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THE EFFECTS OF A NON-ROUTINE PROBLEM SOLVING INSTRUCTION ON THE 7TH GRADERS' BRAIN HEMISPHERICITY

Gizem YAPAR SÖĞÜT, Yeliz YAZGAN

Abstract: This study aims to evaluate the effects of a non-routine problem solving instruction on the brain hemisphericity of the 7th graders (aged 13-14 years). One sample experimental design was used and twenty-one seventh graders participated in the study. Validated by Kök (2005), Brain Hemisphericity Inventory (BHI) was conducted to the experimental group as a pre-test. Participants were given an instruction which lasted for 18 lesson hours, and participants solved 80 non-routine problems throughout the instruction. The BHI was then applied to the experimental group as a post-test.

The findings showed that there were significant differences between pre-and post-test scores of the participants. Although participants were mostly left-brained before the instruction, the number of left-brained participants decreased, and the number of right-brained students increased after the instruction. Findings indicated that non-routine problem solving may have a potential to change brain hemisphericity of the students. Based on that, it was concluded that amount of time and place given for non-routine problems in text-books and learning environments should be increased.

Key words: brain hemisphericity, brain dominance, non-routine problem, problem solving

1. Introduction

Including a vast number of neural networks, the brain is like a mine that still has many things to be explored. The sophistication of these neural networks plays a significant role in high order thinking activities such as critical, creative, logical, analytical, and reflective ones. All these thinking types are also essential for problem solving, which is another vital function of the brain (Lee, 2003).

The current study has two components. The first component, brain hemisphericity signifies the preference of an individual to process information through the left hemisphere or the right hemisphere or in combination (Springer and Deutsch, 1993). The left hemisphere is specialized in verbal, analytical, abstract, temporal, and digital operations. Hence, left hemispheric dominants think analytically, rely on language in thinking and remembering, give verbal reaction to instructions and explanations, like systematic and controlled experiments, and prefer precise information. The right hemisphere operates in a non-verbal, holistic, concrete, creative, analogical, and aesthetic fashion. On the other hand, right hemispheric dominants tend to be intuitive and spontaneous, rely on imaging in thinking and remembering, respond to demonstrated or illustrated instructions, like random and less restrained experiments, and prefer uncertain information (Singh, 2015). However, people's tendency to use either the left or right hemisphere does not indicate that they do not activate both hemispheres. Instead, people make both hemispheres active while they are processing the information (Roubinek, Bell, & Cates, 1987). Learning how to develop and integrate both sides of the brain is essential in today's world.

According to some researchers, brain hemisphericity is directly related to genes. However, the second group of researchers asserts that brain hemisphericity is determined by the culture and educational practices. From the latter group, Saleh and Iran- Nejad (1995) claims that practices in schools and culture emphasize the left hemisphere's analytical abilities. Therefore, the right hemisphere dominant

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students have difficulty in adapting to school life. To overcome this imbalance, activities in which both hemispheres work together should be performed in educational settings.

The second component is about competence in solving non-routine problems. A non-routine problem is "a cognitively non-trivial task; that is, the solver does not already know a method of solution" (Selden, Selden, Hauk, & Mason, 2000, p. 129). These kinds of problems call for high order thinking skills, and using facts and procedures in unfamiliar ways. On the contrary, “routine problems can be solved using methods familiar to students by replicating previously learned methods in a step-by-step fashion" (Woodward et al., 2012, p.11). Many math educators believe that non-routine problems are crucial for enhancing the reasoning skills of students (e.g. Cai, 2003, Polya, 1957; Schoenfeld, 1992).

Non-routine problem solving strategies are rules of thumb that might help individuals in solving non-routine mathematical problems. Although these strategies provide non-rigorous suggestions to achieve the solution, they are of paramount importance in the mathematical process experienced by individuals while solving non-routine problems. Besides, they can be employed through types of questions and topic areas, in contrast with algorithms. *Looking for a pattern, making a systematic list, working backward, guessing and checking, making a drawing or diagram, writing an equation or open sentence, simplifying the problem, making a table,* and *using logical reasoning* are the most common and well-known strategies in the literature (Herr & Johnson, 2002; Leng, 2008; Posamentier & Krulik, 2008).

