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A Study of Elementary School Students' Geometric Reasoning using Digital Origami Simulation Tool

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ABSTRACT

The purpose of this study is to explore the effects of applying Digital Origami Simulation System to promote sixth-grade students' learning of geometric reasoning ability. The participants were 90 students who studied the sixth grade in central Taiwan. This research adopts quasi-experimental design. The participants are divided into two groups: experimental group and control group. The experimental group takes Digital Origami Simulation Tool to support learning, and the control group takes traditional teaching. The instruments included Assessment of Line Symmetrical Graphics and Graphics Reasoning Ability. Data collection required participants to perform a pretest, a post-tests and learning records. The results of the study are presented below. Experimental group students have greater performance on the ability to geometric reasoning than the control group ones. Overall, the effect of Digital Origami Simulation Tool in geometric reasoning helps the students improve their performances.

KEYWORDS

Geometric reasoning, Line symmetrical graphics, Origami, Digital origami simulation tool, Paper folding

1 INTRODUCTION

Art education, the purpose of arts education is not to train students to become artists but to inspire their different thinking mechanism. We know that scientists and artists have a very important job which is to discover new matters and stimulate more creativity. The Director-General Federico Mayro Zaragoza of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1997 agreed with this idea. The researcher advocates that origami should incorporate such functions and applicability. The reason is that origami is not only a form of art. It possesses the learning function of hand-brain-eye coordination and can help students immerse in the process and unleash their potentials to discipline the body and mind. As the Paper Art Association of Hong Kong Chairman David Chan have ever said [1], "Origami can help train a person's overall coordination skills, including hand, eye, and brain." Therefore, the origami is a multi-learning tool. Because it can develops of students' scientific cultivation, exploration, and deduction skills. [2].

Origami is originated from Japanese words. "Ori" means folding and "kami" means paper. Earliest historical records proven that Origami originally came from Japan. While the English name "origami" is adopted globally, another way of calling it is "paper folding," although most people prefer the former. Origami requires no other tools aside from a square-shaped paper. A seemingly monotonous piece of paper can immediately become a 3D model through the simple folding it with both hands. The origami process can be referred to as a presentation of creativity. It is an art education and it also has been gaining respect from mathematics educators and spatial perception has become a core objective of schools' mathematics education [3]. Under the new educational concepts, students are frequently encouraged to use daily essentials to explore geometric relationships and vocabularies, as well as understand line symmetry and other related mathematical concepts through origami [4]. In addition, NCTM (National Council of Teachers of Mathematics) established its 10-phase standard and the 3rd standard is geometry and spatial perception. Pellegrino & Hunt [5] stressed that spatial ability presents the reasoning skills of visual patterns. When we apply spatial application skills to address our everyday problems, we are also applying our reasoning skills.

We can observe that children's origami operation and use processing, techniques and strategies of origami denotes the application and transfer of a series of spatial pattern concepts. A planar piece of paper can be folded multiple times. The geometric concepts and spatial concepts used in the process can benefit students in terms of mathematical and scientific developments [6, 7]. During the paper-folding process, the shape and structure change between 2D and 3D. Students continuously manipulate the shape and structure and have already developed a correct image in their minds. Then, students fold the paper according to basic paper-folding techniques and compare their imagined image with the assigned origami shape and structure. Therefore, the emphasis of this study is to observe whether or not students' observation or judgment of spatial figure reasoning skills changes before and after the origami activity.

Developing digital computer systems can compensate for the inadequacies of traditional classroom teaching and the two forms of teaching can complement each other. Moreover, another objective of the developing the "Digital Origami Simulation Tool" is to transcend the limitation of real papers. In traditional Origami process, unwanted creases are bound to appear after folding the paper repeatedly. These creases or wrinkles can be possibly removed by reverse folding though the effect is only limited. The same situation occurs using our system, but the good thing is you can just press the undo button, and the wrinkles will be completely gone. That is the benefit of using digital system. Also, the kind of paper being used in Origami can also affect the result of the process and the appearance of the paper. For example, if a person used a thick paper and it was folded repeatedly, it will result in errors and will also affect the folding accuracy. On the other hand, the paper will easily have cracks after repeated folding if the paper used is too thin. A digital system does not have these limitations [8].

