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An investigation of the relationship between metacognition and mathematics achievement

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Abstract The aim of this study is to determine fifth-grade students' metacognitive knowledge and skills and its relationship with mathematics achievements. A total of 242 primary school students from six different schools were participated in the study. Turkish version of Metacognitive Knowledge and Skills Assessment (MSA-TR) was used to measure metacognitive knowledge and skills. The results demonstrated a significant and positive relationship ($r = .648$, $p < .01$) between metacognition and mathematics achievement. Furthermore, research results showed that 42% of total variance of mathematics achievement could be explained with metacognitive knowledge and skills.

Keywords Metacognition · Metacognitive knowledge · Metacognitive skills · Achievement · Mathematics achievement

Introduction

Successful students are the ones, who are aware of when they behave strategically and when they do not (Eggen and Kauchak 2001). Because only if learning is done consciously, it can be effective. Conscious individuals will be able to take part in society only if they are armed with self-knowledge ability (Morin 2003). The efforts for educating conscious individuals began to follow a more meaningful trend, with appearance of metacognition concept and the studies done in this connection. Metacognition means an individual's awareness of his own thinking processes and his ability to control these processes (Cakiroglu 2007; Desoete and Ozsoy 2009; Flavell 1979, 1999; Huitt 1997; Hacker and Dunlosky 2003; Ozsoy et al. 2009). Metacognition is a model of cognition, which acts at a meta-level, and is related to the object-world, through the monitoring and control function (Efklides 2001). It is observed that modern studies discuss the metacognition under three main facets: Metacognitive knowledge, metacognitive control (Desoete and Roeyers 2006; Flavell 1979; Nelson and Narens 1990; Otani and Widner 2005; Ozsoy et al. 2010; Sungur 2007) and metacognitive experiences (Efklides 2001, 2008; Flavell 1979). "Metacognitive knowledge is knowledge we retrieve from memory and regards what the person knows or believes about him/herself and the others as cognitive beings, their relations with various cognitive tasks, goals, actions or strategies as well as the experiences s/he has had in relation to them" (Efklides 2001, p. 299). Metacognitive knowledge can be described as the knowledge, awareness, and deeper understanding of one's own cognitive processes and products (Flavell and Wellman 1977). It consists of person, task, and strategy knowledge (Efklides 2001). It also mathematically refers to the mathematical processes and techniques students have and their ideas about the nature of mathematics. Paris et al. (1984) suggested that metacognitive knowledge can be divided into three areas. These areas are declarative, procedural, and conditional knowledge. Declarative knowledge refers to knowledge about one's general processing abilities. The knowledge about how to successfully solve problems is called procedural knowledge. Conditional knowledge means knowledge about when to employ specific strategies (Sperling et al. 2004). However, metacognition requires one, besides the knowledge mentioned earlier, to use this knowledge effectively. The ability to use metacognitive knowledge, on

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the other hand, can be called metacognitive control or regulation.

Metacognitive control skills consist of leading mental operations in metacognitive processes and can be defined as the ability to use the metacognitive knowledge strategically in order to attain cognitive objectives (Desoete 2008; Schraw and Moshman 1995). The literature focuses on four metacognitive control skills; prediction, planning, monitoring and evaluation (Brown 1980; Desoete et al. 2001a; Desoete and Roeyers 2002; Lucangeli and Cornoldi 1997). Metacognitive control/regulation is considered as the ability to use knowledge to regulate and control cognitive processes (Brown 1980). Metacognitive control is related with metacognitive activities that help to control one's thinking or learning (Ozsoy 2008). Students having the prediction skill think about the learning objectives, proper learning characteristics, and the available time. Prediction skill enables students to predict the difficulty of a task, by this way they use that prediction to regulate their engagement related to outcome. The selection of appropriate strategies and allocation of resources closely related with the prediction skill (Desoete 2008). Monitoring refers to one's on-line awareness of comprehension and task performance. The ability to engage in periodic self-testing while learning is a good example of monitoring skill (Winne 1997). Students having the evaluation skill appraise the products and regulatory processes of their learning. Students can re-evaluate their goals and conclusions. Evaluation enables students to evaluate their performance on the task, students can compare their performances with each other and they can use the result of comparison to locate the error in the solution process (Desoete et al. 2001a; Lucangeli et al. 1998).

