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Promoting children's procedural knowledge in problem solving via metacognition

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The current study was aimed at examining the importance of procedural knowledge in the context of metacognitive instruction in problem solving. Participants were 38 Greek Year 3 children, half of which were assigned to metacognitive instruction (experimental group) while the others were not (control group). Results indicated that students who were exposed to metacognitive instruction outperformed their counterparts on procedural knowledge, whereas before the intervention there was not such a difference between the two groups. Educational implications for metacognition in mathematical problem solving are discussed.

Keywords: Metacognitive instruction, procedural knowledge, problem solving.

Introduction

Children's mathematical achievement has captured an increasing amount of attention in the mathematical problem-solving literature, possibly because children who rely more on their problem-solving ability seem to be advantaged in general mathematics performance. Nowadays, there is a clear consensus that metacognition is involved in children's mathematics achievement, especially in problem solving (Lee et al., 2014). However, current school practice seems to hinder the development of metacognition. This study, as part of a larger research project, tries to highlight the importance of a particular facet of metacognition, that is, procedural knowledge, since its role to problem-solving success is ignored and knowing that there is a lack of metacognitive instruction, especially at a primary level in Greece (e.g., Mocos & Kafoussi, 2013; Vissariou & Desli, 2019).

Metacognition has been mostly defined as knowledge about one's own cognition and regulation of cognitive activities and includes three main facets: metacognitive knowledge, metacognitive skills and metacognitive experiences (e.g., Aşık & Erktin, 2019). Metacognitive knowledge, considered as the knowledge about the interplay between person, task and strategy in a learning situation (Flavell, 1979), is divided into three interrelated types of knowledge: declarative, procedural and conditional knowledge. Declarative knowledge refers to "what" is known about the world and the influencing factors of human thinking (e.g., strengths, weaknesses, beliefs, etc.). Procedural knowledge can be described as the knowledge of "how" declarative knowledge is to be applied, in order to address task demands. It regulates and co-ordinates the skills required for task completion and success. It is also called "metastrategic knowing", since it involves the procedural strategy knowledge of the application of strategies which facilitate the realization of a problem's goal (Kuhn, 2000). Conditional knowledge involves knowing "when and why to use declarative and procedural knowledge" (Schraw, 1998, p. 114). Similarly to all kinds of metacognitive knowledge, procedural knowledge is influenced by person, task and strategy variables (Ellis et al., 2014). For

example, strategy selection, application, alternation and transferability affect person's self-concept as a problem solver (e.g., beliefs, positive or negative, about oneself as a learner) and task knowledge (e.g., beliefs about task difficulty).

Montague (1992) claimed that procedural knowledge is necessary for the effective application of declarative knowledge, as well as the co-ordination of cognitive and metacognitive procedures in problem solving. Through experience procedural knowledge can become unconscious and automatic process, especially in familiar problems. Children with well developed procedural knowledge are able to monitor and regulate their actions when working on a problem, use strategies effectively and are aware of their progress during problem solving. As Desoete (2009) indicates, self-monitoring can take place either before, during or after a learning procedure and improves children's prediction and evaluation skills, respectively. Prediction skills assist children to anticipate task difficulties and to associate certain problems with other similar problems. Evaluation skills enable them to assess their own performance and to recognize errors within the problem-solving process.

Considering metacognition as an important predictor for mathematics performance, several instructional approaches have been developed aiming at improving children's metacognition in mathematical problem solving (Desoete & De Craene, 2019). Such interventions promote children's self-regulatory and control skills, help them activate their knowledge and justify their actions and conclusions (e.g., Shilo & Kramarski, 2018). In the current study, we focused on one particular aspect of metacognitive knowledge: the procedural knowledge and its development in non-routine problem solving due to a new instructional model based on the metacognitive teaching scheme STARtUP proposed by Lee et al. (2014). The new model gives emphasis on the procedural facet of problem-solving process, for the activation of which procedural knowledge is a prerequisite. In view of the appreciation of procedural knowledge in mathematics education, which, however, is insufficiently examined in primary school level, the present study aimed to investigate the impact of metacognitive instruction on third graders' procedural knowledge in non-routine problem solving. The research questions are as follows: a) to what extent does metacognitive instruction improve the procedural metacognitive knowledge of third graders? b) does school performance after instruction affect procedural metacognitive knowledge?

