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Examining cyclical phase relations and predictive influences of self-regulated learning processes on mathematics task performance

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Abstract
The current study used microanalytic interviews and behavioral traces to examine sequential phase relations among forethought, performance, and self-reflection processes, and to investigate the predictive influence of these processes on mathematics performance of 96 eighth grade students. Consistent with expectations, students' microanlaytic goals and strategic plans (i.e., forethought phase) correlated at a statistically significant level with students' strategy use (i.e., performance phase), which, in turn, correlated with their attributions following performance (i.e., self-reflection phase). Regression analysis revealed that goal-setting and planning each explained a unique and medium amount of the variance in performance phase strategy use. Further, as expected, the two forethought phase processes did not predict any self-reflection phase processes. Contrary to expectations, however, metacognitive-monitoring (i.e., performance phase) did not correlate with most SRL processes, and students' strategy use were not empirically linked with students' adaptive inferences (i.e., self-reflection phase). In terms of predictive influences, students' strategic planning, strategy use, and metacognitive-monitoring correlated significantly and positively with mathematics performance, with strategy use and metacognitive-monitoring emerging as unique predictors of performance.

Keywords Self-regulated learning · SRL · Metacognition · Microanalysis · Mathematical problem solving · Middle school mathematics · Strategy use

Self-regulated learning (SRL) is generally conceptualized as a multi-dimensional set of processes (e.g., goal-setting, planning, strategy use, monitoring, & reflection) that enable the management and control over goal-directed thoughts, actions, and emotions (Panadero 2017;

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Schunk 2001). A variety of theoretical frameworks have been developed over the past few decades (Efklides 2011; Pintrich 2000; Winne and Hadwin 1998; Zimmerman 2000). Although these theories differ in important ways, such as the emphasis placed on cognition and metacognition, sources of motivation, and the nature of cyclical phases of SRL (Panadero 2017; Puustinen and Pulkkinen 2001), they also overlap in many respects. For example, most theories emphasize the integration of multiple regulatory processes, such as goal-setting, planning, strategy use, monitoring, and reflection. Moreover, SRL theories tend to depict SRL in terms of a *cyclical feedback loop*; a process that integrates multiple regulatory processes to guide planning, performance, evaluation, and adaptation to optimize success (Cleary and Zimmerman 2012).

Although the feedback loops described in each of the major models of SRL possess unique advantages, Zimmerman's three-phase model has been widely cited and used across multiple disciplines (Cleary and Callan 2017; Panadero 2017). Zimmerman (2000) illustrates the feedback loop in terms of three interconnected phases: *forethought, performance, and self-reflection*. From this perspective, forethought processes occur before performance and can enhance the quality and frequency of self-control (e.g., use of task strategies, attention focusing) and self-observation during performance. These performance phase processes will, in turn, influence the nature of student self-reflection, such as the self-judgments they make as well as their reactions to performance (Zimmerman 2000; Zimmerman and Moylan 2009). Future cycles of SRL are initiated as self-reflection processes influence the goals, plans, and motivation that students exhibit to continue their learning attempts.

Part of the reason for the broad appeal of Zimmerman's model to educators and researchers include its clarity in explaining SRL, its comprehensiveness in integrating the many sub-processes underlying regulation, and its applicability to intervention planning and development (Panadero 2017). Further, and of particular relevance to this study, Zimmerman's model has served as the theoretical foundation and guiding force behind the development of SRL microanalytic assessment protocols (Cleary and Callan 2017; Cleary et al. 2012); the key assessment approach utilized in the current study.

Although there is extensive data to support many of the assumptions and components of Zimmerman's model (Panadero 2017; Zimmerman 2013), there have been few attempts to systematically and comprehensively examine the empirical links among multiple sub-processes within each of the three phases that emerge during specific learning activities. The current study addresses this gap by using SRL microanalytic assessment procedures and trace methods to assess multiple phase-specific sub-processes of SRL exhibited by middle school students during a mathematics problem-solving practice activity.

Overview of Zimmerman's model of SRL

During his career, Zimmerman developed different social cognitive models of SRL to explain the components, dimensions, and development of human regulation (Zimmerman 2000, 2013). His initial model was based on Bandura's notion of reciprocal determinism, and the causal reciprocal relations that exist among personal, behavioral, and environmental dimensions (Zimmerman 1989). This model depicted three forms of SRL (i.e., personal, behavioral, and environmental), with each form represented by a strategy feedback loop. A key component of this model was that although the three feedback loops were separate, they could operate in an interdependent fashion to help individuals manage or adapt these different domains to optimize their learning or performance.