According to Flavell (1979), metacognitive experiences are "any conscious cognitive or affective experience that accompanies and pertains to any intellectual enterprise". Metacognitive experiences are defined as the awareness and feelings which arises when an individual comes across a task and processes the information related to it (Efklides 2008). Metacognitive experiences form the online awareness of the person as s/he is performing a task (Flavell 1979). Metacognitive feelings have both affective and cognitive properties. The affective character of metacognitive experiences can be explained by two feedback loops. The first one is related to the outcome of cognitive processing and detects the discrepancy from the goal set. Error detection and feeling of difficulty are associated with negative affect (Efklides 2006). By metacognitive experiences, the person becomes aware of his or her cognition. Besides, metacognitive experiences trigger control processes that serve the pursued goal of the self-regulation process (Efklides 2008; Koriat 2007). However, the person can feel highly confident, even if the outcome of cognitive processing is not correct, just because the solution was produced fluently, thus endangering appropriate control decisions. This is particularly true for persons who are not aware of their ignorance (Efklides 2008; Kruger and Dunning 1999).

From a developmental perspective, metacognitive awareness may arise at the age of 4–6 years (Demetriou and Efklides 1990; Efklides 2009; Rottier 2003). There is a substantial increase in metacognitive development during the primary school years as a function of age and experiences (Flavell 1988; Karably and Zabrucky 2009). Experimental studies support that these skills exist in pre-school children and soar during primary education (Schneider and Lockl 2002). According to Veenman et al. (2006), metacognitive knowledge and skills develop during preschool or early-school years at a very basic level, but become more sophisticated and academically oriented whenever formal educational requires the explicit utilization of a metacognitive repertoire.

In literature metacognition has been found essential to come to successful learning (Caviola et al. 2009; Desoete et al. 2001b; Ozsoy and Ataman 2009; Pugalee 2001; Schoenfeld 1985; Teong 2002; Victor 2004). On the other hand, in some researches, it has been concluded that there was reasonable relation between students' academic success level and metacognitive skills (Case et al. 1992; Desoete and Roeyers 2002; Kirby and Ashman 1984). To gain a better understanding of successful mathematical performance, metacognition seems to be important (Lucangeli and Cornoldi 1997). Academically successful students acquire the self-understanding that supports effective strategies to solve problems (Garrett et al. 2006). For good mathematical competence, the subject must make good use of cognitive resources and must use them well in the sense of awareness and control over what to do and how to do it (Lucangeli and Cornoldi 1997). Various researchers have stated that metacognition has an important role in being successful in mathematics (Borkowski and Thorpe 1994; De Clercq et al. 2000; Desoete et al. 2001a, b; Schoenfeld 1992). Artz and Armour-Thomas (1992) point out that the main reason underlying the failure of students in problem solving is that they cannot monitor their own mental processes during problem solving.

Metacognition may affect how children learn or perform mathematics. Students must learn how to monitor and regulate the steps and procedures used to meet the goal of solving problems. Academically successful students acquire the self-understanding that supports effective strategies to solve problems (Garrett et al. 2006). In addition, the study conducted by Desoete et al. (2001a) indicated that metacognitive knowledge and skills account for 37% of the achievement in mathematical problem solving. Lucangeli et al. (1995) found that metacognitive training positively affects mathematical problem solving. Studies conducted with this purpose in mind suggested that there exist positive and significant increases in the achievement of children using instruction activities toward developing metacognitive skills (McDougall and Brady 1998; Naglieri and Johnson 2000; Ozsoy and Ataman 2009; Ozsoy et al. 2009; Teong 2002; Victor 2004).

According to Schoenfeld (1985), who emphasizes that metacognitive skills are generally ignored in education processes, metacognitive skills and mathematical knowledge are an inseparable entity. One of the leading problems that are observed in students in all educational levels is lack of the development of metacognitive skills and mathematical knowledge. Because mathematics education predominantly focuses on situations and processes but it does not attach sufficient importance to the studies that develops understanding. This lies behind the failure of students in mathematics courses (Schoenfeld 1985).