This study developed two systems – "Line Symmetrical Graphics" and "Graphics Reasoning." We call the two systems "Digital Origami Simulation Tool." The purpose of this study is to develop a Digital Origami Simulation Tool. And we use the system to do 6 teaching sessions that determine whether or not Grade 6 students' line symmetrical graphics of geometry and reasoning skills can be improved.

2 SURVEY OF RELATED RESEARCHES

Origami is intricately related to geometry and spatial concepts. The basic steps of origami are simple [9] and similar to Euclid's geometry system as all proofs start with a few basic axioms [10]. In the mathematics textbooks of Taiwan's Grade 4 and 5 students, students are taught how to produce right angles and discover isosceles triangle and right triangle properties through origami. In middle school textbooks, students are taught how to realize line symmetry and angle bisector through origami. In addition to ruler and compass construction, another good way to learn geometry is through origami [11, 12]. Geometry is a tool to learn mathematics and science. Through our experience with spatial situation, we can transform our knowledge of spatial geometry into creative thinking [13].

Origami involves creating different shape and structure through repeated folding of a piece of planar paper. The series of spatial structure changes is in fact the best observation target for the learner. It also represents a simple and interesting teaching activity for the development of scientific exploration and reasoning skills. Wehman and McLaughlin [14] classified visual-motor characterization into separation and continuous. The former indicates hand-eye coordination, which has a distinct starting point and end point. Continuous characterization indicates the continuous change and adjustment of a series of visual motion. Origami possesses the above two visual-motor characteristics. The continuous change of the paper shape and structure, and the planning of spatial relationships are very beneficial toward the training of creativity.

People with poor spatial visualization ability are often unable to create 3D shape and structure from 2D graphics because their spatial visualization creates confusion and thus their answers are affected. Some scholars believe that spatial ability refers to the ability to perform mental rotation of 2D or 3D graphics using mental imagery after acquiring the related 2D and 3D information, as well as the ability to grasp the cognitive process and surrounding relationships of mental rotation [15, 16, 17]. The spatial concepts of children are shaped as they grow up. Spatial concepts are built on the foundations of location, distance, and displaced spatial concept awareness. The ability to distinguish between up/down is developed before the ability to distinguish between left/right. Distance, for example, far or near [18]. Also, direction is determined by using the self as a central representation before replacing the self with other people or objects.

“Spatial rotation and movement ability” refers to the ability to distinguish and memorize 2D and 3D spatial graphics. “Spatial visual imagery ability” is the utilization of reasoning to imagine or visualize the graphic characteristics or relations. “Spatial orientation ability” is the ability to determine the direction and relative position of objects, and “Spatial orientation application ability” denotes the ability to address spatial orientation issues in our everyday lives [19]. These abilities are highly correlated to our everyday lives, e.g., reading maps, road signs, the size of objects, and spatial location. Hoffer [19] noted that if students have difficulties with these abilities, they could write upside down or be confused with the characters “d” and “b”. Therefore, training students’ spatial perception is the key to developing their problem-solving skills in the future, especially visual spatial problems.

The Digital Origami Simulation Tool developed different from general animated paper-folding systems, famous websites such as the origami-club (http://www.origami-club.com) can only display one form of paper folding. Since the functions available include only play, forward, rewind, pause and adjusting play speed, the system cannot directly demonstrate the operating behavior of paper-folding. There is also the Origami Paper Airplane Folds in 3D [20], which runs on the tablet PC. While this is a 3D origami system that allows for free paper rotation and scale, the paper-folding screenshots are pre-recorded.

3 METHODOLOGY

3.1 Research Design and Participants

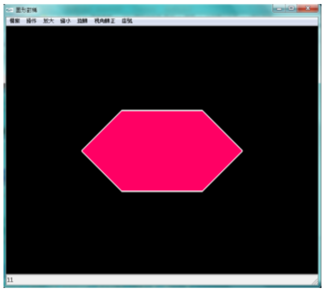
This study adopts a quasi-experiment approach in which the experiment group was taught the Line Symmetrical Graphics, Graphics Reasoning and the control group was administrated traditional teaching activity. A week prior to the teaching of the experimental group, both groups received a pre-test of the “Assessment of Line Symmetrical Graphics and Graphics Reasoning Ability.” In the experiment phase, the experiment group received 6 digital simulation system teaching sessions. Each session is 40 minutes. Two days after the experiment, a post-test was assessed to both the experiment group and the control group. Samples of this research were taken from 4 classes of Grade 6 students in central Taiwan, of which the experiment group consisted of 44 students and the control group consisted of 46 students.

