabled students to understand the shapes and combinations of objects, and enabled the experimental group to make a significant improvement in spatial perception. Use of Blokus and Ubongo can help develop the ability of identification. Because the students had to reflect on how to flip and form blocks, their ability of spatial identification significantly improved. The students can use SOMA Cube and Rumis (Blokus 3D) to develop the ability of spatial rotation. During game playing, in order to form the designated shapes, the students had to continuously flip LEGO blocks. Through the rotation and operation processes of mental imagery, students could learn by playing, and their ability of spatial rotation improved significantly. Board games enabled students to develop the ability of rotation of mental imagery, spatial vision, and reasoning. Therefore, students' 2D and 3D spatial learning improved significantly.

5.4 Suggestions for future studies

In terms of research themes, future studies are advised to increase background variables of students and variables of experience of playing board games and choose videos as assistive tool for learning of spatial concepts. Playing of videos enables students to understand the essences of board game and develop spatial concept with half the effort. The association with teaching materials in junior high schools and R&D of relevant board games take into account course progress, as well as enable students to engage in knowledge learning. Moreover, for research methods, research sample diversity can be increased. Future studies are advised to expand samples to schools in urban area and more remote area for long-term and complete observation and research. Future studies are also advised to perform long-term observation, recording, interviews, and analysis on mental thinking of students to understand their thinking and spatial judgment.

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