There are different methods of assessing metacognition; self-report questionnaires; think-aloud protocols and systematic observation of behavior (Desoete 2008, 2009). Each metacognitive assessment tool has its strengths and weaknesses (Larkin 2010). Most of these tools also are not suitable for every context. To assess metacognitive knowledge, self-report questionnaires and to assess metacognitive experiences self-ratings are frequently used (Efklides 2008). In addition to self report measures, think-aloud protocols or systematic observation of behavior can be used to measure metacognitive skills (Veenman and Elshout 1999). Recently often multi-method techniques are being used. Because evidences suggest that what learners say they do or intend to do is not what they do in practice (Veenman 2005, 2007). By reason of limitations of self-report questionnaires and think-aloud protocols, a multi-method inventory, Metacognitive Knowledge and Skills Assessment Inventory (MSA) developed by Desoete et al. (2001a) is used in this study.

Present study

The first aim of this study is to assess fifth-grade students' metacognitive knowledge and skills, and to investigate the relationship between students' mathematics achievement and metacognition. It is hypothesized that metacognitive scores will correlate with the mathematical achievement scores. This study also aimed at gaining better insights into relationships between metacognitive parameters and mathematics achievement.

Method

Participants

The participants of the study consist of 242 fifth-grade students (mean age 11.3, SD = .59) from six public primary schools in Zonguldak-Eregli, which is a medium-sized city on northwest coast of Turkey. The study carried out during the spring semester of 2009. One hundred and thirty-four of the students were girls (55.4%) and 108 boys (44.6%).

Instruments

Metacognitive skills and knowledge assessment

In order to measure the metacognitive knowledge and skills of students, an adapted version of MSA (Metacognitive Skills and Knowledge Assessment) (Desoete et al. 2001a) was used. The MSA is a multi-method inventory in which the predictions are compared with the student performance as well. The MSA assesses two metacognitive components (knowledge and skills) including seven metacognitive parameters: Declarative, procedural, and conditional knowledge, and prediction, planning, monitoring, and evaluation skills (Desoete et al. 2001a). In the measurement of "declarative knowledge", children are asked to choose the easiest and the most difficult exercise out of five and to retrieve their own difficult or easy addition, subtraction, multiplication, division or word problem. In order for this hard/easy distinction to be made and graded properly, these operations have been determined through a test applied to fifth-grade students of a primary school, in accordance with the method followed during the development of original inventory. As a result of this process, the operations have been placed in the inventory in a way that will grade the least successfully answered questions as the hardest and the most successfully answered ones as the easiest. The exercises on "procedural knowledge" require children to explain how they solved exercises. "Conditional knowledge" is assessed by asking for an explanation of why an exercise is easy or difficult and asking for an exercise to be made more difficult or easier by changing it as little as possible (Desoete et al. 2001a). In the assessment of "prediction", children are asked to look at exercises without solving them and to predict whether they would be successful in this task. Children might predict well and solve the exercise wrongly, or vice versa. Children were then scored on "evaluation" doing the exercises on the same rating scale. The answers were scored and coded according to the procedures used in the assessment of prediction skills. For "planning", children had to put 10 sequences necessary to calculate in order. When the answers were put in the right order the children received 1 point. The following types of questions measured 'monitoring': What kind of errors can you make doing such an exercise? How can you help younger children to perform well on this kind of exercises? Complete and adequate strategies were awarded 2 points. Hardly adequate but not incorrect strategies (such as 'I pay attention') received 1 point. Answers that were neither plausible nor useful did not receive any points (Desoete et al. 2001a).

The inventory consists of 160 items and through this inventory a student can score a minimum point of 0 and a maximum point of 360. During the development process of the inventory (MSA), the test–retest correlation has been $r = .81$ ($p < .0005$) in the analyses conducted by Desoete et al. (2001a). To examine the psychometric characteristics of the metacognitive parameters, Cronbach's alpha reliability analyses were conducted by the developers. For declarative knowledge, procedural knowledge, and conditional knowledge Cronbach's alpha values were .66, .74, and .70, respectively. For prediction, planning, monitoring, and evaluation Cronbach's alpha values were .64, .71, .87, and .60, respectively (Desoete et al. 2001a).