To more fully operationalize the nature of these feedback loops and to underscore the casual relations that potentially exist among SRL processes and motivation beliefs, Zimmerman developed a three-phase model of SRL. This model consisted of a forethought phase, performance phase, and self-reflection phase, within which all sub-processes of regulation were hypothesized to fall (Zimmerman 2000). The forethought phase entails processes and beliefs that occur as individuals prepare to learn or perform, such as deciding upon desired outcomes of learning or performance (i.e., goal-setting) and the methods or approaches that are needed to perform well on a given activity (i.e., strategic planning). A variety of motivation beliefs, such as self-efficacy and task-interest, are also included in the forethought phase given that engaging in SRL often requires much effort and persistence (Eccles and Wigfield 2002; Popa 2015). Zimmerman (2000) argued that collectively, forethought phase processes set the stage for learning and should, theoretically, impact how individuals regulate during learning, or the *performance phase*.

It is during learning or performance that individuals use various strategies (e.g., cognitive, metacognitive, and task strategies) to support and optimize attention, learning, and task completion. Regulated learners are also keen on engaging in self-observation, such as mental tracking of one's learning outcomes and behaviors or related processes (i.e., metacognitive-monitoring) or physically documenting these learning outcomes and processes (i.e., self-recording, Zimmerman 2013). These forms of self-observation are important because they help individuals optimize and track their learning during a task, but also because they help push the cyclical loop forward. Specifically, self-monitored information regarding achievement, behavior, cognition, affect, or environmental conditions serve as feedback that individuals can use to evaluate and react during self-reflection (Zimmerman 2000).

During this final phase of *self-reflection*, individuals address important questions regarding the level of performance or goal attainment (i.e., self-evaluation), their satisfaction or affect with the outcome (i.e., self-satisfaction), potential causes of successes or failures (i.e., attributions), and conclusions about necessary actions to optimize one's learning and progress toward goals (i.e., adaptive inferences). The reflection phase is a critical aspect of the feedback loop because of its potential influence on students' affective, cognitive, and behavioral reactions and propensity to adapt or change SRL for future task-engagement.

Zimmerman also created a multilevel model to describe the different levels through which individuals progress to become independent, self-sufficient regulators, such as observation, emulation, self-control, and self-regulated learning (Zimmerman 2000). It is with this model that educators and researchers have conceptualized and developed instructional or intervention programs to optimize student SRL (Cleary et al. 2017). Although each of the three Zimmerman models that were reviewed are important to understanding social-cognitive accounts of SRL, this manuscript examined the nature of the cyclical phase relations espoused in the three-phase model.

Empirical evidence for relations among SRL processes

There is a substantial literature base supporting the notion that SRL processes subsumed within the three-phase model (e.g., planning, motivation beliefs, strategy use, attributions) often correlate at a statistically significant level and/or causally influence each other. To examine these relations among context-specific regulatory processes, researchers have typically deployed event measures of SRL, such as think alouds, behavioral traces, or SRL microanalysis, in either experimental or descriptive designs. However, less research has measured multiple processes from each SRL phase *during a single task* to identify the unique contributions of individual SRL processes to predict subsequent phase processes.

Regarding experimental designs, research supports the causal relations between some forethought, performance, and/or self-reflection phase processes. For example, training individuals in forethought processes, such as goal-setting, has been shown to have positive impacts on performance phase SRL. When Schunk and Swartz (1993) trained students to focus on a process goal (i.e., to learn the steps of a strategy) and provided progress feedback, those students were significantly more strategic during a writing task compared to students who were directed to focus on a general goal (i.e., do their best).

There is also evidence that training students in both forethought and performance phase processes lead to adaptive changes in self-reflection phase processes, such as attributions or adaptive inferences. For example, Kitsantas and Zimmerman (1998) trained high school students to set goals, utilize task strategies, and self-monitor during a dart throwing task. Compared to the control group, the students who were trained to self-monitor their approach displayed more adaptive self-reflection in that they were significantly more likely to attribute failure to ineffective strategy use. Along a similar vein, training college students to set goals and self-monitor during a free-throw shooting task resulted in more strategic attributions and adaptive inferences following successful and unsuccessful free-throw attempts (Cleary et al. 2006).

Some research has also examined the link between reflection phase processes and forethought for future activities. As described earlier, Kitsantas and Zimmerman (1998) trained students to set goals, utilize strategies, and self-monitor, which influenced reflection phase attributions. In that study, individuals who made more adaptive attributions for failed dart-throwing attempts also tended to report greater levels of self-efficacy, satisfaction, and interest for future attempts (Kitsantas and Zimmerman 1998).