3.2 Development of Instrumentations

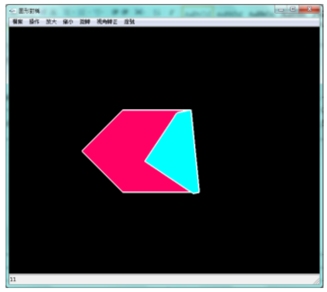
This instrumentation consists of three items, Line Symmetrical Graphics, Graphics Reasoning and Assessment of Line Symmetrical Graphics and Graphics Reasoning Ability. A more details will be described below.

3.2.1 Line Symmetrical Graphics

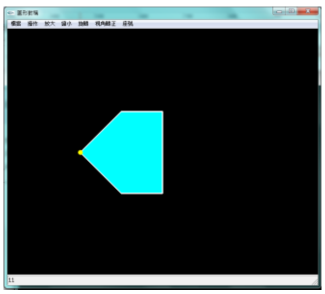
This research created the “Line Symmetrical Graphics” as a modified and extended system from Open Media Laboratory of Chukyo University at Japan (http://www.om.sist.chukyo-u.ac.jp/research/origami/). The major purpose of the Line Symmetrical Graphics is to help students learn about line symmetry principles through a digital origami system, as well as learning by doing and leaning by self-observation through actual operation and exploration. In particular, students only have to follow the basic principles of “identify a straight line in a graphic, double fold along the straight line and so you can achieve entire overlap, and then this geometric graphic is a symmetrical graphic." "Learning by doing" is the most important element in a digital system. Figure 1 illustrates the operation of line symmetry.



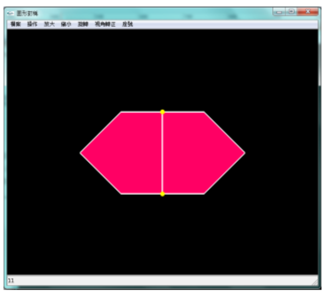
(a) Locate the line symmetry graphic paper



(b) Drag the mouse to the desired direction



(c) Release the mouse at the destination



(d) A crease line is formed by spreading out the overlapped paper

Figure 1. Line Symmetrical graphics – screenshot of digital origami system operations

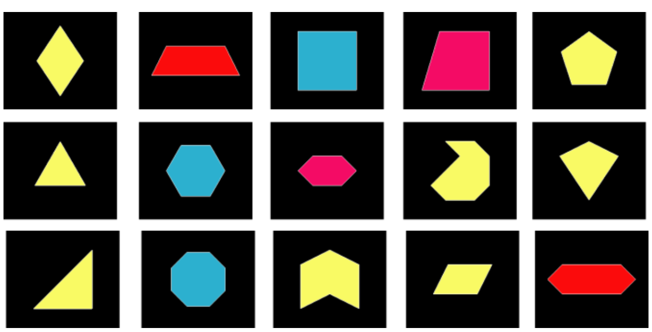


Figure 2. Survey questions

Line Symmetrical Graphics contains 15 questions (see Figure 2) and scripts can be used to add or remove the number of questions. The items consisted of line symmetrical graphics and non-line symmetrical graphics. This system will automatically record students' responses to each question to facilitate the researchers' analysis. Students would erroneously believe that some questions are line symmetrical geometric graphics because they often use intuition to form judgment. Therefore, this system forces students to prove through actual operation and observation whether or not line symmetrical graphics exists.

3.2.2 Graphics Reasoning

Graphics Reasoning was developed with the "Unity" game engine. This major purpose of the system is to train students: relative graphic position, spatial reasoning skill and moving/ rotation skill. A picture with a transparent background is placed at the right hand side of the screen. The dashed lines in the middle represent folded lines. After the picture on the right is folded to the left so that the right and left overlap, students are asked what type of graphic would emerge (e.g. Figure 3). The purpose here is to train students' graphic reasoning skill and test students' graphic symmetry and relative position, as well as reasoning skill after the rotation.