The adaptation of the inventory to Turkish has been carried out by the researcher (Ozsoy and Ataman 2009; Ozsoy et al. 2009). The reliability of the inventory restudied in the adaptation process. The inventory applied 92 students and Cronbach's α values of MSA-TR were .71 for declarative knowledge, .70 for procedural knowledge, and .79 for conditional knowledge. For prediction, planning, monitoring, and evaluation, Cronbach's α values were .73, .78, .80, and .76, respectively. We have resorted to the method test–retest in reliability study due to the scope and quality of the inventory. The inventory has been applied to 45 students two times at an 8 weeks' interval and the consistency between this resting results have been analyzed. The correlation value between two applications has been found to be .85 ($p < .01$).

Mathematics achievement test

Mathematics Achievement Test (MAT) is used to determine mathematical achievement levels of students. The MAT is developed by the researcher (Ozsoy 2005) and consists of 30 multiple choice questions. The questions of the MAT are updated for this study to be appropriate with the objectives of the Turkish Elementary School Mathematics Curricula. It includes numbers and operations, geometry, measurement, and statistics questions; consistently with the curricula (See "Appendix" for sample items). The maximum and minimum scores on the mathematics test could be 30 and 0, respectively. The validity of the questionnaire was assured by taking the views of three professionals about the relevancy of each item. Based on the experts' suggestions, last modifications of the second version of the test were made. This version is piloted ($n = 200$) and Cronbach's alpha reliability for the test was found to be $r = .89$ ($M = 20.72$, SD $= 5.52$). Depending on the results of the pilot study MAT is decided to be used to measure mathematical achievement in the study.

Procedure

Data of the research were obtained at the end of the spring semester in 2009. All participants assessed using MAT and MSA-TR, inside the classroom setting for a total about 4 h in four different days. Then data obtained were analyzed using SPSS 15.0 software. During the analysis of data obtained, results assessed with the significance level (p) of .01.

Results

In respect of MAT results, the average MAT score is 17.86 (SD $= 5.61$). When the scores of participants are examined, it is observed that the lowest score obtained from MAT was 8 and the highest one was 29.

In respect of MSA-TR results, the scores that the students received from metacognition and its parameters are shown in Table 1.

As it is seen in Table 1, while the mean metacognition scores of students is 148.37; as regards the scores they got from the parameters of metacognition, declarative knowledge score is 18.16, procedural knowledge score is 17.94, conditional knowledge score is 33.14, prediction skill score is 22.10, planning skill score is 12.36, monitoring skill score is 23.02, and evaluation skill score is 21.38.

The intercorrelation table that shows the relationship between mathematical achievement and seven metacognition parameters (declarative knowledge, procedural knowledge, conditional knowledge, prediction, planning, monitoring and evaluation) is presented in Table 2.

As it is seen in the Table 2, there is a significant relationship ($p < .01$) between the seven parameters that are metacognitive knowledge and skills and mathematics achievement. Among them, procedural knowledge ($r = .629$, $p < .01$), prediction skill ($r = .616$, $p < .01$), and

Table 1 MSA-TR scores ($n = 242$)

	M	PMS	SD
Metacognitive knowledge			
Declarative knowledge	18.16	40	7.54
Procedural knowledge	17.94	40	7.04
Conditional knowledge	33.14	80	13.008
Metacognitive skills			
Prediction	22.10	60	10.54
Planning	12.36	40	9.26
Monitoring	23.02	40	6.58
Evaluation	21.38	60	12.86
Total	148.37	360	51.699

PMS Possible maximum score

Table 2 Intercorrelation matrix of metacognitive parameters and mathematics achievement

	Math. achievement	Declarative knowledge	Conditional knowledge	Procedural knowledge	Prediction	Planning	Monitoring	Evaluation
Math. achievement	1							
Declarative knowledge	.284	1						
Conditional knowledge	.484	.486	1					
Procedural knowledge	.629	.283	.448	1				
Prediction	.616	.463	.737	.556	1			
Planning	.370	.466	.598	.437	.626	1		
Monitoring	.481	.275	.417	.449	.511	.459	1	
Evaluation	.592	.267	.743	.469	.710	.460	.394	1

All correlations given in the table are significant at the .01 level

evaluation skill ($r = .592$, $p < .01$) have the highest scores. The metacognitive parameters, declarative knowledge ($r = .284$, $p < .01$) and planning ($r = .370$, $p < .01$) have the lowest scores. On the other hand, it is seen that there are associations between each parameters composing metacognition, in the table. There are significant relationships ($p < .01$) between each metacognition parameters. Among those, the relation between evaluation skill and conditional knowledge ($r = .743$, $p < .01$), between conditional and prediction skill ($r = .737$, $p < .01$), and between evaluation and prediction skills are high-level and very remarkable.

