Metacognition, Motivation, and Emotions: Contribution of Self-Regulated Learning to Solving Mathematical Problems

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Abstract

Mathematical problem solving is one of the most valuable aspects of mathematics education. It is also the most difficult for elementary-school students (Verschaffel, Greer, & De Corte, 2000). Students experience cognitive and metacognitive difficulties in this area and develop negative emotions and poor motivation, which hamper their efforts (Kramarski, Weiss, & Kololshi-Minsker, 2010). The ages of nine through 11 seem to be the most critical for developing attitudes and emotional reactions towards mathematics (Artino, 2009). These metacognitive and motivational-emotional reactions are fundamental aspects of self-regulated learning (SRL), a non-innate process which requires systematic, explicit student training (Pintrich, 2000; Zimmerman, 2000).

Most self-regulation studies about problem solving tend to focus on metacognition; few have explored the motivational-emotional component. This study developed, examined, and compared two SRL interventions dealing with two components of self-regulation: metacognitive regulation (MC) and motivational-emotional regulation (ME). The study conducted a two-group intervention to examine the possible effects on the self-regulation aspect of student problem-solving ability of increasing one group's metacognitive awareness, while leaving the motivational-emotional component alone, and of increasing the motivational-emotional awareness of the other group, while leaving metacognitive awareness alone. It also examined the contribution of these components to students' problem solving and self-regulation.

Participants were 118 fifth-grade students randomly assigned to two groups. The groups completed self-regulation questionnaires before and after intervention to examine metacognition, motivation, and emotion. Students also solved two forms of arithmetic series problems: verbal and numeric. After intervention, a novel transfer problem was also examined. The intervention consisted of 10 hours over five weeks. Following intervention, the groups exhibited similar improvements in all problems. The MC group performed best in metacognitive self-regulation, and the ME group performed best in certain motivational-emotional aspects of self-regulation. Research implications are discussed.

Keywords

metacognition, motivation, emotions, self-regulated learning (SRL), mathematical problem solving

Introduction

Research studies have shown that elementary school students have difficulty solving mathematical problems (Organization

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for Economic Cooperation and Development [OECD], 2003; Verschaffel, Greer, & De Corte, 000). Multi-step problem solving calls for coordination of multiple cognitive actions and experiences, including use of existing knowledge (such as facts, definitions, and competencies) and problem-solving strategies (such as analysis). Students have difficulty understanding math-problem texts and perceiving alternate ways of solving math problems, and lack confidence when calculating and verifying solutions (Desoete, Roeyers, & De Clercq, 2003; Schoenfeld, 1992). Moreover, researchers (including Schoenfeld, 1992; Verschaffel, Greer, & De Corte, 2000) have shown that student problem-solving difficulties do not always stem from a lack of mathematical knowledge, but rather from ineffective activation of their knowledge, since they lack the metacognitive skills needed to control, monitor, and reflect on the solution processes.

Cognitive/metacognitive difficulties cause many students to develop negative feelings towards mathematics, thus hampering learning and achievement (Artino, 2009; Duckworth, Akerman, MacGregor, Sattler, & Vorhaus, 2009; Efklides, 2011; Efklides & Petkaki, 2005). Because of such problems in this key subject, the question arises: How can we improve students' skills and the way they tackle mathematical problems? This research aimed to investigate the efficacy of self-regulated learning components (MC, ME) in the context of mathematical problem solving for young students.

Self-Regulated Learning (SRL)

In recent years, the role of SRL in education has elicited considerable interest as a desirable aspect of successful learning (for example, Schraw, Crippen, & Hartley, 2006; Zimmerman, 2000). Self-regulated learning is an active, constructive process involving several components: cognition-metacognition (MC), motivation-emotions (ME), and behavior. Self-regulated learning allows learners to determine their own learning goals, and to try to monitor, regulate, and control them, while being guided and constrained by the goals and contextual features of the learning environment (Pintrich, 2000).

Most studies of intervention programs that encourage self-regulation when solving mathematical problems specifically focus on MC (Kramarski & Mevarech, 2003). Few explore the way in which direct intervention aimed at developing learners' ME regulation influences learners' self-regulation and achievement. Until now, not many have compared the way these components affect student achievement in mathematical problem solving, or their impact on SRL processes. This research compared the contribution of self-regulation involving the MC component and self-regulation involving the ME component to learners' achievements in solving arithmetic series problems, and to students' metacognitive and motivational-emotional regulation processes.

Metacognitive Component

Researchers believe that metacognition is especially important for SRL (Schraw, Crippen, & Hartley, 2006; Zimmerman, 2000, 2008). . Metacognition enables learners to plan and allocate learning resources, monitor their own knowledge and skill levels, and evaluate their own learning levels at different points during learning acquisition. Metacognition researchers distinguish between two components of metacognition: Knowledge of cognition and regulation of cognition. *Knowledge of cognition* refers to what individuals know about their own cognition, or about cognition in general. It includes three different kinds of metacognitive awareness: declarative, procedural, and conditional knowledge (Brown, 1987; Schraw & Moshman, 1995).

The term *declarative knowledge*, which describes what we know "about" things, also includes our knowledge about ourselves as learners and about what influences our performance (Schraw, 1998). The term *procedural knowledge*, in contrast, relates to our knowledge about "how" to do things. Much of this knowledge is presented heuristically and via strategies. A person with a high level of procedural knowledge is likely to have acquired a large portfolio of strategies and to know how to sequence them well (Pressley, Borkowski, & Schneider, 1987). *Conditional knowledge* refers to knowing when to apply particular components of the previous two types of knowledge to a problem, and why these particular components may be effective. *Regulation of cognition* refers to a set of activities that help students to plan, monitor, and evaluate their own work.

