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Development of Pre-service Teachers' Perceptions of Using Metacognitive Skills in Teaching and Learning Mathematics

Wajeeh DAHER
An-Najah National University

Nimer BAYA'A
Al-Qasemi Academic College of Education

Ahlam ANABOUSY
Al-Qasemi Academic College of Education

Otman JABER
Al-Qasemi Academic College of Education

Abstract: In the present research, we educated mathematics pre-service teachers in using metacognition in their teaching of mathematics. This education was performed in one-year and was part of the participants' practical training in the training schools and in the frame of a reflection-based course related to the practical training. We studied the development of pre-service teachers' perceptions of using metacognition in teaching and learning mathematics. Twenty four pre-service teachers participated in the preparation. They were in their third academic year majoring in teaching mathematics and computer science in middle schools. We held interviews with the participating pre-service teachers twice, once at the beginning of the preparation and once at the end of it. To analyze the interview transcripts, we used inductive and deductive content analysis. The research results indicate that the participants developed their perceptions regarding metacognition and its use in students' learning, but at the same time, due to the time pressure, they intend to use mainly the 'planning skill' in their teaching of mathematics.

Keywords: Metacognition, Metacognitive skills, Mathematics teachers, Pre-service teachers

Introduction

One aspect of students' learning which researchers are taking care of in recent years is the metacognitive aspect. Metacognition makes students aware of their learning, where this awareness supports the internalization of what one learns (Belet & Guven, 2011). This awareness makes students consider how to answer problems posed in the classroom. The advantages of metacognition for students' learning make it necessary that colleges attempt to prepare pre-service teachers, so that they develop their knowledge of applying metacognition for teaching. This development is expected to develop also their perceptions of metacognition in teaching and learning. In the preparation that the present research reports and assesses, we intended to develop the metacognitive skills of mathematics pre-service teachers in addition to their use of metacognition in teaching mathematics. It is our intention to assess, through interviewing the participating pre-service teachers, the development of perceptions of metacognition for the teaching and learning of mathematics.

Literature Review

Researchers considered metacognition as cognition about cognition or knowledge about knowledge (Flavell, 1976; Panaoura, Philippou & Christou, 2003; Veenman, Van Hout-Wolters, & Afflerbach, 2006). Flavell (1976) was the first to use the term 'metacognition', which refers to the individual's awareness and control of his/her

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cognitive processes and strategies. Du Toit and Kotze (2009) argue that the various definitions of metacognitive processes in the literature, including that of Schoenfeld (1992), emphasize the monitoring and regulation of cognitive processes. Flavell (1999) described metacognition as 'knowledge that takes as its object or regulates any aspect of any cognitive endeavor' (p. 8). Furthermore, Panaoura et al. (2003) say that it coordinates cognition, affecting it and, as a result, affecting students' academic success. All the definitions and descriptions consider metacognition as the management of cognition.

Veenman et al. (2006) argue that the most common distinction in metacognition distinguishes between metacognitive knowledge and metacognitive skills. Flavell (1999) defines metacognitive knowledge as the knowledge about the factors that act and interact to affect the course and outcome of cognitive enterprises. These factors include the person, the task and the strategy. The person factor concerns what a person believes about himself/herself and other people as cognitive processors. The task factor concerns the information about the object available to a person during a cognitive enterprise, where different tasks entail different mental operations. The strategy factor involves knowledge about effective strategies in achieving goals and their cognitive undertakings.

Metacognitive skills in which the present research is interested refer to a person's procedural knowledge for regulating one's learning activities including problem solving (Brown & DeLoache, 1978; Veenman, 2005). Moreover, these skills are implied in Flavell (1976) referring to metacognition as the active monitoring, the consequent regulation and orchestration of processes performed on cognitive objects. They are also implied in Bonds, Bonds and Peach (1992) statement that metacognition is the regulation, evaluation, and monitoring of one's thinking. So, generally speaking, metacognitive skills are concerned with planning, monitoring, evaluating, orchestrating, reflecting on and controlling one's learning and cognitive processes.