Method

Participants

Participants were thirty eight Year 3 children (20 male), being evenly recruited from two state primary schools located in districts with varying socioeconomic and academic statuses in Greece. Their average age was 8 years and 3 months at the beginning of the study. The participating children from one school were assigned to metacognitive instruction for four months (experimental group), whereas children from the other school were not (control group). They were also classified by their mathematics teachers into three sub-groups according to their mathematics performance, those with low, average and high performance.

Research design and data collection instrument

Following a questionnaire-based quasi-experiment design, all participants were presented with a self-report questionnaire which was constructed on the basis of the “H.I.S.P.” (Sperling et al., 2002) and “Metacognition Scale” (Yildiz et al., 2009) inventories. The questionnaire aimed to assess the level of children’s metacognitive procedural knowledge and consisted of nine statements covering a range of likely metacognitive actions about procedural knowledge before and after problem solving process (Figure 1). Children were advised to read carefully each statement and choose the answer that best describes the way they are working on a problem using a five-point Likert scale (1=never, 2=rarely, 3=sometimes, 4=often, 5=always). The validity and the reliability of the statements were checked in the pilot study, after which careful modifications were made in order the statements to be fully understood by the participants, according to their age and cognitive level.

1. I try to use solution methods that have been proven effective for me earlier in problems.
2. I distinguish the important information from the less important in a problem.
3. When I read a problem, I know what steps I will make to solve it.
4. I solve a problem better, when I am interested in its subject.
5. I pay attention to what the problem asks.
6. To solve a problem, I try to connect it with situations from my everyday life.
7. I try to remember if I have solved a problem like this again.
8. I try to formulate the problem in my own words.
9. I think different solution methods depending on the type of problem.

Figure 1: The statements for procedural knowledge

Procedure

At the beginning of the school year, all participants were asked to fill in the questionnaire individually in their classroom (pretest) during one teaching hour (45 minutes). The experimental group was then exposed for four months to a new model of metacognitive instruction (STARtUP, Lee et al., 2014) which concentrates on teaching strategies, is appropriate for rich mathematical tasks, like non-routine problems and focuses on the first stages of problem-solving process (Understand and Planning). Every week students were engaged in solving two mathematical tasks, accompanied by metacognitive questions answered in writing (e.g., “How can I represent this problem?”, “Do I have all the necessary information?”, “What would be the best first step to take?”, etc.). Specifically, before beginning to solve a problem, children were asked to work on the information given, identify which of them are the most important, understand its goal, make a solution plan, choose the solution method, etc. Similarly, as they worked on a problem, children were asked to implement the plan they had devised before, monitor their progress, change their strategy when needed, identify any mistakes and try to revise them appropriately, check the time remaining for the solution, etc. After they finished working on a problem, children were asked to review and reflect the whole procedure of the problem-solving process. The worksheets were collected at the end of each problem instruction and generic feedback on students’ solutions was

given. During the intervention, students were presented with a total of 32 non-routine problems and generic feedback on their solutions was given. However, metacognitive instruction will not further be described, as it goes beyond the purpose of the present paper. The control group received traditional instruction, using the mathematics textbooks of the Greek Ministry of Education. After the intervention, a post-test identical to pretest was administered to both groups.

Results

Procedural knowledge

In order to examine whether experimental group children differed in their responses from control group children regarding the statements of procedural knowledge before the instruction, an independent samples t-test was conducted. The analysis revealed no statistical significant differences [$t(36)=1,93, p=.072$]: both groups children responded in a similar way (experimental group: $M=2,84, df=36$, control group: $M=2,54, df=36$), and most of their responses were “rarely” and “sometimes”. On the contrary, in the second measurement (after the instruction), the same analysis revealed statistically significant differences [$t(36)=8,48, p<.001$]: experimental group children answered more positively ($M=3,47, df=36$) compared to control group children ($M=1,87, df=36$), with most of their responses being between “sometimes” and “often” (Table 1). More specifically, the highest mean level was reported at statements 4 and 5: the majority of experimental group children stated that they often/always *solve a problem better, when they are interested in its subject* and *pay attention to what the problem asks* ($M=4,11$ and $M=3,89$, respectively). These findings indicate that the subject and the goal of a problem are issues of great importance for the participants of experimental group. For the control group children, the highest mean level observed was at statements 1, 2, 3 and 5: most children stated that they rarely *try to use solution methods that have been proven effective for them earlier in a problem* ($M=2,05$) or *distinguish the important information from the less important in a problem* ($M=2,11$). Furthermore, they rarely *know what steps they will make to solve a problem when they read it* ($M=2,05$) and sometimes *pay attention to what the problem asks* ($M=2,32$).