- Planning involves choosing appropriate strategies and allocating resources that affect performance;
- Monitoring refers to students' awareness of their own understanding and performance quality while performing tasks; and,
- Evaluation refers to the evaluation of SR outcomes and processes.

Training in metacognitive regulation aims to increase learning competence by providing systematic and explicit guidance to learners as they think and reflect on their tasks (Schraw, Crippen, & Hartley, 2006; Veenman, Van Hout-Wolters, & Afflerbach, 2006).

The classic model of metacognitive regulation in the context of mathematical problem solving is the model developed by Polya (1945). Polya proposed dividing the problem-solving process into four main stages: 1) Understanding the problem. In this stage, the learner examines the known and missing data and tries to understand what she is required to do: for example, provide a simpler formulation of the problem, or use representations such as graphs and drawings. 2) The stage of devising a plan. In this stage, the learner organizes the facts and problem variables and decides which solution strategy is most appropriate. 3) Implementing the strategy. While solving the problem, the learner uses proofs to determine whether her chosen strategy was helpful, and weighs alternative strategies. 4) Checking the solution. The learner checks her answer while asking self-questions such as: Did I find it difficult/easy, and why? How can I reduce those difficulties? Can I solve the problem a different way?

Over the years, programs that provide metacognitive support for solving mathematical problems have been developed (for example, Kramarski & Mevarech, 2003; Kramarski & Zoldan, 2008; Schoenfeld, 1992). Research has shown that metacognitive support aimed at helping students solve these problems may empower their achievements and improve self-regulation skills.

Motivational-emotional Component

Motivational-emotional regulation refers to students' thoughts, actions, and behaviors when learning that affect their efforts, persistence, and emotions when performing academic tasks. Most researchers believe that motivation regulation is best illuminated by achievement goals theory (Ames, 1992; Kaplan & Maehr, 2002). Achievement goals theory suggests that an environment's goal structure can affect student motivation, cognitive engagement, and achievement (Ames, 1992; Kaplan & Maehr, 2002). *Goal structure* describes the type of achievement goal and most current theory.

The theory of achievement goals suggests that there can be two sorts of environment that affect the way an individual's goals are fostered. An environment that encourages the individual to focus on his or her own *mastery* of a subject will have instructional practices, policies, and norms which convey to students that learning is important, that all students are valued, that trying hard is important, and that all students can be successful if they work hard to learn — in other words, the goal is to master the subject (Midgley, Kaplan, & Middleton, 2001; Patrick, Anderman, Ryan, Edelin, & Midgley, 2001). This contrasts with an environment that communicates that being successful means getting extrinsic rewards, demonstrating high ability, and doing better than others. Thus, subject mastery is but a means to these ends; in other words, the goal is to meet some external standard. In the latter sort of environment especially, a less able child may come to pursue neither subject mastery, nor externally-judged excellence, but rather the *performance-avoidance goal,* in which the child seeks to avoid displaying a lack of ability and attracting others' negative evaluation (Church, Elliot, & Gable, 2001). Of course, there is no clear-cut division among these goals and all three may co-exist, with one degree of strength or another, within the same person.

Already, for several decades, researchers have been investigating different aspects of motivation and emotion (e.g., Bachman, 1970; Fennema & Sherman, 1976; Schoenfeld, 1989; Leder, 1982). In recent years, self-regulation researchers have looked at motivation and emotion in parallel (Artino, 2009; Duckworth, Akerman, MacGregor, Salter, & Vorhaus, 2009): examining the effects of positive and negative emotions on the adoption of achievement goals, cognitive processes, and achievements. Research has shown that affect guides and regulates cognitive and motivational systems (Olafson & Ferraro, 2001; Pintrich, 2003). It also produces a change in working memory load by occupying cognitive resources that could be devoted to the academic task. Emotions affect cognitive processing in various ways: they lead to particular emphases in attention and memory; they activate action tendencies; and they are regarded as functional and playing a key part in human coping and adaptation (Zan, Brown, Evans, & Hannula, 2006).

Emotions also affect certain aspects of self-regulation, including strategy selection. Experimental mood research shows that negative affect in particular can lead to inflexible ways of processing information, whereas positive affect can generate creative, flexible, and holistic thinking, which is beneficial for heuristic processing (Fiedler, 2001; Linnenbrink & Pintrich, 2002; Pintrich, 2003). Indeed, many studies on emotions and mathematics highlight this area as deserving special attention. Meta-analysis studies demonstrate that negative attitudes and emotions have far-reaching consequences. These included avoiding mathematics (Hembree, 1990); stress (Tobias, 1978); sense of hopelessness (Verschaffel, Greer, & De Corte, 2000); and finally, flight at different stages of the solution process (Ziender, 1998). Researchers indicate that these symptoms already appear in elementary school, peaking in grades five and six (Pekrun, Frenzel, Götz, & Perry, 2007).

Despite the great importance of the motivational-emotional component in relation to SRL and achievement, few interventions have been developed to address this combined component. In the present study, we developed a ME regulation intervention for young learners in the context of mathematical problems and examined the intervention's efficacy in terms of achievements in problem solving and SRL processes compared to MC regulation interventions.

Theoretical Foundation of the Intervention

Pintrich's (2000) theory of self-regulated learning adapted for the young student provided the theoretical framework for two interventions comparing the metacognitive and motivational-emotional components of SRL. The main principles of Pintrich's self-regulation model are presented in **Table 1.**

Table 1. Main Principles of Pintrich's Self-Regulation Model

Phase	MC Component	ME Component
Pre-learning stage Forethought, planning, activation	Task comprehension and planning solution strategy were examined	Achievement goals (*mastery goal/ performance-approach goal / performance-avoidance goal*) and negative / positive feelings towards task were examined.
During–learning stage Monitoring and control	Examination of: Metacognitive awareness Monitoring cognition Strategy and strategy efficacy	Type of goal used in solution was examined. Emotions and strategy for managing emotions and motivation were examined.
Post-learning stage Reaction, reflection	After solving problems students reflected on the solution and its process	Emotional reactions at the end of the task were examined and students reflected on their achievement goals.