Regarding descriptive studies, researchers have recently used SRL microanalytic measures to examine the hypothesized relations among SRL processes across different phases of the feedback loop (Cleary et al. 2015; DiBenedetto and Zimmerman 2013). SRL microanalysis is a structured interview protocol that involves administering context-specific questions targeting SRL processes while individuals engage in a learning or performance attempt (Cleary et al. 2012). Microanalysis measures often entail brief, open-ended measures consisting of a single item, which contrasts more traditional measures, such as self-report questionnaires, that generally include several Likert type items that are aggregated to create a composite score.

Microanalysis protocols have been used to examine SRL processes across various activities, such as athletic tasks (e.g., throwing darts; Kolovelonis et al. 2010), academic or learning activities (e.g., reading and studying; DiBenedetto and Zimmerman 2013), and clinical-related activities (e.g., diagnostic reasoning; Artino et al. 2014). Regardless of the specific task around which one seeks to embed SRL microanalysis, it is important that the task be well-defined with a clear beginning, middle, and end because this enables researchers to embed the forethought, performance, and self-reflection microanalysis measures into the natural fabric of the activity. That is, forethought phase measures are administered before beginning the task, performance measures are administered during task-engagement, and self-reflection measures are administered following performance (Cleary 2011). By linking assessment with SRL theory and directly mapping the assessment administration onto the temporal aspects of the target task, researchers can collect real-time data regarding how SRL processes are initiated, sustained, or modified during authentic tasks.

Prior research has shown microanalysis measures to predict achievement or performance in a variety of contexts. For example, Kitsantas and Zimmerman (2002) administered 12 microanalytic measures while college-age participants practiced serving a volleyball. Collectively, these 12 measures explained 90% of the variance in volleyball serving skill at posttest. Relative to some other SRL measurement tools, microanalysis is a strong predictor. For example, microanalysis explained more variance in college student exam performance (Cleary et al. 2015) and middle school mathematics achievement (Callan and Cleary 2018) than a self-report questionnaire. In addition, interrater reliability has generally been very high when qualitative data is transformed to quantitative data (Cleary et al. 2012).

There are limitations associated with SRL microanalysis, such as the reliance on self-reported data and greater time requirements compared to some brief self-report questionnaires. Although microanalysis protocols are designed to minimize participant reactivity, to the authors' knowledge, no published research has examined the extent to which responding to microanalysis measures may influence participants' SRL or performance.

Regarding the use of SRL microanalysis to examine cyclical relations, DiBenedetto and Zimmerman (2013) studied high school students' SRL during a study session and a subsequent test. The authors of that study measured strategic planning just prior to students' engagement in a study session, whereas strategy use and metacognitive judgements of learning were measured while students completed a subsequent test. Finally, after the test, students provided self-evaluative judgements of their learning. The results provided some support for the cyclical assumption of SRL. Specifically, strategic planning correlated with two measures of students' metacognitive judgments of learning during test-taking (*r's ranging from* .28 to .35). In contrast, strategic planning did not predict students' reported use of strategies during performance. In terms of the performance – self-reflection phase link, the authors reported that strategy use and metacognitive judgments of learning (i.e., performance phase) correlated at a statistically significant level with students' overall evaluative judgments about their learning (*r's ranging from* .36 to .66, respectively).

Cleary et al. (2015) used microanalytic procedures to examine the link between self-reflection phase processes and future forethought. College students were interviewed regarding their self-reflection on a previous course exam and their motivational beliefs for a future exam. The results showed that all three reflection processes (i.e., satisfaction, self-evaluative standards, and attributions) were strongly correlated with students' subsequent self-efficacy perceptions (*r's ranging from* .38 to .68).

Despite evidence from experimental and descriptive studies supporting some aspects of the cyclical feedback loop, there have been relatively few attempts to examine the extent to which sequential phase relations exist across multiple sub-processes within each of these phases. Along a similar vein, these studies have not identified the unique contributions of individual processes in the prediction of subsequent phase processes (e.g., to what extent do forethought phase planning and goal-setting uniquely predict performance phase strategy use and metacognitive-monitoring). Addressing the nature of these cyclical phase relations is consistent with recent research calls to comprehensively examine the various regulatory sub-processes embedded in SRL models as they emerge in specific contexts or situations (Cleary and Callan 2017; Panadero 2017). In addition, prior microanaltyic studies examining cyclical relations have often shifted across multiple related tasks (i.e., studying for and taking an exam). Thus, there is a need to utilize microanalysis to study cyclical relations among SRL processes within a single, complex, academic task.

Objectives and purposes

The primary purpose of the current study was to examine whether cyclical phase relations existed across the three-phases as students engaged in a mathematics problem-solving activity. Using a comprehensive SRL microanalytic protocol, we assessed students' SRL processes before they attempted to solve the mathematics problems (i.e., forethought; goal-setting, strategic planning) during their attempts to solve mathematics problems (i.e., performance; strategy use, metacognitive-monitoring), and following feedback about performance (i.e., self-reflection; attributions, adaptive inferences). We supplemented the performance phase data with behavioral traces to examine in a more robust way students' use of strategies during the task. Prior research has not utilized microanalysis and behavioral traces concurrently to examine cyclical phase relations.