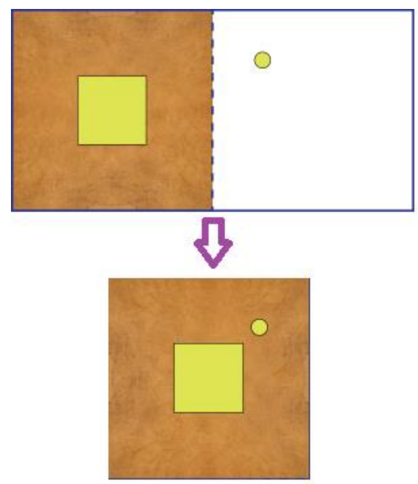


Figure 3. An example of the graphic reasoning

There are two versions of Graphics Reasoning: game version and timed version. The game version is designed for students' use in exercises, and the timed version is for their use in the actual testing. A total of 80 questions are provided in the game version to help students exercise and summarize their thoughts. Students can freely use the hint function, but the score well be lower every time they use it. To encourage students' thoughtful response in the exercise process, students are awarded a puzzle depending on their score. The purpose of the puzzle is to stimulate students' learning motivation.

The interface of the game version can be classified into "Scoring area," "Puzzle area," "Questions area," "Options area," and "Functions area" (see Figure 4). The "Scoring area" shows that when the score reaches 100, the student is awarded a puzzle. Collecting all 9 pieces of the puzzle completes a portrait. "Questions area" and "Options area" indicate the text description of the questions and answering options, respectively. "Functions area" provides students with hints so that when students are stuck, they can use the "paper folding" and "rotation" functions to help with their response. When students hit the "paper folding" function, the screen will show an animation of the right-to-left folding; when students hit the "rotation" function, the picture will be rotated clock-wise.

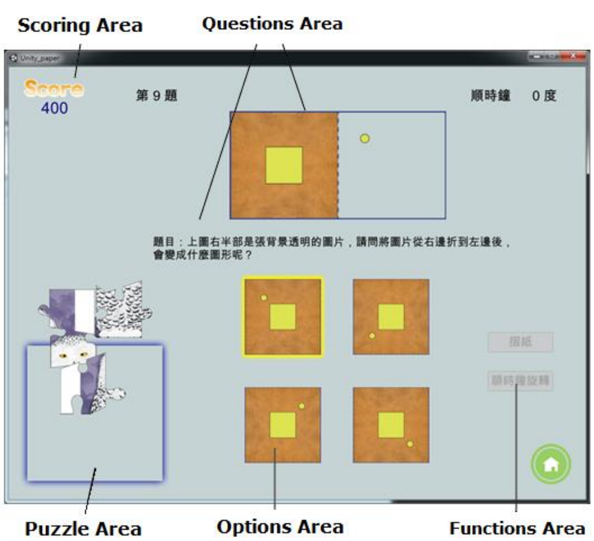


Figure 4. Illustration of the game version interface

The interface of the timed version is classified into "Timing area," "Hints area," "Questions area," "Options area," and "Functions area" (refer to Figure 5). The "Questions area," "Options area," and "Functions area" are similar to the game version, while "Timing area" records the amount of time students spend on each question and "Hints area" provides the hint function. In the 25 questions of the test, students can only perform paper folding and rotation 4 times. It is therefore essential for students to consider carefully before using the hint function.

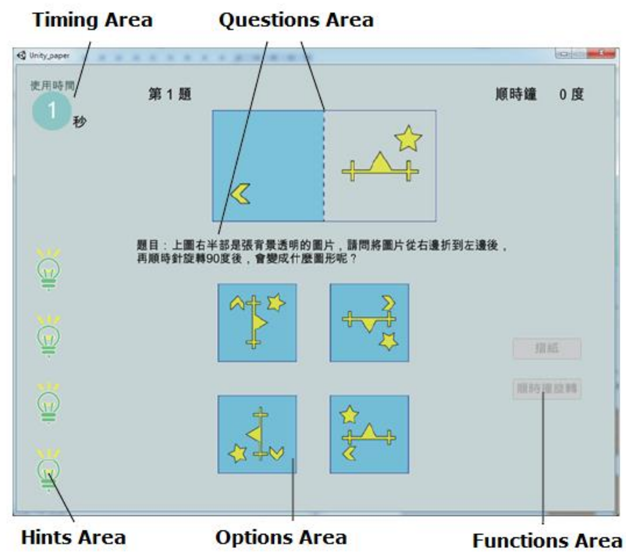


Figure 5. Illustration of the timed version interface

3.3.3 Assessment of Line Symmetrical Graphics and Graphics Reasoning Ability

After collecting and discussing the related literature of spatial ability, we designed 9 questions to evaluate students' symmetrical graphics and graphic reasoning ability, as well as what questions are appropriate for elementary students. The researchers invited a panel of experts and senior teachers of elementary school mathematics, and asked them to modify the questions and create expert validity. After completing the draft of the pilot test, a test with an allotted time of 35 minutes was administered to 23 students form Grade 6. After statistical analysis, the Cronbach's α of the 23 samples was .804. Therefore, the inventory used in this study has good reliability.