Besides Pintrich's theoretical framework, the interventions focused on two key factors, which have been identified as effective in metacognitive regulation intervention, and which the present study extended to include motivational self-regulation. These factors are explicit training and asking self-questions.

Explicit training

In this type of training, the teacher explains the learning strategy to the students, stressing its meaning and importance (Otto, 2009; Veenman, 2007). Students benefit most when they are taught explicit strategies (Camahalan, 2006; Kistner et al., 2010). This is because the skills needed for self-regulation are not innate and cannot be acquired naturally (Dignath & Büttner, 2008; Kramarski, Weiss, & Kololshi-Minsker, 2010; Masui & De Corte, 2005; Perels, Gürtler, & Schmitz, 2005; Van Luit & Kroesbergen, 2006; Veenman, Van Hout-Wolters, & Afflerbach, 2006).

Self-questioning

Research in metacognitive self-questioning and mathematical problem solving has suggested that student achievements may be improved by self-questioning techniques (King, 1992; Karmarski & Mevarech, 2003; Mevarech & Karmarski, 1997; Schoenfeld, 1992; Veenman, Van Hout-Wolters, & Afflerbach, 2006). The goal of the self-questioning exercise was to increase students' awareness of their own understanding by encouraging them to practice thinking of questions to ask themselves during and after problem solving.

Following this, in our research the self-questioning strategy was extended to the motivational-emotional component of self-regulation and applied to arithmetic series problem solving in the two intervention programs. The two fifth-grade groups were given arithmetic series problems to solve before and after the intervention; they also completed the various sections (metacognition, motivation, and emotion) of the self-regulation questionnaires before and after the intervention.

The study examined two central research questions:

1. Will there be differences between the MC and ME groups in terms of:
   - 1.1. Improving arithmetic series problems (before and after the intervention)?
   - 1.2. Solving a novel transfer problem (after the intervention)?
2. Will there be differences in the self-regulation components of the MC and ME groups before and after the intervention, namely in students':
   - 2.1. Metacognitive regulation (knowledge of cognition and regulation of cognition);
   - 2.2. Motivation (mastery goals, performance-approach goals, performance-avoidance goals); or,
   - 2.3. Positive and negative emotions?

Sample

The sample consisted of 118 fifth graders (50 percent boys, 50 percent girls) aged 10 and 11. Students were from three middle-socioeconomic schools with the same nurturance index (criteria used by the Israeli Ministry of Education). Four classes were selected randomly from the schools, and pupils were assigned randomly to the two groups: the MC group (n = 64), or the ME group (n = 54). Pre-intervention testing found no significant differences between the groups in terms of gender $\chi^2 = .14$, $df = 1$, $p > 0.05$ or mathematical and linguistic level $F(3,103) =. 58$, $p > .05$.

The three phases of the study can be seen in **Table 2.**

Method

Table 2. Three Phases of the Study

<table>
<tr><th>Phase</th><th>MC Regulation</th><th>ME Regulation</th></tr>
<tr><td>Pre-intervention</td><td>Test / Questionnaire
–Prior mathematical knowledge (Test)
–Linguistic knowledge (Test)
–Arithmetic series problems (Tests)
–Meta-cognition (Questionnaire)
–Motivation (Questionnaire)
–Positive and negative emotions (Questionnaire)</td><td>Pre-intervention</td></tr>
<tr><td rowspan="2">Intervention</td><td colspan="2">Each group's intervention consisted of ten hours, delivered as two one-hour sessions per week, for five weeks. Intervention structure was the same for each group, only the content changed.</td></tr>
<tr><td>MC regulation while solving arithmetic series problems.</td><td>ME regulation while solving Arithmetic series problems</td></tr>
<tr><td>Post-intervention</td><td>Test / Questionnaire
– Arithmetic series problem, Novel transfer problem (Tests)
– Meta-cognition (Questionnaire)
– Motivation (Questionnaire)
– Positive and Negative Emotions (Questionnaire)</td><td></td></tr>
</table>

The interventions were taught during the participants' regular math lessons, and presented by four math teachers trained by the researcher. The researcher-author first met with the four teachers as a group to explain the study design. She then met with the teachers individually to explain the intervention details. This took an hour and a half. The researcher supplied each teacher with binders for all the students in his or her group, along with the necessary questionnaires, tests, and tasks. The researcher was not present in the classrooms during the interventions: an external researcher who was unaware of the research goals assistant was present. Finally, the researcher discussed the next stage of the intervention with each teacher at the end of each lesson.

Table 3 shows the structure of intervention for the two groups.

Table 4 presents the strategy for MC and ME regulation based on Pintrich's model self-question approach.

Table 3. Structure of Intervention for the Two Groups

Session No.	MC Regulation	ME Regulation
1	a. Analysis of a scenario portraying metacognitive processes; discussion of the importance of these processes for learning. b. Building an MC self-regulated learning strategy (Pintrich 2000). See **Table 4.**	a. Analysis of a scenario portraying positive and negative emotions, and motivation; discussion of importance of these processes for learning. b. Building an ME self-regulated learning strategy (Pintrich 2000). See **Table 4.**
2-9	a. Revision of metacognitive strategy b. Participants solve two arithmetic series problems. Increasing complexity with each session (for example, see Appendix 1). c. Discussion	a. Revision of motivational-emotional strategy b. Participants solve two arithmetic series problems. Increasing complexity with each session (for example, see Appendix 1). c. Discussion
10	The teachers of the two groups summarized the intervention and discussed its usefulness with their students.	