We addressed several broad research questions. First, we tested the assumption that forethought phase processes (i.e., goal-setting and strategic planning) are predictive of performance processes (i.e., strategy use and metacognitive monitoring), which in turn are predictive of self-reflection phase processes (i.e., attributions and adaptive inferences). In doing so, we examined the extent to which each process uniquely predicted subsequent phase processes. Based on theory and prior research (DiBenedetto and Zimmerman 2013; Zimmerman 2000), we expected to observe positive relations between forethought and performance processes and between performance and self-reflection processes. In comparison to the relationships between theoretically adjacent processes, we expected to observe smaller relationships between forethought and self-reflection phase processes.

The second objective was to identify the SRL processes that emerged as the strongest predictors of students' mathematical problem solving (MPS) performance. MPS is important because it is a task with which many students struggle and it may act as a barrier to career options (Forgione 1999). Although prior research suggests that several SRL processes, such as strategic planning (Schoenfeld 1985), strategy use (Montague 2008), and metacognitive-monitoring (Callan and Cleary 2018; Schoenfeld 1985) relate positively with mathematics achievement, research is needed to examine multiple SRL processes concurrently while students are authentically engaged in a mathematics task. Such research can help to identify the relative weight of individual SRL processes. Moreover, microanalysis has most often been used to study motor tasks (Cleary et al. 2012). Extending microanalysis to complex academic tasks, such as MPS, is an important contribution to the microanalytic literature and may also lead to instructional supports for students.

In prior microanalytic research, measures of strategic planning, strategy use, and metacognitive-monitoring typically emerged as strong predictors of achievement (Callan and Cleary 2018; Cleary and Callan 2017; DiBenedetto and Zimmerman, 2013). Thus, based on prior microanalytic and mathematics research, we hypothesize that these measures will emerge as the strongest predictors. Although self-reflection phase processes have also been shown to predict achievement in prior microanalytic research, we did not include these measures in predictions of mathematics performance in the current study because they were administered following performance feedback on the mathematics outcome.

Methodology

Participants

The sample consisted of 96 eighth graders attending an urban school district in the Midwest of the United States. Fifty-four females (56.2%) participated and most of the sample (90.7%) met eligibility requirements for free or reduced lunch. The sample included 49 (51%) Hispanic-Latino students, 45 (46.9%) African-American students, and 2 (2.1%) Caucasian students.

Procedures

Each participant met individually with a graduate research assistant to complete a *mathematics practice session* consisting of three, individually administered, multi-step mathematical word-problems. The mathematics problems ranged in difficulty to increase the probability that participants experienced some challenge or failure on at least one problem. Students were provided scrap paper to perform operations, make a drawing, write out notes, etc. There was no time limit, but the activity typically lasted 20–30 min.

Several SRL microanalytic questions were administered before, during, and after the practice session. Forethought phase questions (i.e., goal-setting, planning) were administered prior to solving problems, performance phase questions (i.e., strategy use, metacognitive monitoring) during the problem-solving, and self-reflection questions (i.e., attributions, adaptive inferences) following the practice session. Immediately before participants attempted to solve the mathematics problems, the examiner instructed them to briefly read and preview them. This helped to ensure that participants understood the nature of the problems prior to answering the two forethought questions. The examiner then administered the goal-setting question which was followed by the strategic planning measure. After recording participant responses, the examiner provided participants with paper and a pencil and instructed them to begin working on the first problem.

Solving the mathematics problems was considered the during phase of the practice session, and thus, SRL microanalytic performance phase measures of strategy use and metacognitive-monitoring were administered at that time. Consistent with prior SRL microanalytic research (Kitsantas and Zimmerman 2002), we elected to administer the strategy use measures immediately following the completion of the first and third mathematics problems, rather than during problem solution, to minimize disruptions or prompting that might influence examinees' natural engagement in strategy use during the task. The scrap paper provided to participants was used to gather behavioral trace data. After completing all three mathematics problems, participants completed a metacognitive-monitoring item regarding their perceived performance on each item. The interviewer then directed all participants' attention to the first problem that they solved incorrectly to standardize the outcome about which they were reflecting. This was done because reflection may differ across outcome types (i.e., success or failure). The two microanalytic self-reflection measures (i.e., attributions and adaptive inferences) were then administered.