Regression analysis was done in order to determine the correlation between mathematics achievements and metacognition scores of the students, who participated in the research. In respect of analysis results, a high-level positive and reasonable relation was found between mathematics achievement and metacognitive skills ($r = .648$, $p < .01$). And in light of analysis results, it is seen that metacognition is the most important predictor of success in mathematics [$R^2 = 0.42$, $F_{(1.240)} = 173.52$, $p < .01$]. This result demonstrates that 42% of total variance in mathematics achievement can be explained with metacognitive skills.

In order to assess this relation more broadly, the relationship between mathematics achievement and metacognitive parameters was examined with multiple regression analysis. Multiple linear regression analysis results are showed in Table 3.

Table 3 Regression analyses for mathematics achievement

Independent variable	B	SE	β
Declarative knowledge	.117	.131	.048
Procedural knowledge	.959	.144	.364*
Conditional knowledge	−.150	.112	−.106
Prediction	.432	.139	.246*
Planning	−.226	.121	−.113
Monitoring	.437	.149	.155*
Evaluation	.437	.105	.303*

* $p < .01$

Multiple linear regression analyses were conducted to address the main research question. The model accounted for 41% of the variance in students' mathematics achievement [$F_{(7,234)} = 41.783$, $p < .01$]. Prediction ($\beta = .246$), evaluation ($\beta = .303$), monitoring ($\beta = .155$), and procedural knowledge ($\beta = .364$) were four significant predictors of students' mathematics achievement (see Table 3).

Discussion

The objective of the current research was to examine the relationship between metacognitive knowledge and skills, and mathematics achievement in fifth-grade elementary students. In light of the findings obtained in the research, it was seen that a positive, high-level, and significant relationship between metacognition and mathematics achievement was found, similarly previous research studies (Case et al. 1992; Kirby and Ashman 1984; Lucangeli and Cornoldi 1997; Ozsoy and Ataman 2009; Schoenfeld 1985; Victor 2004). This result means that high achievement in mathematics is linked to high metacognitive ability. Significant and positive relationships between performances on mathematical tasks and levels of metacognitive ability of school children reported earlier by Swanson (1990) and Maqsud (1997) similarly.

In view of the results of MSA-TR that was applied 242 students, while mean metacognition score of the students was 148.37; the highest score obtained was 297 and the lowest one was 57. Considering that the maximum score was 360 in the scale, it can be said that metacognitive levels of the students participated in the research were below the average. In terms of the metacognition skill scores of the students, it is understood that mean scores is consistent with the results of previous studies (Ozsoy and Ataman 2009; Ozsoy et al. 2009) of the researcher that was performed with 47 fifth-grade students in Turkey, in 2007 and 2009. However, in the view of the results of the research, which was carried out with 80 third-grade by Desoete et al. (2001a, b), who developed MSA scale, of which adapted version used in this study, declarative knowledge score was $M = 25.54$ (SD = 4.96), conditional knowledge was $M = 7.76$ (SD = 3.60), procedural knowledge was $M = 18.21$ (SD = 5.92), prediction was $M = 15.86$ (SD = 5.26), planning was $M = 5.01$ (SD = 2.04), monitoring was $M = 19.27$ (SD = 5.08), and evaluation $M = 14.99$ (SD = 5.20) as metacognition parameter scores of the students. If results obtained are compared with present study, it is seen that declarative knowledge scores of the students participated in the research are higher than present study but regarding other parameters of metacognition, the scores of the students participated in present study were higher. However, considering that above-mentioned research was performed with 8 and 9 aged students while this research was performed with average 11.3 aged students, it can be said that the difference observed is related to development. Because it is known that age specific development is a key factor as well as education, in metacognitive development (Flavell 1988; Schneider and Lockl 2002). However, in order to determine the intercultural and international difference in better way, it can be useful to do a research in the same age groups.