In addition, researchers suggested ways to encourage students to use metacognitive processes (e.g., Spiller & Ferguson, 2011). Flavell (1979) emphasizes that metacognition improves with practice. Schoenfeld (1992) describes ways that students can practice to monitor and evaluate their performance on math problems. For example, pause frequently during problem solving to ask themselves questions such as "What am I doing right now?" Spiller and Ferguson (2011) say that if we want students to use metacognitive processes, we need to encourage them to consider the nature and sequence of their own thinking processes. Chauhan and Singh (2014) say that as students become more skilled at using metacognitive strategies, they become confident and more independent as learners. This independence leads to ownership as students realize their ability to answer and pursue their own academic needs.

Metacognition in Learning Mathematics

Metacognition has attracted the attention of mathematics education researchers. Schoenfeld (1992), as described above, suggests ways that students perform to use metacognition in mathematical problem solving. Barbacena and Sy (2015) examined university students' use of metacognitive skills in mathematical problem solving and found that the students exhibited metacognitive awareness, metacognitive evaluation and metacognitive regulation that operated as pathways from one to another metacognitive function. Moreover, Awawdeh-Shahbari, Daher and Rasslan (2014) investigated the relationship between mathematical knowledge and cognitive and metacognitive processes exhibited by students from Grades 6, 7, and 8 who engaged in a set of model-eliciting activities. The results of the study showed that the highest percent of cognitive processes and lowest percent of metacognitive processes occurred amongst the Grade 6 students, while the lowest percent of cognitive processes and highest percent of metacognitive processes occurred amongst the Grade 8 students. The Grade 6 students' metacognitive processes were more awareness than regulation and evaluation skills. Conversely, the Grade 7 and 8 students employed more regulation and evaluation processes. Furthermore, Daher, Anabousy and Jabarin (2018), studying the relations between the social aspect, the metacognitive aspect and the cognitive aspect of students' learning found that most of the means of claiming leadership were metacognitive in nature and were performed to enable the advancement of the group learning of the mathematical topic. The contribution of the metacognitive skills and knowledge to students' learning makes it necessary for educators to educate pre-service teachers to value and use these metacognitive knowledge and skills in their learning and teaching. Baya'a, Daher, Jaber and Anabousy (2018) report the educating of mathematics pre-service teachers to use metacognitive skills. This preparation encouraged the participants to use these skills as learners, where this use utilized the mobile technologies. In a later phase, the pre-service teachers used these skills as teachers to encourage their students to use metacognitive skills collaboratively (Baya'a et al., 2018).

Research Question

How would mathematics pre-service teachers develop their perceptions of metacognition in mathematics teaching and learning as a result of one year preparation?

Methodology

Research Context and Participants

The preparation was held for a full academic year 2016-2017. Twenty four pre-service teachers participated in the preparation. They were in their third academic year majoring in teaching mathematics and computer science in middle schools. Two of the authors, who were the pedagogical supervisors of these pre-service teachers, accompanied them in two middle schools in the frame of the practical training. Our preparation of the pre-service teachers in metacognitive knowledge and skills was based on the work of Davidson and Steinberg (1998) with special emphasis on using mobile technologies for solution strategies. In addition, special attention was given for collaborative learning among the pre-service teachers' students groups.

The preparation of the pre-service teachers went through the following phases (Daher, Baya'a, Jaber & Anabousy, 2018): (1) Theoretical preparation of metacognitive thinking, (2) designing activities that encourage metacognitive thinking, (3) implementing the metacognitive activities as learners and as teachers, (4) reflection and evaluation of the whole preparation process.

Data Collection and Analysis

We held interviews with the participating pre-service teachers twice, once at the beginning of the preparation and once at the end of it. The interviews were focus group. We stressed at the beginning of each interview that there are no wrong answers but rather differing points of view (Krueger, 2002). We also directed the participants to feel free to share their perceptions of metacognition and metacognition in teaching even if it differs from what others hold.