Measures

Six microanalytic measures were used to examine students' SRL processes across the three phases of SRL: forethought (i.e., goal-setting and strategic planning), performance control (i.e., strategy use and metacognitive-monitoring), and self-reflection phases (i.e., attributions and adaptive inferences) in relation to the practice session. Except for the metacognitive-monitoring measure, all SRL microanalytic measures adhered to a free-response format. For these questions, responses were audio recorded, transcribed, and coded by two independent raters. A behavioral trace measure was used to examine participants' use of strategies when solving mathematics problems.

Goal-setting Consistent with prior research (Cleary and Zimmerman 2001), goal-setting was measured using a single, contextualized question. Specifically, the interviewer asked, "Do you have a goal in mind as you prepare to practice these math problems? If so, what is it?" The coding manual in the current study emphasized the comprehensiveness of goals. Thus, coders counted the number of components of mathematical strategies that students listed within their goal. A coding manual that identified 5 categories of tactics, such as identifying key information, transforming or elaborating upon problem information (e.g., analogous problem or drawing a picture), hypothesizing an answer, developing an equation, and checking work was developed following an analysis of mathematics literature, expert consensus, prior coding manuals, and pilot testing (see Appendix Table 6 for further details regarding the tactics). Prior research has shown similar one-item goal-setting measures to significantly differentiate expertise levels in motoric contexts and to correlate with other regulatory processes (Cleary and Zimmerman 2001). The inter-rater reliability in the current study was excellent (98.6% agreement).

Strategic planning This one-item forethought measure examined participants' strategic plans prior to solving the mathematics problems. The interviewer asked, "Do you have any plans for how to successfully complete these math problems?" If a codeable response was provided, the interviewer prompted, "Is there anything else that you did?" a maximum of two times. A coding scheme (identical to the goal-setting item; see Appendix Table 6) was used to count the number of strategy components identified within students' plans. For example, if students indicated a plan to "draw a picture" the coders would count one strategy component. Prior research has shown a similar one-item strategic planning SRL microanalytic measure to exhibit high inter-rater reliability and to reliably differentiate experts, non-experts, and novices (DiBenedetto and Zimmerman 2013). The inter-rater reliability in the current study was high (96.3% agreement).

Strategy use Strategy use was measured using two distinct measures, a microanalytic strategy question and behavioral traces. Regarding the microanalytic measure, immediately following students' completion of each of the first and third mathematics problems, the interviewer administered the question, "Tell me all of the things that you did to solve this problem." Prompting and coding procedures were identical to the strategic planning item. Coders counted and then averaged the number of strategies listed for the first and third mathematics problem. Prior research has shown a similar measure to predict future performance on academic tasks (DiBenedetto and Zimmerman 2013). The inter-rater reliability in the current study was high (96.8% agreement).

Behavioral traces entail examining work products to identify indicators of SRL. For example, Perry and Winne (2006) utilized a behavioral trace methodology to examine SRL during a studying task and recorded behavioral traces such as learner-generated notes, graphic organizers, mnemonics, or underlining of text. In the current study, students were provided each mathematics problem which included blank space to complete work. In addition to this "work paper" participants could request additional paper. Students were instructed to do their work on the paper, to not erase any of their work, and to lightly cross out their work if they decided to start over. Two independent coders visually inspected the work paper that each participant used to work out the first and third problems as the basis of the behavioral traces measure of strategy use. Coding of behavioral traces entailed counting the number of visible strategies on the work paper such as lists of key information, drawing, etc. For example, when looking at the work paper, some participants underlined key words in the problem description. This would be an example of a strategy. The coding categories were identical to the micro-analysis items (see Appendix Table 6 for additional details). Two independent raters displayed high inter-rater agreement (percent agreement = 98.5%).

Metacognitive-monitoring The metacognitive-monitoring measure examined the accuracy of participants' performance estimations relative to their actual performance on the three word problems. Immediately after students completed all three mathematics problems, the examiner asked, "How sure are you that you solved this problem correctly?" Students responded on a 7-point Likert scale for each problem. Anchor points for this measure included 1 (not sure), 3 (somewhat sure), 5 (pretty sure), and 7 (very sure). Each student's actual performance (1 to 7) was subtracted from his or her confidence rating for that problem (1 to 7). If a student reported high confidence (7), and answered the question completely correct (7), their score revealed perfect accuracy (7–7 = 0). In contrast, if the student indicated high confidence (7), but answered the problem completely incorrectly (1), their score reveals high inaccuracy (7–1 = 6). The absolute value of the difference score was used. Thus, scores for each mathematics problem could range from zero to six, and the mean was computed across the three practice session problems. Because greater accuracy is considered adaptive, values were reversed so higher scores represented better accuracy. Prior research has shown this type of measure to differentiate achievement groups and to predict future achievement (Zabrucky et al. 2009).