In order to examine the effectiveness of the teaching method, children’s responses were subjected to a mixed model ANOVA in which the instruction (2: experimental and control group) was the between subjects factor and the time of testing (2: before and after the instruction) was the within subjects factor. The interaction instruction by time of testing was significant ($F_{(1, 36)}=30,280, p<.001, \eta_p^2=.457$), indicating that the difference between children’s responses before and after the instruction was not the same for experimental and control group children. More specifically, metacognitive instruction improved experimental group children’s procedural knowledge, whereas traditional instruction did not result in any improvement in control group children’s procedural knowledge. This interaction is presented in Figure 2.

Table 1: Mean scores (and standard deviations) for procedural knowledge items before and after the instruction

Statements	Experimental group		Control group	
	Mean (Before)	Mean (after)	Mean (before)	Mean (after)
1	2,89 (1,150)	3,79*** (,976)	2,67 (,688)	2,05 (,780)
2	3,21 (1,228)	3,63*** (1,165)	2,82 (,820)	2,11 (,875)
3	2,32 (1,108)	2,95** (1,026)	2,26 (,653)	2,05 (,848)
4	3,63 (1,300)	4,11*** (,994)	2,79 (,713)	1,84 (,602)
5	3,58 (1,170)	3,89*** (,937)	3,11 (,809)	2,32 (,749)
6	2,32 (1,057)	3,37*** (1,383)	2,05 (,621)	1,53 (,612)
7	3,26 (1,408)	3,32*** (1,204)	2,95 (,705)	1,84 (,765)
8	2,21 (1,032)	3,53*** (1,264)	1,79 (,787)	1,47 (,612)
9	2,16 (1,425)	2,63** (1,342)	1,89 (,737)	1,63 (,684)

*Significant correlation at the $p < .05$ level, **Significant correlation at the $p < .01$ level, and ***Significant correlation at the $p < .001$ level.

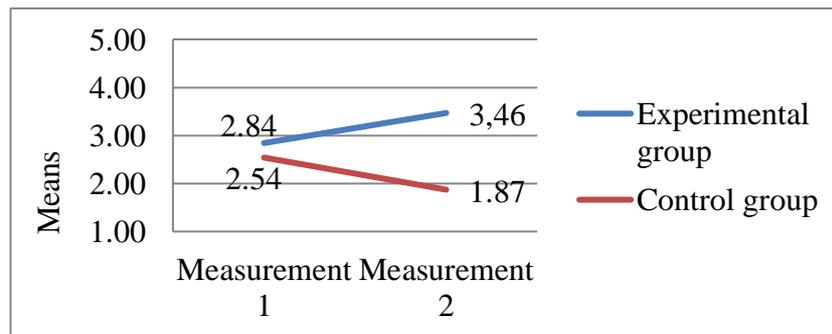


Figure 2: Children's procedural knowledge before and after the instruction

Procedural knowledge and school performance

Statistical significant differences were observed between children's responses and their school performance before the instruction for the total of children ($F_{(2, 35)}=1,569, p < .05$) as well as for each group separately ($F_{(2, 16)}=3,092, p < .05$ and $F_{(2, 16)}=2,952, p < .01$, for control and experimental group, respectively). Tukey post hoc tests showed that these differences were due to children with high performance, who showed significantly higher means than children with low performance ($p < .05$). However, the Anova analysis conducted after the instruction revealed significant differences only for control group children ($F_{(2, 16)}=12,295, p < .01$). Children with high performance had significantly higher means than children with average ($p < .01$) and low ($p < .001$) performance. On the contrary, such differences were not confirmed for experimental group children ($F_{(2, 16)}=1,605, p = .232$),

indicating that for them the level of school performance did not influence their procedural knowledge.

General Discussion

The current study tried to shed some light on the importance of procedural knowledge at primary level problem solving, which seems to be ignored in Greek school practice. We studied this by exploring the effectiveness of a metacognitive instruction on third graders' procedural knowledge during mathematical problem solving.

