IMPROVING METACOGNITIVE MONITORING IN MATH USING CUETHINKEF+

MEJORANDO EL MONITOREO METACOGNITIVO EN MATHEMÁTICAS USANDO CUETHINKEF+

Antonio Gutierrez de Blume	Sam Rhodes	Rick Bryck
Georgia Southern University	Georgia Southern University	Landmark College
agutierrez@georgiasouthern.edu	srhodes@georgiasouthern.edu	rickbryck@landmark.edu

Metacognition (MC) has been found to be a critical component of mathematical problem solving (PS; Rhodes et al., 2023). We report on the results of a study that employed an ANCOVA to examine the impact of a PS intervention that included MC supports (e.g., journaling) on students' objective MC within a sample of 276 middle school students. The results suggest that the intervention group significantly improved in their MC.

Keywords: Metacognition; Problem-Solving

Research has suggested that mathematical problem solving (PS) should be embedded within core instruction and should not be isolated from other factors such as content and metacognition (MC; Cai & Lester, 2010). Moreover, MC has been found to be a crucial factor influencing PS proficiency (Rhodes et al., 2023; Lester, 2013). Specifically, MC is thought to support problem solvers in nearly every aspect of the PS process, such as making sense of the problem, selecting and applying strategies, and reflecting and revising their thinking (Tan & Limjap, 2018).

Given these findings, it is unsurprising that interventions that include metacognitive training have been found to significantly improve students' PS performance (e.g., Kramarski et al., 2002). Metacognitive training is operationalized here-in as any support designed to help students utilize MC in the moment (e.g., being more intentional in heuristic selection, self-generating feedback based on their progress, etc.). Indeed, research has suggested that it is ineffective to attempt to isolate instruction on PS from the cognitive and metacognitive factors that influence it (e.g., Cai & Lester, 2010; Lesh & Zawojewski, 2007). However, few studies have explored whether interventions that interweave PS instruction with metacognitive supports result in improved MC. Thus, the purpose of the present study was to examine the effects of a web-based application, CueThinkEF+, that intentionally integrated scaffolds and supports that targeted MC, executive functions, and PS, on students' MC as operationalized by miscomprehension accuracy (the degree to which a person is able to accurately predict performance on a given task or measure).

Learning strategy use emerges from both contextual, cognitive, and personal factors (Panadero, 2017). Research differentiates between types of learning strategies that are hypothesized to improve metacomprehension accuracy, such as when judgments of comprehension are delayed (Shiu & Chen, 2013), individuals receive feedback (Brannick et al., 2005), and learners receive practice (Bol et al., 2005; Gutierrez & Schraw, 2015; Gutierrez & Price, 2017; Hacker et al., 2008; Thiede et al., 2012). Similarly, Nietfeld and Schraw (2002) and Gutierrez and Schraw (2015) found that students who received learning strategy instruction showed superior learning and more accurate monitoring. In the Nietfeld and Schraw (2002) study, which involved performance on probabilities, participants received an instructional sequence of five learning strategies (e.g., self-generated feedback, planning, self-questioning, etc.) discussed during instruction. Gutierrez and Schraw (2015) adapted these strategies and added others. The CueThinkEF+ intervention employs, among others, prompts that encourage self-questioning and intentional planning and reflection.

Additional work such as that of Nietfeld et al. (2006) found that distributed learning strategy instruction with feedback produced higher performance, confidence, and metacomprehension accuracy among college students, while Huff and Nietfeld (2009) found that strategy instruction with 5th grade students improved performance and metacomprehension accuracy. Bensley and Spero (2014) demonstrated that the direct infusion of learning strategies increased students' posttest metacomprehension accuracy while Schleinschok et al. (2017) reported that students who were taught to diagram as a learning strategy improved their metacomprehension accuracy of how well they thought they learned. However, students in the control condition also showed improved monitoring at posttest, although smaller than the treatment condition. This research supports the hypothesis that diagramming, as an example of a specific learning strategy, can improve metacomprehension accuracy. Furthermore, Miller and Geraci (2011) found that strategy instruction was only successful at improving metacomprehension accuracy for lower-performing students because higher-performing students already exhibited high metacomprehension accuracy. Taken together, these findings uniformly supported the hypothesis that metacomprehension accuracy was trainable and could be improved because of learning strategy instruction in various contexts and levels of specificity, including math.

Given the literature surveyed, the purpose of the present study was to answer the following research question: what is the effect of the CueThinkEF+ intervention on middle school students' metacognitive monitoring accuracy?

Conceptual Framework

Efklides (2011) devised the Metacognitive and Affective Model of Self-Regulated Learning (MASRL) in which metacognitive and motivational processes are key, centered on task, person, and task by person levels. The present study employs Efklides' (2011) MASRL as a theoretical guide because this model focuses on the central role metacognitive monitoring and control processes play in learning. More specifically, this model helps us better understand how person-level characteristics (e.g., motivation, engagement, interest, autonomy, task value, etc.) interact with the task (in this case, the CueThinkEF+ platform) and how metacognitive skills like monitoring and control help the moderate this interaction.

Method

Description of the Intervention

Over the course of one academic year, students in the control group continued with business-as-usual instruction while the intervention group used CueThinkEF+ approximately 5-7 times. Incorporating elements from the research noted above, CueThinkEF+ intentionally targeted MC during each phase of the PS process. Exemplifying this several of the supports, students were asked to: 1) consider what they noticed and wondered; 2) restate the question being asked in their own words; 3) create a journal of their plan for solving each problem which could then be updated or revised as they solved the problem; 4) record themselves explaining how they solved the problem, showing their work on a digital whiteboard including various tools and manipulatives; 5) watch the recordings of their peers and write annotations (e.g., "My strategy is like yours because…").