Examples on the interview questions are:

1. What is the difference between metacognition and cognition?
2. How can the mathematics teacher encourage her students to use metacognitive skills in their learning of mathematics?

To analyze the data (the interview transcripts), we used inductive and deductive content analysis which is a process designed to condense raw data into categories or themes based on valid inference and interpretation that use inductive and deductive reasoning. The goal of deductive reasoning is generating concepts or variables from theory (Patton, 2002). Using the deductive reasoning we looked for themes related to the metacognitive skills as described in Davidson and Steinberg (1998). Using the inductive reasoning, we tried to find out if additional metacognitive skills, not given in the literature, are described by the pre-service teachers.

Findings

Perceptions of Metacognitive Skills

In the pre-interview, some of the pre-service teachers knew theoretically what metacognition is. They knew that (1) it involves thinking on thinking, (2) it involves skills as evaluating and modifying the solution process or method, and (3) these skills come in a series. Some of the students' descriptions were the following, where the participants' descriptions targeted the three previous issues.

"Metacognition involves thinking about thinking", "We start a solution, we think about difficulties in this solution and think about other strategies to solve, then we decide what to do", "We start a solution, we monitor our solution method for effectivity, we modify to a more effective solution method", and "Sometimes, I discover during the solution that I make the solution more complicated, so I change to a different solution method".

In addition, some of the participants associated metacognition with transferring to a new domain, especially real life. For example, one participant said: “To find the tree height from the length of its shade is metacognition because I used mathematical thinking in a different context, that of real life”.

In the post-interview the participants elaborated their perceptions of the construct metacognition. They described it as thinking about the thinking in which they were previously involved. In addition, they pointed at the element of time as important in metacognitive engagement: “metacognitive thinking means taking time to manage your thinking, to arrange your thoughts, to assess your thoughts, to take decisions”.

The pre-service teachers, in the post-interview, gave more examples on using metacognition in teaching and learning mathematics. One pre-service teacher emphasized: “metacognition means encouraging the student to think about her previous thinking. It means encouraging her to manage her learning before solving through planning her solution and giving her time after the solving to evaluate the solution” One of the participants gave an example of learning mathematics using metacognition: “Let us take for example a student who comes to solve a problem. She first plans the solution by writing down the givens of the problem; she comes afterwards to solve the problem. She puts down in her head the different solution methods of the problem. She decides upon the most effective method and engages in it. Here comes my role as a teacher. To encourage metacognition, I ask the other students to evaluate the problem solution. I ask: what do you think about your solution method? Do you have a different method? Do you have a better method? Why?”

In addition, in the post-interview, the participants described metacognition in more specific terms, differentiating between writing the givens, representing the problem, decomposing the problem, planning, choosing a solution strategy, monitoring, modifying and evaluating solutions. Specifically, in the pre-interview the participants did not differentiate between writing the givens and representing the problem, while, in the post-interview they did that. One pre-service teacher, in the post-interview, said: “To write the givens sometimes needs knowing how to do translation from one representation to another, but the student needs to know that representing the problem is one step further. Writing the givens could be done by steps, as in a geometric problem, while representing the problem results in a whole representation of the problem”.

Differences between Cognition and Metacognition

In the pre-interview, the participants mixed between cognitive and metacognitive skills. Doing that, their statements were sometimes ambiguous. Some of the participants considered requesting a student to describe how she solved a problem as requesting her to perform metacognitive skills. In the same way, they considered experimenting with the solution of a problem as a kind of metacognition. Other participants said that directing students to solve mathematical problems encourages their use of metacognition. In addition, some participants said that the difference between a student who uses metacognition and one that does not is that this who uses metacognition can generalize. Requesting the participants to elaborate more, they did not succeed to do so. All the previous sayings indicate vague sense of metacognition.

In the post-interview, the participants were more aware that describing how, does not guarantee alone that the process is metacognitive, and that metacognition is related to managing the learning process. One participant said: "Now we understand that writing how we performed the solution is not necessarily metacognitive. Metacognition is knowing why we used a solution and not another".