1.1. Literature Review

Mathematics achievement and brain hemisphericity

The descriptive studies that examine relationship between brain hemisphericity and mathematical achievement without any intervention will be our starting point to overview the related literature. The education levels of the participants in these studies vary between eleventh grade and undergraduate. The authors of a few studies in this category make further investigations by focusing on a specific subject, such as algebra, Van Hiele geometric thinking levels or using graphics calculators. However, almost all findings reported in these studies show that there is not any significant relation between mathematical achievement and brain hemisphericity (Akay, 2013; Ali & Kor, 2007; Ferrer, 2015; Singh, 2015). In only one study carried out by Bhuvaneswari and Sarala (2015), the results indicate a statistically significant connection between brain hemisphericity and mathematics achievement.

There are some experimental/empirical studies related to brain hemisphericity and success in mathematics. Uyangör’s (2012) study aimed to examine the effects of the 4MAT teaching model on the 7th graders’ level of mathematics course achievement. Tatar and Dikici (2009) conducted a study similar to that of Uyangör (2012). However, their purpose was different: They examined the effectiveness of the 4MAT method of instruction given to 9th graders in teaching binary operations and its properties. Both studies found out that the 4MAT method of instruction can affect the students’ success and attitude in a positive way.

In summary, almost all findings of the related studies in this section have shown that there is no significant relationship between brain dominance and success in mathematics (or other special domains of mathematics). However, it seems that instruction that depends on learning styles that have been generated by the help of the relationship between brain and learning (e.g. 4MAT) can enhance the achievement.

Problem solving and brain hemisphericity

According to findings of early studies on the link between brain hemisphericity and problem solving, individuals’ brain hemisphericity echoes in their problem solving behaviors as well. For example, the left-brained children summarize the problem first, plan each stage elaborately, and then solve the problem. On the other hand, the right-brained children “read the problem several times, perhaps look at notes and seem to go through an idle period while mulling thoughts around, then solve the problem” (Creswell, Gifford, and Huffman, 1998, p. 119).

Recently, there are many studies that elaborate on brain activity during problem solving. For example, study of Dündar et al. (2014) aimed at investigating the brain activities of pre-service teachers with different cognitive styles in the process of solving various mathematical problems. Statistically significant differences were found between the two groups when brain waves of students with different styles were analyzed in terms of cerebral lobes. Different cognitive styles showed different brain activation in solving arithmetic problems. In their functional Magnetic Resonance Imaging (fMRI) study, Grabner, Ansari, Koschutnig and Reishofer (2009) also aimed at identifying brain areas supporting various strategies in arithmetic problem solving. The analyses revealed that recalling facts resulted in the more active use of the left angular gyrus, whereas an intense activation in a fronto-parietal network was observed during the implementation of procedural strategies. In another study by Newman, Carpenter, Varma and Just (2000), brain activities of undergraduate students were scanned using fMRI while they were solving "Tower of London" task. Findings showed that (1) while both the left and right prefrontal cortices were equally involved during the solution of moderate and difficult versions of the problem, the activation on the right brain was differentially attenuated during the solution of the easy versions of the problem (2) the activation observed in the right prefrontal cortex was highly correlated with individual differences in working memory; and (3) different patterns of functional connectivity were observed in the left and right prefrontal cortices.

Generally, the most recent studies related to brain-problem solving relationships use devices, such as EEG or fMRI, to see activated brain areas while participants are solving problems. It seems that no special part of the brain is liable for problem solving. Conversely, different brain areas may become active during problem solving, and this situation may be influenced from the factors such as cognitive styles of individuals, types and difficulty levels of problems, etc.