Participants

Three middle schools from a suburban school district participated in the study with one school serving as the intervention group and the other two schools serving as the control group. The district was located on the West Coast and all mathematics teachers at the three participating schools who taught grades 6-8 were invited to participate in the study. Ten teachers signed up to participate in the study and all students of participating teachers were then invited to participate in the study. Of the participating students, 278 students had complete data on the measures utilized within the present analyses. Given that only two of the students with complete data were 8th graders, the present analyses were confined to students in grades 6 and 7. Of the 276 remaining students, 188 students were in the intervention group and 88 students were in the control group. Within each group, the students were evenly split between 6 and 7th graders. Additional demographic data on the students is provided in Table 1 and Table 2 below.

Table 1: Number of Participants by Group and Gender

	n	Female	Male	Non-binary	Other/Did not Specify
Intervention	188	106	73	1	8
Control	88	36	39	2	11

Table 2: Participants by Group and Ethnicity

	Asian	Black/ African American	Hispanic/ Latin(x)	Middle Eastern	White	2 or More Races	Other/Did not Specify
Intervention	7.4%	4.3%	33.5%	24.5%	1.6%	16.5%	12.2%
Control	4.5%	4.5%	22.7%	36.4%	3.4%	17.0%	11.4%

Instruments and Materials

Problem Solving. PS items were compiled from items written by Illustrative Mathematics (IM) and aligned by the researchers to district pacing guides. For each grade level, three cognitively demanding items were selected with the only modification being that directions were added to require students to show or explain their thinking, when needed. Each item was scored for correctness using answer keys that were developed by IM. The interrater agreement on scoring was calculated using Fleiss' kappa and was .961 for 6th grade and .880 for 7th grade.

Metacognition. Prior to completing the PS measure, students were given a list of the mathematical topics that would be covered by the problems on the measure. Students were then asked to predict how well they would do by writing a numerical answer between 0 and 100, inclusive. Prediction accuracy scores were calculated by comparing participants' confidence in performance judgments before the performance assessment against their actual performance. Comparing prediction confidence in performance judgments against actual performance yielded continuous, absolute accuracy scores, as described by Schraw (2009). A score of "0" indicates perfect monitoring; conversely, the further a score is from "0," the greater the inaccuracy.

Data Analysis

Data were first tested for requisite statistical assumptions and tested for univariate outliers using box-and-whisker plots. The data met the assumptions of normality using skewness and kurtosis metrics, homogeneity of variance, and homogeneity of regression slopes. Further, the data did not contain any extreme outliers that would otherwise undermine the trustworthiness of the findings. Hence, data analysis proceeded without making any statistical adjustments.

To answer our research question, we employed a one-way analysis of covariance (ANCOVA), with condition (intervention, control) serving as our fixed factor, pretest prediction accuracy scores serving as the covariate, and posttest prediction accuracy scores serving as the outcome. The results of this analysis demonstrated that pretest prediction scores did not significantly influence posttest prediction scores, and hence, the analysis reverted to a one-way analysis of variance (ANOVA). Eta square (η^2) served as the metric for effect size estimate. Cohen (1988) was used for interpretative guidance on effect size within the present study.

Results

Results of the one-way ANOVA revealed a statistically significant main effect for condition on posttest prediction scores, $F(1,273) = 13.23$, $p < .001$, $\eta^2 = .045$, indicating a small-to-moderate effect size. Table 1 contains the descriptive statistics for the intervention and control groups, and it indicates that the intervention group manifested significantly higher posttest prediction monitoring accuracy compared to the control group.

Table 1: Descriptive Statistics of Posttest Prediction Monitoring Accuracy for the Intervention and Control Groups

	M	*SD*
Intervention (*n* = 188)	32.19	22.09
Control (*n* = 88)	41.98	22.77

Discussion and Limitations

The purpose of the present study was to investigate the effect of CueThinkEF+ on students' metacognitive monitoring accuracy in math. Results revealed a small-to-moderate effect of CueThinkEF+ on students' prediction accuracy when compared to business-as-usual instruction. These results extend the extant literature on metacognitive monitoring accuracy in a math context. They are also congruent with the body of literature that concludes that learning strategy interventions are successful at improving not only learners' performance, but also their monitoring accuracy using control processes to adjust their confidence in performance judgments (e.g., Gutierrez & Price, 2017; Nietfeld and Schraw, 2002; Thiede et al., 2012).

Moreover, the results of the present study provide additional evidence that MC and PS instruction should be intertwined in instruction (e.g. Lesh and Zawojewski, 2007). Specifically, the present study demonstrates that the intervention led to improvements in students metacognitive monitoring accuracy, extending prior analyses showing that the intervention also resulted in increases in student's PS proficiency (Rhodes et al., in preparation). Thus, it is possible that intentionally intertwining metacognitive training and supports with PS instruction may lead to meaningful gains in both areas.

Despite these promising results, the generalizability of the findings is limited by the fact that the study only included samples of students from grades 6 and 7 from a single district. In addition, the present study operationalized MC as metacomprehension monitoring accuracy. Future research should consider using additional measures of MC as well.

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