Table 4. Strategy for MC and ME Regulation Based on the Pintrich Model's Self-Question Approach

Phase	**MC Regulation**	**ME Regulation**
Pre-Learning (Forethought)	“Do I understand the task?” “Have I solved a similar task?” “Which strategy should I choose?”	“How do I feel?” “Do I solve problems in order to understand?” “Is the problem easy or hard?”
During Learning (Monitoring & Control)	“Is my chosen strategy effective?” “How do I choose a different strategy?”	**How shall I deal with negative emotions?** 1. Tell myself “I can do it”. 2. Try to relax. 3. Take time out.
Post- Learning (Reflection)	“Is the solution reasonable?”	“How do I feel”?

Table 5. Reliability of the mathematics tests and questionnaires

Measure	**Internal Consistence Test — Chronbach's α**
Numerical form of problem	.86
Verbal form of problem	.87
Novel transfer problem	.76
Judges assessed	0.92
Metacognitive regulation questionnaire	
Knowledge of cognition	0.64
Regulation of cognition	0.80
Motivation questionnaire based on achievement goals theory	
Mastery goals	0.82
Performance goals	0.89
Performance avoidance goals	0.73
Positive and negative emotions questionnaire	
Positive feelings	0.82
Negative feelings	0.83

Measures

To examine the effect of each type of intervention, participants received arithmetic series problems to solve pre- and post-intervention. There were two forms of problem: a numerical form and a verbal form. Students also received a novel transfer problem after the intervention. Before and after the intervention, self-regulated learning (metacognition, motivation, and emotions) questionnaires were also administered to the participants.

A statistical test for internal consistency (Cronbach's α) was applied, and all of these sets of statements proved reliable. **Table 5** presents the reliability of the mathematics tests and questionnaires.

Numerical form of problem

Problems using this form were adapted from the standardized Meitzav exam for the fifth grade, originally developed by the Israeli Ministry of Education (2004, Version A). Problems were administered pre- and post-intervention, and the numbers were changed. To solve these problems, students were required to compute how each term in the series was calculated and compute the next term. To answer the problem, students were required to indicate either "yes" or "no." A correct answer scored "1" and an incorrect answer scored "0".

Verbal form of problem

(See Karmarski, Weiss, & Kololshi-Minsker, 2010). Problems using this form were divided into three parts. Students were required to continue the series, which was presented verbally, and to reach a conclusion regarding the next term in the series. The answer to this problem had to be written as a number, which was a continuation of the series. A score of 1 was given for a correct answer, and 0 if the answer was wrong.

Novel transfer problem

(Kramarski & Mizrachi, 2006). To examine students' ability to transfer skills, they were asked to solve a novel transfer problem. This problem included a graph and called for high cognitive performance and the ability to make comparisons and draw conclusions: skills not required previously. An indicator was constructed to score the task. This comprised four scores, 0-3, in which a higher score indicated greater accuracy. Two judges assessed the indicator's reliability.

Metacognitive regulation questionnaire

The questionnaire was administered pre- and -post-intervention to examine the effect of the two interventions on participants' metacognitive regulation. It was based on the Junior Metacognitive Awareness Inventory developed by Sperling, Howard, Miller, and Murphy (2002) .The questionnaire contained 24 items, which produced two principal factors (Brown, 1987): Knowledge of cognition (for example: "I learn better when I am interested in a subject") and regulation of cognition (for example: "I ask myself if I am working the right way when I learn something new") formulated as statements and scored on a five-point Likert scale ranging from "1," Never," to "5," Always." Every respondent was required to rank each statement according to how true it was for him or her when solving the arithmetic series problems. An answer of 1 indicated little use of metacognitive processes, and an answer of 5 indicated considerable use of metacognitive processes.

Motivation questionnaire based on achievement goals theory

This questionnaire was administered pre- and post-intervention to examine the effect of the two interventions on participants' achievement goals (mastery, performance-approach, performance-avoidance). The questionnaire was developed by Midgley et al. (2000), and Kaplan adapted a Hebrew version (see, for example, Levi-Tossman, Kaplan, & Assor, 2007). The questionnaire included 19 statements relating to achievement goals, and was used a five-point Likert scale ranging from 1,"Not true at all," to 5, "Very true." The respondent ranked each statement according to how true it was for him or her when solving the reasoning problems. Statements were divided into three groups: six statements about mastery goals (for example, "It is important for me to understand clearly what I learn in class"), where an answer of 1 showed a low mastery-goals orientation and an answer of 5 a indicated high mastery-goals approach, which is effective for self-regulation processes; six statements relating to performance-approach goals (for example, "It is important for me that students in my class think that I am good at tasks"), where 1 showed low performance-approach goals and 5 indicated high performance-approach goals, which is less effective for self-regulation processes; and seven statements relating to performance-avoidance goals (for example: "It is important for me not to look stupid at school"), where 1 indicated low performance-avoidance goals and 5 indicated high performance-avoidance goals, which is less effective for self-regulation processes.

Positive and negative emotions questionnaire

To establish the intervention's effect on the participants' positive and negative emotions when working on arithmetic series problems, the questionnaire was administered pre- and post- intervention. The basis for this 20-item questionnaire was the Hebrew version (adapted by Margalit & Ankonina, 1991) of the Moos Affect Scale (Moos, Cronkite, Billings, & Finney, 1987).