The analysis of children's responses revealed two main findings. First, despite the fact that children's procedural knowledge in both groups was at approximately the same level before the intervention, experimental group children improved their procedural knowledge on the post-test, whereas traditional instruction in control group did not result in any improvement. This finding supports prior research findings according to which the development of metacognition cannot be considered as a given in the absence of metacognitive instruction (Desoete & De Craene, 2019). Interestingly, various qualitative characteristics were observed in experimental group children's written responses, highlighting the role of procedural knowledge during all stages of problem solving. For example, when a female student of average performance attempted to solve a non-routine problem (*"In a small village live 15 families. Each family has either one, either two, either three children. More specifically, as many families have one child, so many others have three children. How many children are there in the village?"*) after the intervention, she came up with seven different ways, all of which led her to a correct solution, whereas before the instruction she did not manage to find any solution. As can be seen in Figure 3, for each of the ways she presented she drew the relevant table. Therefore, her well developed procedural knowledge resulted in the correct use of strategies (drawing tables, visual representation of the givens) and in a sequence of steps and actions that led her to the problem solving success.

Second, children's procedural knowledge was found to be related to their school performance in different ways for children who received metacognitive instruction and those who did not. While high-achieving children showed more advanced procedural knowledge than average and low achievers in both groups of participants before the instruction, it was metacognitive instruction that brought some mitigation to these differences. More specifically, although all children in the experimental group benefited from metacognitive instruction and increased their procedural knowledge, those with low and average school performance benefited the most as they managed to close their differences with high achievers. On the other hand, traditional instruction maintained the initial differences between school achievement and procedural knowledge to the advantage of high achievers. This finding gives prominence to previous findings according to which metacognitive instruction is more effective for children with low mathematical performance (e.g., Cornoldi et al., 2015).

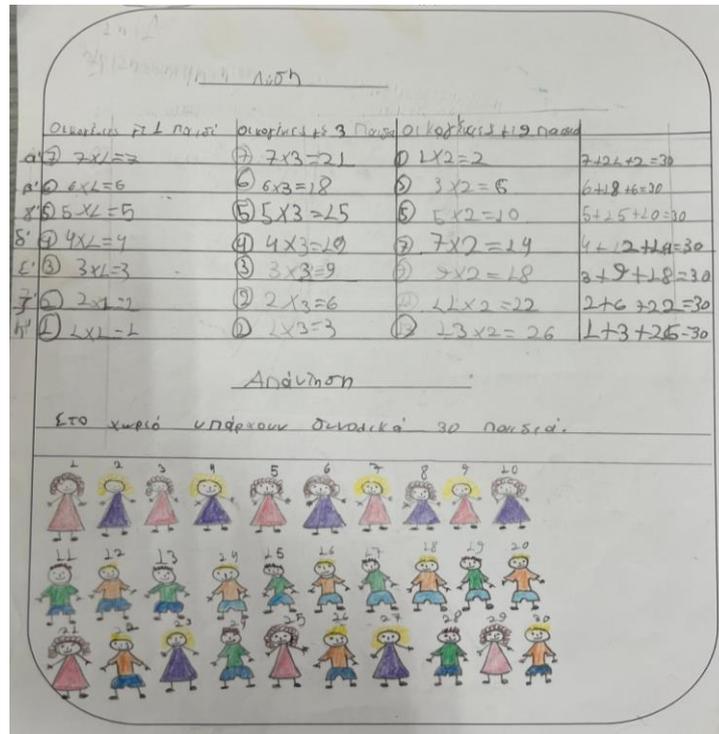


Figure 3: A student's solution after the instruction

These results should be interpreted with care, since there are some limitations to the present study. First of all, the small sample size should be acknowledged. Future research can be conducted with a larger sample size that can provide more conclusive results. Additionally, from a methodological perspective, it is important to note that a self-report questionnaire as the one used in the present study might provide only a little about children's procedural metacognitive knowledge (Winne, 2010). Last, it should be taken into account the fact that children in the control group were not exposed to non-routine problems and were not expected to show an improvement in their procedural knowledge. Therefore, it would be interesting for future research to focus on changes in children's procedural knowledge within routine problem solving processes, which might provide another perspective on procedural knowledge and metacognitive knowledge in general. Last, it would be interesting for future research to focus on declarative and conditional knowledge, in order an overall view of children's metacognitive knowledge to be obtained.

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