Non-routine problem solving and brain hemisphericity

Studies by Fernandez (2011) and Oliver (2009) deal with non-routine problem solving in conjunction with brain hemisphericity. In Fernandez (2011)'s study, the link between brain hemisphericity and mathematics achievement of high school students was investigated. A Hemisphere Dominance Questionnaire was used to establish the students' brain hemisphericity. The Mathematics Achievement Test consisting of two parts was utilized to have information about students' mathematics achievement levels. The first part included multiple choice questions, while the second part included non-routine problems. The results showed that the vast majority of the students were left-brained, and their mathematics achievement was close to the average. Students' mathematics achievement did not differ according to brain hemisphericity. The most relevant result in Fernandez's (2011) study is that writing an equation and making logical explanations are predominantly preferred by left-brained students, while the right-brained students opt for making diagrams and illustrations.

In the study by Oliver (2009), the question of whether there is any relationship between problem solving strategies and brain hemisphericity of ninth graders was sought. In this context, correlations between strategies used to solve an open-ended non-routine problem and the scores obtained from the Style of Learning and Thinking Questionnaire were examined. Similar to the findings of Fernandez (2011), left-brained students preferred to use a written logical explanation strategy, while right-brained students generally preferred to make drawings. As an exception, making a systematic list was not used by left-brained students as expected. Mostly right-brained students referred to this strategy.

Although their participants' class levels are different, both studies mentioned above pointed out differences between left and right-brained students' usage of non-routine problem-solving strategies. According to their results, it seems that left-brained students use more verbal and analytic strategies, such as writing an equation or making logical written explanation, while right brained students tend to use more visual strategies, such as making a drawing to solve non-routine problems.

1.2. Importance and the Aim of the Present Study

Although there have been various experimental and descriptive studies related to the relationships between brain hemisphericity - academic achievement and brain hemisphericity – problem solving, the studies elaborating on relations between non-routine problem solving and brain hemisphericity are really rare and do not have an empirical stance. Therefore, the present study intends to investigate the effects of a learning environment that features non-routine problems on brain hemisphericity of students at the seventh grade level in Turkey.

1.3. Research Question

Does an instruction that focuses on non-routine problem solving have any significant effects on the 7th graders' brain hemisphericity? If so, in what way?

2. Method

2.1. Research Model

In this research, a one-sample experimental design was used. In this design, it is studied with a person or a group in a given period without a control group. That is, a single group is measured or observed not only after being exposed to a treatment of some sort, but also before (Fraenkel & Wallen, 2008). Within the context of this research model, in the current study, the Brain Hemisphericity Inventory (BHI) was administered to the experimental group as a pre-test to find out participants' brain hemispheric dominance before instruction. After instruction, the BHI was applied to participants again as a post-test. Namely, our findings were based on each student's brain hemisphericity score before and after the experimental part.

2.2. Participants

Twenty one seventh graders (8 females and 13 males) participated in this study. The students were aged 13-14, and they were attending a state school in Turkey in a region that had an average socioeconomic level. The first author was the teacher of an optional "Applied Mathematics" course of the participants. This course was used to implement the experimental/empirical part of this study. Therefore, convenience sampling was used. Convenience sampling is a method that involves "choosing the nearest individuals to serve as respondents and continuing that process until the required sample size has been obtained or those who happen to be available and accessible at the time" (Cohen, Manion, & Morrison, 2007, p.113-114).

2.3. Instrument and Scoring

BHI, adapted by Davis, Nur, and Ruru (1994) and translated into Turkish by Kök (2005), was utilized to identify the brain hemisphericity of students. There were 39 items in the instrument. The reliability and validity of Turkish version of BHI was checked by Kök (2005) as follows: Firstly, the views of three field experts who had used BHI before were taken for the content and face validity. Then, four different people translated the instrument into Turkish, and final version of BHI was commonly formed. Later, four versions of BHI were conducted to four groups, consisting of 200 prospective teachers in all. In the first version, the first 20 items were in English while the others were in Turkish. In the second version, the languages of the items in the first version were reversed. The third version was entirely in English, while all items were in Turkish in the fourth version. Three weeks later, the same process was carried out again, and cross-checks were made. By implementing the test-retest method to a different group of English prospective teachers, Kök (2005) computed the Cronbach's Alpha coefficient of the final Turkish form of the BHI as .87.