A principal component analysis was performed to examine the factors. The analysis found that two factors could explain 46 percent of the variance. Two statement categories were identified: the first contained 10 statements relating to positive emotions (e.g., happy, relaxed); the second contained 10 statements relating to negative emotions (e.g., afraid, angry.) The distribution factors was the same as the original one (Tzohar-Rozen & Kramarski, 2013). The questionnaire was formulated as statements and scored on a five-point Likert scale from 1-5: 1, "Not true," to 5, "Very true." An answer of 1, for a positive statement, showed a weak positive emotion, while an answer of 5 showed a strong positive emotion; for a negative statement, an answer of 1 showed a weak negative emotion, and an answer of 5 showed a strong negative emotion.

Results

The results analysis will first address the findings for the problem-solving achievements and then examine the findings for the self-regulation processes (metacognitive and motivational-emotional).

Achievements in Solving Arithmetic Series Problems Presented Verbally and Numerically

Pretest and posttest differences were examined in terms of the research groups' achievements when solving arithmetic series problems presented either verbally or numerically. To examine differences between the groups, we first conducted a MANOVA to compare the pre-intervention measurements for the two groups' performance. The results found no statistically significant difference between the two groups: $F(2,115) = 0.40$, $p > 0.05$.

A 2 X 2 MANOVA (Groups X Time) with repeated measurements for time was then conducted to determine whether the learners' achievements improved as a result of the intervention and to establish differences between the groups in terms of changes between the pretest and posttest. This analysis showed a significant difference in the pretest and posttest measurements: $F(2,110) = 267.23$, $p < .001$, $\eta 2 = .83$. No significant Groups X Time interaction was found, however: $F(2,110) = 0.99$, $p > .05$. Thus, there was no difference found between the groups in the change between the pretest and posttest measurements. **Table 6** presents pre- and post-intervention means and standard deviations for the achievements for series problems presented verbally and numerically.

Table 6 shows significant differences between the measurements (before and after) in two indices. The means indicate that both indices improved as a result of the intervention.

Table 6. Pre- and Post-Intervention Means and Standard Deviations for the Achievements in Series Problems Presented Verbally and Numerically

Measure	Pre- Intervention		Post-Intervention		$F(1,111)$	η^2
	M	*SD*	*M*	*SD*		
Verbal	5.27	1.30	9.90	2.10	463.16***	.81
Numerical	4.04	2.29	8.30	2.23	158.31***	.59

***p<.001

Post-Intervention Differences in the Groups' Novel Transfer Problem Achievements

After the intervention, we examined the ability of the two groups to transfer the skills they had learned to a new task, in this case a novel graph task. The analysis of variance found no significant difference between the two groups: $F(2,115) = 2.11$, p > .05.

Pre- and Post-Intervention Differences in Self-Regulation Components Differences in meta-cognitive component

The study examined two metacognitive processes before and after the intervention: knowledge of cognition and regulation of cognition. There was no significant difference between the groups in these two indices before the intervention: $F(2,114) = 2.86$, p > .05. A MANOVA to examine differences between the measurement before and after the intervention, and to compare the change in the two measurements for the two groups, found no significant difference between the measurements: $F(2,111) = 0.48$, p > .05, and no significant interaction between Groups X Time: $F(2,111) = 1.99$, p > .05.

However, as we see from **Table 7**, the analysis of variance conducted for each measure separately showed a significant interaction in the regulation of cognition index. **Table 7** shows pre- and post-intervention means and standard deviations for knowledge of cognition and regulation of cognition by groups.

Table 7. Pre- and Post-Intervention Means and Standard Deviations for Knowledge of Cognition and Regulation of Cognition by Groups

Measure		Groups				Time		Groups X Time	
		MC		ME					
		Pre-interv.	Post-interv	Pre-interv.	Post-interv.	$F(1,112)$	η^2	$F(1,112)$	η^2
Knowledge of cognition	*M*	3.98	3.99	4.20	4.13	35.	00.	60.	.00
	SD	.50	.61	.42	.58				
Regulation of cognition	*M*	3.57	3.68.	3.77	3.70	.32	.00	4.01*	.05
	SD	.61	.66	.40	.63				

*p<.05

Figure 1 presents pre- and post-intervention means for the groups' achievements in regulation of cognition.

Figure 1 shows that whereas the MC group demonstrated an improvement in cognition monitoring, the ME group showed a slight decrease. Simple effect analysis to compare the pre- and post- intervention measurements for the two groups found a significant difference between the measurements for the MC group: $F(1,62) = .418$, $p < .05$, $\eta 2 = .06$. However, there was no significant difference in the ME group: $F(1,50) = 0.81$, $p > 0.05$.

Differences in motivation

Motivation is linked in this study to three types of goals: mastery, performance-approach, and performance-avoidance goals. These measures were examined before and after intervention. A MANOVA compared the two groups before intervention, and a significant difference could be seen between the two groups: $F(3,113) = .3.39$, $p < .05$, $\eta 2 = .08$. Analyses of variance for the measures found no significant difference in performance-approach goals: $F(1,115) = 7.37$, $p < .01$, $\eta 2 = .06$. However, measures of the ME group's performance-approach goals ($M = 3.19$, $SD = 1.18$) were higher than those for the MC group: ($M = 2.63$, $SD = 1.04$).

Due to these differences, a MANCOVA was conducted to compare the changes in the groups that the intervention caused. Indeed, the MANCOVA showed a significant difference in the change in measurements between the two groups: $F(3,107) = 2.90$, $p < .05$, $\eta 2 = .08$. An ANCOVA for each measure showed a significant difference in the performance-approach goals, $F(1,109) = .3.84$, $p < .05$, $\eta 2 = .03$; and performance-avoidance goals: $F(3,109) = 7.89$, $p < .01$, $\eta 2 = .07$; but no significant difference in the mastery goals, $F(1,109) = 0.01$, $p > 0.05$.

Figure 2 presents the pre- and post-intervention means for the performance-approach goals of the different groups.