4 EXPERIMENTAL RESULT AND DISCUSSION

The researchers then analyzed the pre-test Assessment of Line Symmetrical Graphics and Graphics Reasoning Ability scores of students in the experimental group and control group. The experiment group averaged 63.2 (perfect score is 100), with a SD of 23.0, while the control group averaged 64.8, with a SD of 18.5. We also tested for the homogeneity of variance in both group, in which F was insignificant at 1.548 (p=0.075). The researchers then conducted independent t-test to determine whether the average score of the two groups differ in the pre-test. Results showed that the *t*-value was also insignificant at -0.361 (p= 0.360). Therefore, analytic results showed that students' pre-test scores in the two groups did not demonstrate significance. In other words, the Assessment of Line Symmetrical Graphics and Graphics Reasoning Ability of students in the two groups are identical prior to the experiment (Table 1).

Table 1. Comparison of the experimental and the control group in pre-test

Group	Means	SD	F	T
Experimental group (n=44)	63.2	23.0	1.548	-0.361
Control group (n=46)	64.8	18.5		

*: p<0.05; **: p<0.01; ***: p<0.001

The researchers then examined students in the experimental group and control group after the former received 6 teaching sessions. A t-test analysis showed that the experimental group averaged 80.6, with a SD of 16.8, while the control group average 65.9, with a SD of 22.4. The post-test of the two groups showed significant difference as t=3.48 (p=0.0004). The statistical results are illustrated in Table 2.

Table 2. T-test of the post-test score for experimental group and control group

Group	Means	SD	T
Experimental group (n=44)	80.6	16.8	3.48^{***}
Control group (n=46)	65.9	22.4	

*: p<0.05; **: p<0.01; ***: p<0.00

Research results showed that after the Digital Origami Simulation Tool treatment, students in the experimental group have significantly higher scores than students in the control group. We should therefore promote this Digital Origami Simulation Tool to allow users to learn and observe by doing, and learn the concepts and applications of line symmetrical and graphic reasoning.

In addition, the researchers conducted an in-depth analysis of students' response in the Line Symmetrical Graphics and Graphics Reasoning. In the Table 3, of the Line Symmetrical Graphics' 14 questions, the 44 experimental group students had an average correct response rate of 86.16%, and 14 students had perfect scores. Of the Graphics Reasoning's 25 questions, students' average correct response rate was 79.47%, and no student had a perfect score. The above shows that students find operating Line Symmetrical Graphics very easy. Also, after confirmatory operation, students are better able to verify whether a response is correct.

Table 3. Summary of results of experimental group

Item	No.	Average correct response rate	Perfect scores
Symmetrical Graphics (n=44)	14	86.16%	14
Graphics Reasoning System (n=44)	25	79.47%	0

In addition, since the timed version of Graphics Reasoning provides the hint function, we further examined the behavior of students' response. In the Table 4, the 44 students in the experiment group spent an average of 182.8 seconds to complete the 25 questions and used the hint function an average of 1.4 times. In particular, 22 (50%) of the students did not use the hint function.

Table 4. Summary of results of Graphics Reasoning timed version

Average answering time	Average use hit	Without use hit
182.8	1.4	22 (50%)

A correlation analysis of the accuracy, time spent, and use of the hint function shows no significant relationships among the three variables. The analytic results are shown in Table 5.

Table 5. Correlation analysis of accuracy, time spent, and use of hint function

	Accuracy	Time spent	Use of hint function
Accuracy	-		
Time spent	-0.18	-	
Use of hint function	0.04	-0.12	-

*: p<0.05; **: p<0.01; ***: p<0.001

The improvement of the experiment group students in the post-test mainly comes from the learning results of the Digital Origami Simulation Tool. Although the system provides students with a limited number of hints, students' performance is not significantly correlated with the use of hint function. Therefore, if the hint function is taken out of the system, students' error rate would still be the lowest. Therefore, practical operation of the Digital Origami Simulation Tool can boost students' symmetrical and graphic reasoning abilities.