Furthermore, in the post-interview, some of the participants still mixed between cognitive and metacognitive skills. For example, they considered comparing and proving metacognitive skills. One participant said: “When we use the ‘compare’ and ‘prove’ processes, this is metacognition”. In addition, some of the participants still talked generally about metacognition. For example, one participant talked about using more than one solution method to solve a problem as metacognitive skill.

In addition to the said above, in the post-interview, some of the participants still considered metacognition related to connecting mathematical knowledge to real life situation. They did that without further elaboration, as if this connection alone is enough for considering the mathematical process metacognitive.

Functions of Metacognition in the Mathematics classroom

In the pre-interview, the participants' perceptions of the functions of metacognition in the mathematics classroom were general. These perceptions were:
Lessening the students' boredom. One participant said: "It lessens the students' boredom for it is a new practice for them, they are not accustomed to it".

Bringing up independent students. One participant said: "You bring up students who are able to learn, to think and to develop her thinking alone". Another participant said: "You bring up independent students who can learn alone".

In the post-interview, the participants' perceptions of the advantages of the teacher's use of metacognition in the mathematics classroom were less general. Here, the participants talked about the following advantages:
Getting used to evaluating one's own solutions. One of the participants said: "In our group, we suggested three problems that would encourage students to think metacognitively. We were aware that we should go through a metacognitive skill, which is choosing one of the problems to implement with the middle school students. This metacognitive skill involved many cognitive processes, as comparing and classifying. I mean that metacognitive skills make use of many cognitive processes. Through the metacognitive processes, we get to evaluate our own solutions".

Internalizing the mathematical concepts. One of the participants said: "The metacognitive processes make the students internalize the mathematical concepts. In the course of these processes, we need to think, evaluate, decide, modify, and prove. This way we understand deeper".

Effective solving of mathematical problems. One of the participants said: "Planning makes the solution process more effective. There is difference between solving after planning and solving without planning. When we plan, starting from writing the givens, we are able to choose among different solution methods. This ensures that the solution is effective". Another participant said: "mathematics is the science of strategies, so metacognitive skills are needed to solve effectively mathematical problems. Choosing the most appropriate strategy ensures effective solving".

Advancement of the Metacognitive Skills of Students

In the pre-interview, the participants suggested the following methods to encourage students' metacognition: Giving the students a series of problems that gradually get more complicated, giving the students mistaken solutions for evaluation and thinking aloud about a problem's solution. These methods are further described below.

Giving the students a series of problems that gradually get more complicated. For example, one participant said: "We can teach students metacognitive skills by giving them a series of problems where these problems advance gradually in their difficulty. This gradual progression teaches students how to think about solving mathematical problems". Another participant said: "Directing students to solve encourages metacognition".

Thinking aloud about a problem's solution. For example, one participant said: "When I, as a teacher, solve a problem, I think in a loud voice how I think, how I decide which solution method to choose, how I assess the solution method, etc. This shows students how to think".

Giving students mistaken solutions for evaluation. For example, one participant said: "We can give students mistakes that the students make and request them to find the mistake. This encourages them try to avoid these mistakes".

In the post-interview, the participants gave the previous three methods in addition to two additional methods: Requesting students to evaluate their solutions and challenging them with new problems.

Requesting the students to evaluate their solutions. For example, one participant said: "After the students solved a problem, I request them to think about their solution and to make sure that the solution is correct". Another participant said: "After the students solved a problem, I request the students to look for another solution, or an unconventional solution or a more effective solution method, to decide which the most effective solution method is".

Challenging the students with new problems. For example, one participant said: "New problems could lead to metacognition: We show students some solution methods, then we give them a problem that could be solved according to the method, then give them a challenging problem that could not be solved according to the same method. This causes students to think about another way of solution. This is metacognition".

Metacognition in Lesson Preparation

In the pre-interview, the participants' suggestions regarding how to take care of metacognition in the preparation of lessons were related to their perceptions of metacognition, as connecting to real life and as introducing the mathematical activities in a series. Some of the students descriptions were the following: "I use real life problems to make students transfer their mathematical knowledge" and "I use a series of problems that advance gradually in their difficulty".