Figure 1. Pre- and Post-Intervention Means for the Regulation of Cognition of the Different Groups

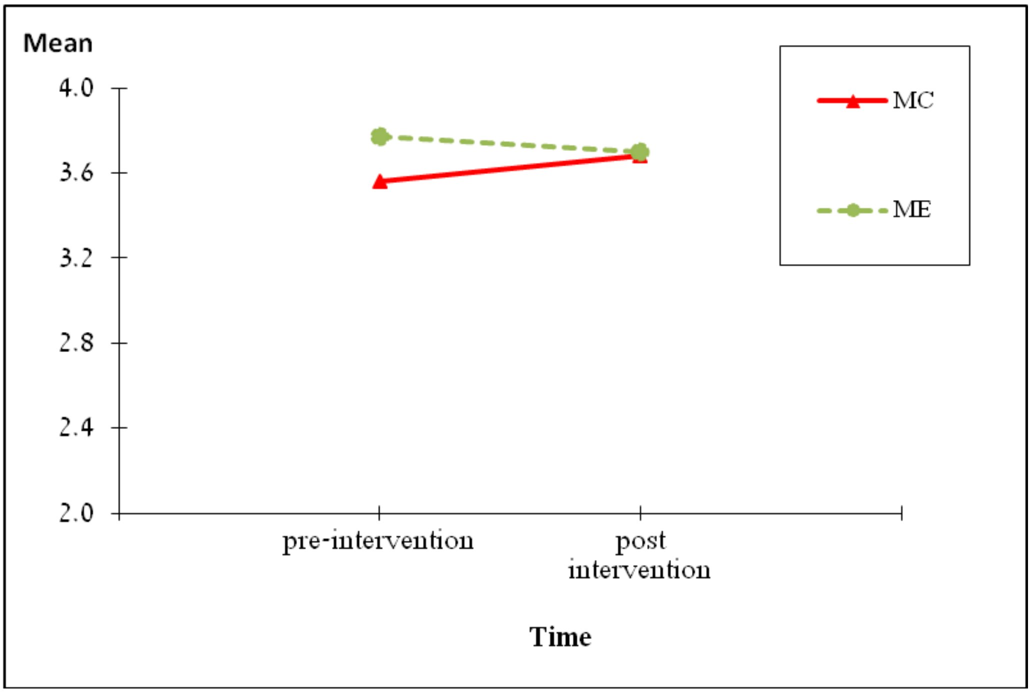
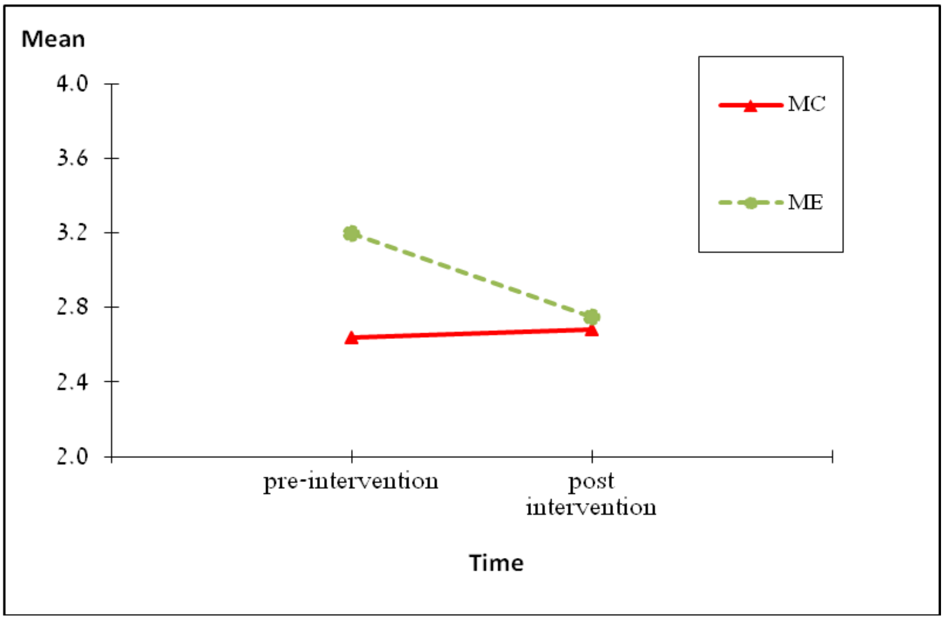


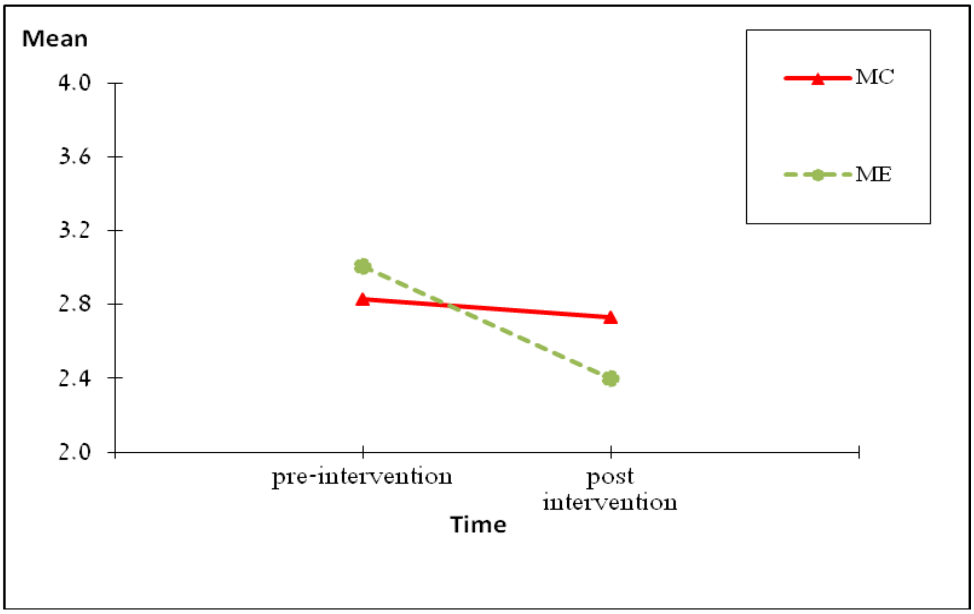
Figure 2. Pre- and Post-Intervention Means for the Performance-Approach Goals of the Different Groups