5 CONCLUSIONS

After 6 teaching sessions, the post-test performance of experimental group students reaches statistical significance. In other words, experimental group students shows significant improvement than the control group in terms of line symmetry, relative graphic position, spatial reasoning ability, and moving/rotation ability. Therefore, simulation learning can effectively help students establish the concepts of line symmetrical and graphic reasoning, learn from doing and observe, and learn by imperceptible influence. In addition, 50% of the students did not use the hint function but their error rate is still the lowest. This means that after taking the exercise, students can independently give responses without the support of the hint function. Although this experiment proves that the digital origami simulation system can effectively enhance students' line symmetrical and graphic reasoning abilities. The effect on other influential factors is unknown, e.g., simulation learning strategy, presentation of animated teaching materials, and hint function etc. We suggest that future studies achieve more in-depth research results by different methods like interviews and observations.

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6 REFERENCES

1. Chen, D., http://paper.people.com.cn/smsb/html/2007-4/03/content_12675356.htm
2. Yang, H.H., Yin, S.K., & Chen, P.Y.: Design and Implementation for the Web of Origami Simulator. Applied Mechanics and Materials, 536, 593-598 (2014).
3. National Council of Teachers of Mathematics (NCTM): The Principles and Standards for School Mathematics. Reston, VA. (1989).
4. National Council of Teachers of Mathematics (NCTM): Principles and standards for school mathematics. Reston, VA: NCTM. (2000).
5. Pellegrino, J. W., & Hunt, E. B.: Cognitive Models for Understanding and Assessing Spatial Abilities. Intelligence: Reconceptualization and measurement, pp.203-225 (1991)
6. McVey, M. D.: Understanding Concepts in Research Methodology: The Role of Spatial Ability. Research in Education, 65, 100-102 (2001).
7. Clements, D. H., & Battista, M. T.: Geometry and Spatial Reasoning. In Grouws, D. A. (Ed.), Handbook of Research on Mathematics Teaching and Learning. New York: Macmillan, pp. 420-464 (1992).
8. Yang, H. H., & Chen, P. Y.: The Design of 3D Origami Based on Tablet PC, 2013 Global Chinese Conference on Computers in Education (GCCCE), pp. 248-255 (2013).
9. Robinson, N.: The Encyclopedia of Origami: The Complete, Fully Illustrated Guide to the Folded Paper Arts. Running Press (2004).
10. Huzita, H.: Axiomatic Development of Origami Geometry. In Proceedings of The First International Meeting of Origami Science and Technology, 143, 143-158 (1989).
11. Robertson, J. M.: Geometric Constructions Using Hinged Mirrors. Mathematics Teacher, 79(5), 380-386 (1986).
12. Gibb, A. A.: Giving Geometry Students an Added Edge in Constructions. Mathematics Teacher, 75(4), 288-290 (1982).
13. Clements, D. H., SARAMA, J., & DiBiase A. M.: Preschool and Kindergarten Mathematics: A National Conference. Teaching Children Mathematics, 8(9), 510-515 (2002).
14. Wehman P., & McLaughlin, P. J.: Program Development in Special Education: Designing Individualized Education Programs. New York: Mc Graw-Hill (1981).
15. McGee M. G.: Human Spatial Abilities: Psychometric Studies and Environmental, Genetic, Hormonal, and Neurological Influences. Psychological Blletin, 86(5), 889-918 (1979).
16. Linn M. C., & Petersen A. C.: Emergence and Characterization of Sex in Spatial Ability: A Meta-analysis. Child Development, 56, 1479-1498 (1985)
17. Bishop, A. J.: Space and Geometry. In Lesh, R. & Landa, M. (Eds.). Acquisition of Mathematics Concepts and Processes. NY: Academic Press, pp. 175-203 (1983).

18. Yuzawa, M., Bart, W. M., Kinne, L. J., Sukemune, S., & Kataoka, M.: The Effect of "Origami" Practice on Size Comparison Strategies Among Young Japanese and American Children. Journal of Research in Childhood Education, 13(2), 133-143 (1999).
19. Hoffer, A. R.: Mathematics Resource Project: Geometry and Visualization. Palo Alto: Creative Publication (1977).
20. Joel B., http://www.joelbeckley. com/org-net/