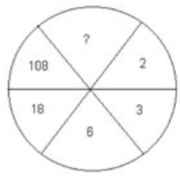
The research results demonstrate that there is significant relationship between each metacognition parameters and mathematics achievement. The three parameters, which have highest relation, are respectively knowledge ($r =$ .629), prediction ($r = .616$), and evaluation ($r = .592$). However, in respect of regression analysis results, prediction, evaluation, monitoring and procedural knowledge, which are metacognition parameters, are meaningful predictors of mathematics achievement. In her research that she did with elementary school 2nd and 3rd grade students, Desoete (2008) found that evaluation skill explains 34.2% of the variance in mathematics achievement and prediction skill explains 34.1% of that. As a result of a similar study, Rottier (2003) reports that planning skill is a significant predictor of mathematics achievement. She founded that 21% of mathematics achievement can be explained with planning skill (Rottier 2003). In this study, it is founded that there is a significant correlation ($r = .37$, $p < .01$) between planning skill and mathematics achievement, but planning skill is not a significant predictor of mathematics achievement inconsistently.

The results of current study show that 42% of total variance in mathematics achievement can be explained with metacognitive skills. When these results are assessed together, research results are consistent with the researches (Borkowski and Thorpe 1994; Case et al. 1992; Desoete et al. 2001a, b; Kirby and Ashman 1984; Lucangeli and Cornoldi 1997; Schoenfeld 1992), which have already been done, in respect of demonstrating that mathematics course achievement is related to metacognition skills.

It was observed that there was a positive and high correlation between metacognition and mathematics achievement. For this reason, metacognition can be used as a useful tool in order to develop mathematical skills. Accordingly, all instruction processes should include the instruction of metacognitive skills. There are many studies reports that teaching metacognitive skills to students may lead to some improvement in their academic achievement (Cardelle-Elawar 1992; Silver 1987; Ozsoy and Ataman 2009). Different approaches to improve metacognitive abilities, such as ‘IMPROVE’ (Mevarech and Fridkin 2006; Mevarech and Kramarski 1997), ‘metacognitive problem solving activities’ (Ozsoy and Ataman 2009), and ‘reciprocal teaching’ (Palincsar and Brown 1984) are available to teachers to provide their students with instruction in metacognitive strategies. On the other hand, during the review of literature for this study, it has been observed that metacognitive skills are studied usually in relationship with the language and math skills. Metacognitive skills can also be studied especially in relationship with courses such as social sciences, science, and arts.

Appendix: Sample items for MAT (Mathematics Achievement Test)—Grade 5

1. In the circle below, the numbers have ordered in a pattern. Which number should be placed instead of "?". *(Patterns)*



A) 1044
B) 1644
C) 1844
D) 1944

2. If a pupil forget to write the separator in the number 256,07; what kind of a mistake he made? *(Numbers and operations)*

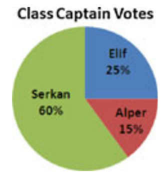
A) Adds 7 to the number
B) Multiplies the number with 10
C) Multiplies the number with 100
D) Multiplies the number with 7

3. The numbers Z and Y given below have four digits and their ones and hundreds digits are replaced. What is the result of Z – Y? *(Numbers and operations)*

Z = A 4 B 2
Y = A 2 B 4

A) 18 B) 98 C) 198 D) 1998

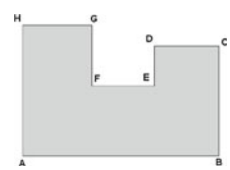
4. The pie chart shows the percentages of votes of candidates got in the class captain election.



Class size is 40 people and all students in the class had voted in this election. Considering the information given, how many votes did Serkan got? *(Statistics)*

A) 24
B) 26
C) 18
D) 22

5. The shape consists of three rectangles.
|AB| = 14 cm, |BC| = 8 cm,
|CD| = 4 cm,
|DE| = 6 cm, |HG| = 6 cm and |HA| = 10 cm.
What is the area of the shape? *(Geometry)*



A) 92 cm^2
B) 100 cm^2
C) 102 cm^2
D) 112 cm^2

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