As we see from **Figure 2**, there was a reduction in level of the ME group's performance-approach goal measurement but no significant change in that of the MC group. Indeed, a simple effect analysis revealed that while a significant difference was found for the ME group's performance-approach goal measurement before and after intervention, $F(1,50) = 11.15$, $p < .01$, $\eta 2 = .18$, there was no significant difference for the MC group's performance-approach goal measurement before and after intervention: $F(1,62) = .12$, $p > .05$. In fact, we had expected to see a decrease in the performance-approach goal measurement. The results were similar for the performance-avoidance goals.

Figure 3 presents the pre- and post-intervention means for the performance-avoidance goals of the different groups.

Figure 3. Pre- and Post-Intervention Means for the Performance-Avoidance Goals of the Different Groups



As we can see from **Figure 3**, a sharp reduction occurred in the level of the ME group's performance-avoidance goal measurement, compared with only a slight reduction for the MC group. A simple effect analysis showed a significant difference in the pretest-posttest measure for the ME group, $F(1,50) = 21.62$, $p < .001$, $\eta 2 = .36$, but no significant difference for the MC group: $F(1,62) = 1.09$, $p > .05$. In fact, we had expected to see a decrease in the performance-avoidance goals measurement.

Differences in positive and negative emotions

Pre- and post-intervention positive and negative emotions were also examined. A unidirectional MANOVA was conducted to determine differences between the groups before intervention, and a significant difference was found between the two groups: $F(1,113) = 5.34$, $p < .01$, $\eta 2 = .09$. The analysis of variance for each measure showed a significant difference in the pre-intervention measurement only for negative emotions: $F(1,114) = 4.40$, $p < .05$, $\eta 2 = .04$. The ME group showed many more negative emotions, $M = 2.12$, $SD = 0.85$, than the MC group: $M = 1.82$, $SD = 0.65$. In fact, we had expected to see a decrease in the negative emotions measurement. As a result of these differences, a MANCOVA was conducted to compare differences in the posttest measurement, with the pretest as a covariant. The MANCOVA showed no difference between the two groups: $F(1,108) = 0.51$, $p > 0.05$.

Discussion

The study examined the significance and contribution of two self-regulation components, the MC component and ME component, to achievements in solving problems of varying difficulties and self-regulation processes: metacognition, motivation, and emotions. This section discusses the contribution of each group, the MC group and the ME group, to self-regulation and problem solving. First, we will discuss the changes in self-regulation in each group. Then, we will discuss the problem-solving achievements.

The self-regulation processes were examined with regard to the MC component and the ME component. With the MC component, the researcher examined two processes: knowledge of cognition (general knowledge of cognition, which provides a metacognitive foundation) and regulation of cognition (regulation and supervision of learning). The study found that the MC group showed greater improvement in regulation of cognition than the ME group, and there was no difference between the groups' pre- and post-intervention knowledge of cognition. These findings make sense, as "knowledge of cognition" is defined as the basis for learning that focuses on general assumptions of cognition (Brown, 1987). In addition, studies show that knowledge of cognition develops before children reach school age (Schraw & Moshman, 1995). There were no differences between the measurements, since the participants were in fifth grade and apparently had already developed this kind of knowledge. On the other hand, regulation of cognition focuses on specific higher complex processes such as planning, monitoring, and evaluation. It seems that the intervention, which targeted MC regulation by providing explicit direct support during cognition regulation while learning ("Did I understand the task?" "Is my chosen strategy effective?" "Is my answer logical?"), fostered the development of higher metacognitive processes, leading to a modest improvement.

Regarding the ME component, the performance-approach goals (learning for the sake of achievement and to demonstrate ability) and the performance-avoidance goals (avoidance of failure) decreased more in the ME group compared with the MC group. There were no differences between the groups in the other measures (mastery goal, positive and negative emotions).

One may assume that this reduction in the ME group is linked to the nature of the intervention this group received, which deliberately targeted motivational and emotional awareness by teaching participants specifically to ask themselves evaluative motivational-emotional questions. These questions stressed the importance of understanding themselves when learning ("Do I learn to understand?") and examining emotions throughout all stages of learning ("How do I feel?"). An explicit "I"-centered strategy was also constructed with the students, and was aimed at motivation and emotion management ("I am capable of succeeding," "I relax and take a break," "I will read the problem again to try and understand it," "If I don't succeed, I will ask for help from an adult or a friend"). This intense, focused training apparently produced a reduction both in the participants' performance-approach goals, characterized by non-adaptive behavior such as avoidance of challenges and behavior characterized by "helplessness" (Midgley et al., 2000), and in the participants' performance-avoidance goals, which are characterized by performance-avoidance and fear of demonstrating inability. Ames (1992) supports this finding, suggesting that an educational environment oriented towards mastery goals reduces performance-avoidance goals. In addition, research suggests that strategies to increase motivation can also help students improve behavioral forms of motivation (Boekaerts & Niemivirta, 2000; Zeidner, 1998).