Attributions This one-item measure examined students' perceptions of the causes of their struggle on a mathematics problem that they solved incorrectly. The examiner stated, "You answered this item incorrectly. Why do you think you were unable to get the right answer for this problem?" Prompting procedures were identical to the strategic planning and strategy use measures. Coding of responses to the attribution was similar to the coding procedures for the strategy use measure in that coders counted the number of strategies (see Appendix Table 6) that participants identified in their response. For example, participants may have mentioned that they failed to get the problem correct because they did not draw a picture to help them understand the problem. Prior research has shown similar measures to reliably differentiate achievement groups and respondents with more strategic attributions also indicated higher self-efficacy, greater task achievement and interest, and more positive self-reactions (Kitsantas and Zimmerman 2002). Inter-rater reliability agreement was excellent in the current study (96.4% agreement).

Adaptive inferences A one-item measure of adaptive inferences was administered to assess participants' conclusions regarding the changes they perceived they needed to make to improve performance on similar mathematics problems. Participants were asked, "If you were given another chance to do a similar math problem, what would you need to do to do well?" Prompting and coding procedures were identical to attributions measure. This measure is a slight variation from prior research that has shown high inter-rater reliability ($r = .93$) and to differentiate achievement groups (DiBenedetto and Zimmerman 2013). The inter-rater reliability in the current study was high (94.3% agreement).

Prior mathematics achievement A district required standardized test of mathematics skill was administered to participants at the beginning of the school year. This measure, the Measure of Academic Progress (MAP; Northwest Evaluation Association 2011), served as a measure of prior mathematics achievement. The MAP is a computer-adaptive test designed to measure mathematics achievement for elementary and secondary students. The MAP has been shown to exhibit strong test-retest reliability (.77 to .94) and large correlations with other academic achievement tests including the Iowa Test of Basic Skills (ITBS; $r = .77$ to .84; NWEA 2011).

Practice session achievement This measure involved students' performance on the three, multistep, algebraic word problems completed during the practice session. The problems were selected by experts from a pool of released NAEP items for their appropriateness. The authors intentionally selected problems ranging from easy to difficult in an effort to ensure that all participants would incorrectly answer one word problem. Item difficulty was determined by normative performance data suggesting that most students (> 80%) would fail to complete the difficult problem correctly and that most students (> 80%) would complete the easy problem correctly. This was done to standardize the self-reflection phase measures (i.e., attributions and adaptive inferences) such that all students would reflect upon a failure experience. Each problem was scored by the first author and a middle school mathematics teacher from a different school district. Scores ranging from one to seven, reflected the proportion of correctly completed steps for each problem. Inter-rater reliability was high (percent agreement 96.3%).

Analysis plan

To examine the cyclical nature of relations among SRL processes, Pearson correlations and regression analyses were used. One-tailed tests were used because directional, a priori hypotheses were established. For the regression analyses, we included prior mathematics achievement as a control given that prior research shows that high-achievers are often more strategic in their approach to solving mathematics problems than their lower achieving peers (Montague 2008).

Regression analyses were also used to identify specific SRL processes that were most predictive of student performance during the mathematics practice session. We computed Pearson correlations between forethought and performance phase SRL process and mathematics practice session achievement. Self-reflection phase processes were not considered in the regression given that these measures were administered following performance feedback. Prior achievement was included in the first step in the regression model, and then all SRL constructs that correlated at a statistically significant level with practice session achievement were then included in the second step of a regression analysis. Semi-partial squared regression coefficients, which indicates the unique predictive contribution of that predictor while controlling all other predictors in the model, were calculated for each predictor variable. An a priori power analysis revealed that our sample size provided adequate power ($\beta => .80$) for the identified regression analyses with an anticipated small effect size.

Results

Means and standard deviations are reported in Table 1. Data screening procedures indicated that statistical assumptions were met. Pearson correlations and regression procedures were used to test hypotheses regarding the cyclical phase relations. Several of the hypothesized relations were confirmed (see Table 2).

Forethought to performance cyclical relations

Both forethought measures (i.e., goal-setting and strategic planning) exhibited statistically significant, medium correlations with the microanalytic measure of strategy use ($r = .30$; $r = .41$), and statistically significant, small correlations with the behavioral trace measure of strategy use ($r = .21$; $r = .24$) gathered during the practice session. Thus, students who set more specific goals and developed more comprehensive strategic plans were more likely to exhibit strategic thinking and behaviors during the practice session.