Since the content and face validity of BHI was provided by Kök (2005), we did not perform so much detailed procedure in this study again. Still, we tried to determine whether BHI was understandable and appropriate for the secondary school students as well as to demonstrate the reliability of it for the present study. Therefore, the BHI was given to 172 randomly selected students (59 fifth, 57 sixth, 56 seventh graders) who were not included in the experimental group although they were attending the same school. As a result of this process, which was completed before the instruction stage, a Cronbach Alpha coefficient was computed as .698, which is very close to the acceptable level (.70). Besides, it was observed that students had no difficulty to answer items in BHI.

There are three options in each item in the BHI as A, B, and C (see Appendix A for sample items). First, the number of A, B, and C answers of a student were counted. The number of A's was subtracted from the number of B's. After, the number of C's was checked. The result was divided by 3, if the number of C's was greater than 16. The result was divided by 2, if the number of C's was greater than 9 and smaller than 17. Otherwise; the result was used as it was. After all, the score rounded the closest integer. Negative scores were correlated to left-brained, while the positive scores were correlated to right-brained. Finally, zero points indicated whole-brained. The meanings of points were given below:

0: Equal usage of both hemispheres

From 1 to 3: Slight Right

From 4 to 6: Moderate Right

From 7 to 9: Dominant Right

From 10 to 11: Very Strong Dominant Right

From -1 to -3: Slight Left

From -4 to -6: Moderate Left

From -7 to -9: Dominant Left

From -10 to -11: Very Strong Dominant Left

2.4. Instruction Phase

After the literature review about non-routine problems and the strategies used to solve these kinds of problems, a question bank was set for the *guessing and checking, working backward, looking for a pattern, making a drawing or diagram, simplifying the problem* and *making a systematic list* strategies. Eighty questions chosen from this bank (see Appendix B for samples) were used through the instruction.

Instruction lasted for 18 lesson hours (two lesson hours in each week) and was carried out in the students' own classroom environment. Students generally worked in pairs while they were solving problems. The main reason for making students work in pairs is to alleviate environmental pressures that might weight on students as they solve problems individually. Another reason is that working in pairs often provides better information about individual students' problem solving processes than do working individually (Schoenfeld, 1985). At the beginning of the instruction, each week was allocated for only one of the strategies. Then, students dealt with problems that could be solved by using different strategies in a mixed way in the last three weeks.

During instruction, each problem to be solved was first presented to students as written texts. While students were trying to solve the problem in pairs, the researcher walked around groups and checked whether the problem to be solved was understood clearly by the students. When students had difficulty in understanding or having an enterprise to solve the problem, leading questions were asked students, and some clues were given to make problems clear. After that, different solutions found by the pairs of students were presented on the board and classroom discussions were generated about solutions. Later, all scripts of students were collected, and a new problem was presented to them. At the end of the lesson, students were asked to review their solutions and give a name for the solution methods which they used throughout the lesson. After students shared the names they determined, a common name was determined for the strategy of the day by the whole class.

2.5. Data Analysis

According to the scoring system of the BHI, each student's brain dominance score and category were first established based on his/her pre-and post-test. Then, frequencies and percentages for each category were computed to hold a general view on development of students from pre-test to post test. Meantime, since the total number of participants is fewer than 30, (N = 27) the Shapiro-Wilk Test was used to calculate the normality of data. Then, the Wilcoxon Signed Rank Sum Test was used to investigate the effects of the instruction on the students' brain hemisphericity.

3. Results

As phrased in Data Analysis section**,** distribution of the data was examined by the Shapiro-Wilk test to select the appropriate statistical analysis method. Test results are presented in Table 1**.**

Table 1. *Shapiro-Wilk test results*

Statistics	df	Significance
.88	21	.009

The test results shown in Table 1 indicated that the data distribution was not normal ($p<.05$). Consequently, the non-parametric Wilcoxon Signed Rank Sum Test was used to analyze the data collected from the students (see Table 2).