The measurements for the mastery goals (learning for understanding) and the positive and negative emotions showed no difference between the groups. It seems that MC regulation and ME regulation produce similar changes in these components. An interesting point arising from this finding concerns the question of whether metacognitive self-regulation positively influences the motivational-emotional processes. Indeed, studies have shown that fostering metacognitive awareness leads to improvement in self-regulation processes as a whole; in other words, that it affects both metacognitive and motivational-emotional processes (Kramarski & Michalsky, 2009; Van Den Boom, Van Merrienboer, & van Gog, 2004). It is possible that the more metacognitive tools a learner has for coping with tasks, the greater will be her desire and motivation for tackling tasks. This finding also relates to and explains the findings relating to achievements in solving arithmetic series problems.

Recall that in order to assess the contribution of each intervention to learners' achievements, the participants of each group were tested with arithmetic series problems that were presented in different forms before and after the intervention. They were also tested on novel transfer problems. Achievements for both groups were the same for all of the problems, meaning that the MC component and ME component made similar contributions to achievement. This is supported by studies demonstrating the contribution of both the MC and ME components to achievement (see, for example, Schraw, Crippen, & Hartley, 2006; Veenman, Van Hout-Wolters, & Afflerbach, 2006).

The similarity in the two groups' achievements can also be explained in terms of the reciprocity between the MC and ME components. It seems that when we nurture one aspect of self-regulation, we affect the entire self-regulation process, thus leading to an improvement in the learner's achievements. This is supported by findings from previous studies examining the relationship between the MC and ME components, which found that one positively affects the other. For example, Kramarski and Michalsky (2009) studied the effects of two hypermedia environments (a system combining hypertext and multimedia) on the self-learning of university students studying teaching: a hypermedia environment with metacognitive instruction, and a hypermedia environment without metacognitive instruction. The results showed that exposure to metacognitive support, which prompted students to ask self-questions, improved the novice teachers' overall self-regulation capacity (MC and ME regulation). A different study, related to the IMPROVE program (metacognitive self-questioning method that engages learners in thinking and reflecting on their learning. The program is implemented mostly in mathematics and science, Mevarech & Kramarski, 1997), showed that this metacognitive intervention improved third graders' achievement in solving mathematical problems, boosted metacognitive abilities, and lowered anxiety levels (Kramarski, Weisse, & Kololshi-Minsker, 2010).

Similar findings have also been reported for middle-school students. For example, Kramarski and colleagues found that the performance of 15-year-old students who participated in online collaborative learning with metacognitive support improved in terms of self-regulation in general, compared to learners taught under the same learning conditions with no metacognitive support (Kramarski & Gutman, 2006; Kramarski & Mizrachi, 2006). It has also been found that support that strengthens learner motivation also improves academic involvement and learning competencies (Reschly, Huebner, Appleton, & Antaramian, 2008), and that a correlation exists between self-efficacy and motivation and metacognitive processes (Hoffman, 2010). Finally, it has also been found that students who believe in their own self-efficacy in performing academic tasks use more cognitive and metacognitive strategies (Hoffman, 2010). Regardless of previous accomplishments or capabilities, they work harder, persist longer, and keep up their achievements and competencies, even when coping with difficulties, as compared to their peers (Pajares, 2008; Pugh & Bergin, 2006).

Contribution of Study

The study offers a theoretical as well as a practical contribution. Theoretically, it deepens our understanding of the importance of supporting self-regulation in each of the two components, MC and ME, with regard to learners' problem-solving achievements and self-regulation processes. It also expands our knowledge of the implications of motivational-emotional awareness with regard to learning, which is a little-researched area. The present study was based on Pintrich's (2000) self-regulation model, a theoretical model focusing on the metacognitive and motivational components of self-regulation in adults. The present study extended this model to the emotional aspect of self-regulation while adapting it for the young learner.

In practical terms, the study developed two unique self-regulation interventions based on one theoretical model (Pintrich, 2000): a MC regulation intervention and a ME regulation intervention. As noted, there is a lack of ME intervention programs, and the study suggests an effective program that can also be tailored to young learners. Both interventions can be useful in teacher training and for training seminars on the subject of self-regulation approaches. These interventions can also be adapted for adults and young learners alike.

Limitations and Future Research

The study examined the effect of the intervention on MC regulation and ME regulation only in relation to solving problems. Furthermore, the interventions only comprised 10 sessions, the effects of which were examined immediately after completion. The interventions' efficacy could therefore be examined in other subjects and in a variety of learning environments. Long-term studies would be useful for determining the impact of the different programs and their long-term impact. In the present study, we also only used quantitative tools. We recommend also using qualitative tools such as interviews, and examining self-regulation processes in real time (solving problems aloud). Finally, since both the interventions were effective in terms of achievement and self-regulation, it would be interesting to explore the added value for achievement of an intervention combining the metacognitive and the motivational-emotional components of self-regulation.

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Appendix

An Example of an arithmetic series problem

Smiling Faces

For Gaya's birthday, Gaya's parents bought her a new computer game called Smiling Faces. Gaya was very excited about the game and read the instructions straight away. The instructions told Gaya that there are different stages in the game and she needs to color on each stage a number of faces that increases equally from stage to stage , as shown in the following example:

Stage 1: 4 faces
Stage 2: 5 faces
Stage 3: 6 faces

A. **Complete the table below**

STAGE	Number of Faces
1	
2	
3	
4	

Please fill in the numbers in the spaces below:

Stage 1: ______ + ________ = ________
Number of faces

Stage 2: ______ + ________ = ________
Number of faces

Stage 3: ______ + ________ = ________
Number of faces

3. Write a rule which describes the **relationship between the Stage number and the number of Faces:**
The rule is: ____

4. Give an example to the rule which describe the **relationship between the Stage number and the number of Faces.**
________ ________