Two follow-up regression analyses were conducted to identify the amount of unique variance in strategy use attributed to goal-setting and planning, after controlling for prior achievement. The first regression utilized the microanalytic strategy use measure as the dependent variable and showed that the SRL microanalytic goal-setting and planning measures collectively accounted for a significant, large (Cohen 1988) increase in strategy use in the second step, $F(3, 93) = 11.27$, $p < .001$, $R^2 = 0.297$ after controlling for prior achievement. Squared semi-partial regression coefficients indicated that goal-setting and planning respectively predicted a small and medium amount (10 and 14%) of the unique variance in strategy use after controlling for all other predictors (see Table 3). The second regression model utilized behavioral traces of strategy use as the dependent variable. A similar, although smaller effect was observed. Goal-setting and planning collectively accounted for a small statistically significant increase in strategy use, $F(3, 93) = 3.153$, $p = .02$, $R^2 = 0.11$, with goal-setting and planning uniquely accounting for a small amount of variance (five and 4 %) in strategy use, respectively, after controlling for all other predictors (see Table 4).

In contrast to our expectations, neither goal-setting nor strategic planning related to students' metacognitive-monitoring during the practice session ($r = -.14$; $r = .00$). That is, students who set specific goals and who developed more comprehensive strategic plans were not more likely to exhibit greater accuracy in judgments of performance relative to the mathematics problems. As a result, a subsequent regression was not completed.

Table 1 Descriptive statistics of key measures and variables

Measure	Mean	SD	Range
Prior mathematics achievement	496.87	34.93	371–600
Micro goal-setting	0.25	0.65	0–3
Micro strategic planning	0.54	0.76	0–4
Micro strategy use	1.2	1.16	0–5
Traces strategy use	2.11	1.32	0–6
Metacognitive-monitoring	3.79	1.03	1.67–5.92
Micro attributions	0.06	0.24	0–1
Micro adaptive inferences	0.58	0.72	0–3
Practice session achievement	6.01	5.0	0–17

"Micro" indicates that the construct was measured via SRL microanalysis. "Traces" indicates that the construct was measured via behavioral traces

Table 2 Correlation coefficients between SRL measures and math achievement

Construct	1	2	3	4	5	6	7	8
1. Micro goal-setting	–							
2. Micro strategic planning	.02	–						
3. Micro strategy use	.30**	.41***	–					
4. Traces strategy use	.21*	.24**	.51***	–				
5. Micro metacognitive-monitoring	−.14	−.00	.01	.05	–			
6. Micro attributions	−.06	−.01	.19*	.05	.07	–		
7. Micro adaptive inferences	.08	.16	.02	−.08	−.18*	.15	–	
8. Practice session achievement	.03	.18*	.28**	.32**	.37***	.10	−.22*	–

"Micro" indicates that the construct was measured with SRL microanalysis. "Traces" indicates that the construct was measured with behavioral traces. Practice session performance = the sum score on the three items administered during the MPS practice session

*Denotes statistically significant finding using one-tailed test at $p < .05$

**Denotes statistically significant finding using one-tailed test at $p < .01$

***Denotes statistically significant finding using one-tailed test at $p < .001$

Forethought to self-reflection cyclical relations

We predicted that forethought processes (i.e., goal-setting and strategic planning) would not correlate significantly with self-reflection phase processes (i.e., attributions and adaptive inferences). This hypothesis was confirmed (attributions, $r = -.06$; $r = -.01$; adaptive inference, $r = .08$; $r = .16$; see Table 2). That is, individuals who created more comprehensive goal and/or strategic plans were not more likely to attribute failure to ineffective strategies or highlight the importance of adapting strategies for future task attempts.

Performance to self-reflection cyclical relations

In terms of the hypothesis that performance phase strategy use is linked to self-reflection phase processes (i.e., attributions and adaptive inferences), the results were mixed. We observed a statistically significant, albeit small, relation between microanalysis strategy use and attributions following failure on a practice session problem ($r = .19$). Thus, students who reported

Table 3 Forethought processes predicting self-reported strategy use during practice session

Variable	*Zero order correlation*	*Semipartial correl. (sr2)*	β	*T*	ΔR^2
Step 1					.05*
Prior math achievement	.22	.22(5%)	0.22	2.02*	
Step 2					.25***
Prior math achievement	.22	.15(2%)	0.15	1.59	
Micro goal-setting	.34	.32(10%)	0.32	3.42**	
Micro strategic planning	.41	.38(14%)	0.38	4.01***	

Step 1: Total/Adjusted R^2 = .047/.036; Step 2: Total/Adjusted R^2 = .297/.271. Micro = this construct was measured with SRL microanalysis. sr^2 = semi-partial squared represents the proportion of unique variance in mathematics test scores accounted for a specific predictor after controlling for all other variables

*$p < .05$

**$p < .01$

***$p < .001$

Table 4 Forethought processes predicting behavioral traces of strategy use during practice session