Table 2. *The results of Wilcoxon Signed Rank Sum Test*

Pretest – Posttest	N	Rank Average	Sum of Rank	z	p
Negative Rank	5[a]	6.00	30.00	-2.211[d]	.027
Positive Rank	12[b]	10.25	123.00		
Equal	4[c]	-	-		

a. Post test < Pre test b. Post test > Pre test c. Post test = Pre test d. Based on negative ranks

Wilcoxon Signed Rank Sum Test results indicated a significant difference between the students' BHI scores before and after the instruction ($Z = -2.211$, Sig. = .027, $p< .05$).

To have more in-depth information about the direction of change in students' brain hemisphericity, frequencies and percentages about each brain dominance category were calculated for both pre- and posttest. Results can be seen in Table 3.

Table 3. *Frequencies and percentages about students' brain hemisphericity before and after instruction*

	Before Instruction		After Instruction	
Brain Hemisphericity	Frequency	Percentage	Frequency	Percentage
Both equally	2	9.5	3	14.3
Slight Left	9	42.9	8	38.1
Moderate Left	6	28.6	1	4.8
Dominant Left	1	4.8	2	9.5
Very Strong Dominant Left	1	4.8	0	0
Slight Right	2	9.5	5	23.8
Moderate Right	0	0	0	0
Dominant Right	0	0	2	9.5
Very Strong Dominant Right	0	0	0	0
Total	21	100.0	21	100.0

According to Table 3, there were 17 left-brained, two right-brained, and two whole-brained students before the instruction. On the other hand, while the number of left-brained students dropped to 11, number of right-brained students reached seven, and the number of whole-brained students arrived at 3 after the instruction. In the light of these results, it can be said that the numbers of the left and right -brained students were more close to each other and the group was more homogeneous in terms of brain hemisphericity subsequent to the instruction. When the values given in Table 2 are looked over based on each category, changes of the moderate left and slight right categories from pre-test to post-test are remarkable. The dominant left category is the only one in which a decrease is observed contrary to general tendency.

Speaking in detail, five left-brained, one whole-brained, and one right-brained student did not change their brain hemisphericity throughout instruction. That is, given instruction did not have any effect on seven participants' brain hemisphericity. The other seven of participants completely changed their brain dominance at the end of instruction. Six of these changes were from left to right, while only one shift from right to left was observed. Five participants' left brain dominance decreased, two of them were whole-brained when instruction was completed. On the contrary, two students' left brain dominance increased. One of them was whole-brained before instruction, but he became left-brained after the instruction.

5. Conclusion

The current study aimed at evaluating the influence of an instruction founded upon non-routine problem solving on the brain hemisphericity of 7th graders. The results implied that non-routine problem solving could have a potential to change brain hemisphericity of students. This was the most important contribution of this study to the literature relevant to the linkage between mathematical problem solving and brain hemisphericity.

As well as the significant changes on the brain hemisphericity of participants, general inclination of these changes was another important aspect of our research. Speaking in more detail, most of the participants were left-brained before the experiment as expected. After instruction, the number of left-brained students decreased by around 35%, while the number of right-brained students increased by 250%. The increase in the number of 'whole-brained' students was 50%. These results were striking since they provided evidence of the experiment's effects on students' brain dominance.

This study had some different dimensions when compared to other studies discussed in the literature. The first distinctive dimension was that it used non-routine problem solving. However, studies by Oliver (2009) and Fernandez (2011) were akin to the present study in this respect, but the numbers of non-routine problems solved by the participants were quite low in these studies. For example, Oliver (2009) used only one non-routine mathematical problem that allows for variation in the strategies to achieve the correct answer. However, this was understandable since studies of Oliver (2009) and Fernandez (2011) were not experimental and had not any aim related explicitly to changes in students' brain dominance. On the contrary, participants of the present study solved many more (eighty) non-routine problems throughout instruction. More to the point, the richness of the strategies that can be exploited to solve these problems was another notable difference. We tried to guarantee that participants could equivalently deal with each of the six strategies that were chosen for this study. The results showed that the number and variety of problems solved during the implementation was enough to have an effect on the brain dominance of the students. The most remarkable evidence of this effect was the complete change in brain hemisphericity of one-third of the participants. As stated before, the use of a variety of strategies during intervention could be a plausible explanation for this situation. For example, one of the students who changed his brain hemisphericity from left to right did not refer to *making a drawing* strategy very often at the start of the implementation. However, after the introduction of this strategy, he increasingly employed it in the course of implementation. Considering *making a drawing* strategy call for effective use of the right hemisphere, it seems that this student expanded his strategy repertoire through implementation and started to use his non-dominant sphere more effectively.