In the post-interview, most of the participants expressed a favorite attitude towards taking care of metacognition in lesson preparation. Most of the participants said that they would utilize the planning phase of metacognition in their lesson preparation. One participant said: "The planning phase serves the solution so much, especially how to arrange the givens. I would use it, but not the other phases, because these phases take a lot of time that the teacher does not have". Another participant said: "If all the teachers in the school teach traditionally, how would I alone use metacognition in my teaching? This is impossible".

Discussion

The present research intended to examine the development of mathematics pre-service teachers' perceptions of metacognition and metacognition in teaching mathematics as a result of their participation in one-year preparation. The research results indicate that the participants developed their perceptions in some aspects of metacognition and its use in mathematics teaching, but they did not develop these perceptions in other aspects of the studied issue.

The participants developed their perceptions regarding the metacognitive strategies. This development was present in the terms and descriptions that they used after the preparation. Before the preparation, their terms and descriptions were general and not specific, but after the preparation these terms and descriptions became more specific: 'She first plans the solution', 'She does so by writing down the givens of the problem', 'She puts down or in her head the different solution methods of the problem', 'She decides upon the most effective solution method', etc. This use of more specific terms related to metacognition, as in Davidson and Sternberg (1998), indicates deeper understanding of what metacognitive skills are, which indicates a development of the participating pre-service teachers' perceptions of metacognitive skills. In addition, in the post-interview, the pre-service teachers talked about metacognition as a tool in the hands of the mathematics teachers who use it to encourage the metacognitive engagement of their students, which points at the influence of the preparation in which they participated on their identity as teachers of mathematics. The pre-service teachers became teachers of mathematics who conceptualize metacognition as helping them manage the cognitive and metacognitive aspects of their students' learning.

Another issue that needs to be taken care of is the pre-service teachers' differentiation between cognitive and metacognitive skills. The results of the present research implied that the participants got more aware of these differences as a result of their one-year education, but they have not overcome their misconceptions regarding this area totally. It seems that what make this differentiation problematic are the participants' perceptions of metacognition as high order thinking, so they associate it with high order thinking skills.

A third issue of the participants' perceptions of metacognition is their perceptions of the functions of metacognition in the mathematics classroom, where the one-year education led the participants to be less general, mentioning the metacognitive processes needed in each function. This development of their perception is expected since they underwent different experiences in the preparation year and in which they performed, more than once, metacognitive processes. This result agrees with previous studies which reported significant development of metacognitive skills of pre-service teachers as a result of education (e.g., Erskine, 2009).

A fourth issue of the participants' perceptions of metacognition is their perceptions of methods to encourage students' use of metacognitive skills. The participants after one-year preparation were aware of more of such methods, where this awareness probably resulted from the one-year preparation, especially from the designing and implementation phases (Daher et al., 2018).

The last issue concerning the participants' perceptions of metacognition is their intention to use metacognition in their students' learning. Here the issue of time pressure influenced the participants' intention, where they claimed that this time pressure could prevent them from implementing metacognitive teaching and learning. In any case, most of them expressed their intention to use planning in the mathematical problem solving in their classes, which shows that they valued this metacognitive skill more than other skills. In addition to the time pressure, it also could be that the participating pre-service teachers, after working with metacognitive learning and teaching got aware that teaching students to be metacognitive requires a complex understanding of both the concept of metacognition and metacognitive thinking strategies (Wilson & Bai, 2010).

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Author Information

Wajeeh Daher
An-Najah National University,
Nablus, Palestine
Contact E-mail:wajeehdaher@najah.edu

Nimer Baya'a
Al-Qasemi Academic College of Education,
Mathematics Education Department,
Baqa, Israel

Ahlam Anabousy
Al-Qasemi Academic College of Education,
Mathematics Education Department,
Baqa, Israel

Otman Jaber
Al-Qasemi Academic College of Education
Mathematics Education Department,
Baqa, Israel