The second distinctive dimension of the current study was that it had an experimental/empirical base. Its uniqueness in this respect made it hard to compare the findings of this research with others. However, results of this study could be compared to those of experimental studies that examined the effects of an instruction based on hemispheric dominant styles of learning on the general mathematical achievements of participants. In this context, Uyangör (2012), Tatar and Dikici (2009) also pointed out the positive effects of the instruction, as found in this study.

As Creswell et al. (1988) emphasized, "The brain operates the best when the cognitive processes which problem demands are of sufficient complexity to activate both hemispheres. Thus, simple repetitive and uninteresting namely routine problems would be poorly learned, with little benefit for either hemisphere. (p.123)" For this reason, we have chosen the non-routine problems for the current study. Findings proved that these kinds of problems might provide an opportunity for activating non-dominant hemisphere. Based on that, it can be said that the amount of time and place given for non-routine problems in text-books and learning environments should be increased. Besides, awareness of in-service and pre-service teachers on non-routine problem solving should be raised so that they can be eager to use mathematical non-routine problem solving as a way or tool for enhancing thinking skills of students.

5.1. Limitations of the Study

One of the most critical limitations of the study is the lack of a control group. This situation makes difficult to attribute the obtained change to the given education. We tried to compensate this deficiency by providing more detail about the changes in brain hemisphericity of the participants. For further research, an experimental design with a control group would help to see the effect of instruction more clearly. With comparatively large numbers of students, and by allocating longer time for instruction, better results or validation of the results suggested here may be attainable. For example, a greater increase in the number of whole-brained students would be a more desirable finding for our research. This point may be addressed in the future studies. Replicating this study with students from different grade or age levels would provide greater comparative power. A possible step for future research could be to determine if any correlation exists between changes in students' strategy usages and changes in their brain hemisphericity. Perceptually diagnosing or determining brain hemisphericity may be misleading. Therefore, a different method (such as neuroimaging or visual field tests) would provide more insight to brain hemisphericity of the participants and to what changes occur in their brain while solving problems. Lastly, working in pairs introduces a whole lot of social and personal variables that our study does not address. Keeping all other conditions the same, another study in which students work individually during instruction can be designed so that results can be compared to that of the current study.

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Appendix A: Sample items from BHI

13: I am:

__a. easily lost in finding directions, especially if I have never been to that place before.
__b. good at finding my way, even when I have never been in that area.
__c. not bad in finding directions, but not really good either

18. I am good at:

__a. explaining things mainly with words.
__b. explaining things with hand movements and action.
__c. doing both equally well.

Appendix B: Samples from non-routine problems used in the instruction

- What is the sum of the numbers in the 29th row of the following array?

$$
\begin{array}{c}
1 \\
3 \quad 5 \\
7 \quad 9 \quad 11 \\
13 \quad 15 \quad 17 \quad 19 \\
21 \quad 23 \quad 25 \quad 27 \quad 29 \\
31 \quad 33 \quad 35 \quad 37 \quad 39 \quad 41
\end{array}
$$

- There is a frog at the bottom of a well that is 10 meters deep. The frog laboriously climbs upward 4 meters during the daytime. However, at night, he fells a sleep and slips back 1 meter. At this rate, how many days will it takes for the frog to get out of the well?

- There are 6 points, no three of which lie on the same line. How many straight line segments are needed to connect every possible pair of dots?

Authors

Gizem YAPAR SÖĞÜT, Ministry of National Education, Bursa (Turkey), e-mail: gzmypr@hotmail.com

Yeliz YAZGAN, Uludağ University Education Faculty, Bursa (Turkey), e-mail: yazgany@uludag.edu.tr

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