Variable	*Zero order correlation*	*Semipartial correl. (sr2)*	β	t	ΔR^2
Step 1					.01
Prior math achievement	.09	.09(<1%)	0.09	0.85	
Step 2					.10*
Prior math achievement	.09	.06(<1%)	0.06	0.52	
Micro goal-setting	.24	.23(5%)	0.23	2.2*	
Micro strategic planning	.21	.22(5%)	0.21	2.0*	

Step 1: Total/Adjusted R^2 = .01/0.0; Step 2: Total/Adjusted R^2 = .11/.07. Micro = this construct was measured with SRL microanalysis. sr^2 = semi-partial squared represents the proportion of unique variance in mathematics test scores accounted for a specific predictor after controlling for all other variables

$^*p < .05$

focusing on specific mathematics strategies during performance were more likely to identify insufficient strategies as the primary reason for their struggle on the problem. However, this relation was not statistically significant when behavioral traces were used as the measure of strategy use ($r = .02$). In contrast to our hypotheses, metacognitive-monitoring did not correlate in a statistically significant, positive direction with either self-reflection phase process. In fact, a small statistically significant and negative correlation was found between monitoring and adaptive inferences ($r = -.18$). Thus, the extent to which students accurately evaluate their performance on the mathematics problems was not empirically linked to the comprehensiveness of their goals, strategic plans, reflective judgments, or reactions.

Predicting mathematics practice session achievement with SRL processes

We examined the predictive contribution of SRL processes on mathematics problem solving achievement during the practice session problems. Strategic planning, strategy use (microanalysis and behavioral traces), and metacognitive-monitoring were found to exhibit small to medium significant and positive correlations with practice session achievement (see Table 2). A regression model, which included prior achievement in the first step and SRL processes in the second step, was computed. In the second step of the regression, prior achievement and strategy use (behavioral traces) each accounted for a small amount (4 %) of the variance in practice session achievement whereas metacognitive-monitoring accounted for a medium amount (13%; see Table 5).

Discussion

The key objectives of the current study were to examine the nature of cyclical phase relations among multiple SRL processes and to identify which processes are most predictive of students' mathematics performance. Although the results were somewhat mixed, they confirmed many theoretical predictions and have important implications. Moreover, this study was important because it was one of the first microanalytic studies to examine the complex relations among multiple processes within each of the phases of Zimmerman's three-phase model of SRL during a single learning activity. This study also contributes to prior research displaying correlations among SRL processes. Specifically, by measuring two sub-processes within each of the three phases and including both microanalytic and behavioral trace

Table 5 SRL processes predicting practice session achievement

Variable	*Zero order correlation*	*Semipartial correl. (sr2)*	β	*t*	ΔR^2
Step 1					.10**
Prior math achievement	.32	.32(10%)	.32	3.06**	
Step 2					.23***
Prior math achievement	.32	.20(4%)	0.21	2.2*	
Micro strategic planning	.12	.01	0.01	0.05	
Micro strategy use	.29	.09(1%)	0.12	0.97	
Traces strategy use	.35	.20(4%)	0.24	2.18*	
Micro metacognitive-monitor	.40	.35(13%)	0.36	3.74***	

Step 1: Total/Adjusted R^2 = .10 /.09; Step 2: Total/Adjusted R^2 = .33 / .29. Micro = this construct was measured with SRL microanalysis. Traces = this construct was measured with behavioral traces. sr^2 = semi-partial squared represents the proportion of unique variance in mathematics test scores accounted for a specific predictor after controlling for all other variables

*$p < .05$

**$p < .01$

***$p < .001$

measures, we were able to perform a more nuanced analysis of the inter-phase relations and to identify the relative predictive contributions of individual processes on subsequent phases. Finally, our results indicated that several processes from multiple phases related to and predicted practice session achievement.

Relations among forethought, performance, and self-reflection phase processes

Overall, support for our hypotheses regarding the relations among forethought, performance, and self-reflection processes was mixed. The most consistent finding was that forethought phase processes were strong predictors of students' strategy use during the practice session. Interestingly, *both* goal-setting and strategic planning each predicted a small to medium amount of unique variance in students' strategies, regardless of the types of measure used (i.e., microanalysis, behavioral traces). These results are compelling because they suggest that multiple preparatory processes play a unique role in students' enactment of strategies during learning. Thus, educators and interventionists may influence strong gains in strategic behavior by optimizing student's goal-setting and planning skills concurrently.

It should be noted that some prior research that has shown large correlations among forethought and performance phase processes when SRL was measured with questionnaires (Toering et al. 2012). The unique predictive contributions in our study were smaller. In addition, the size of the predictions were smaller when strategy use was measured with behavioral traces compared to when microanalysis was used to measure strategy use. Our results may have contrasted prior research due to the use of unique measurement formats (e.g., microanalysis). In addition, the current study was the first time that microanalysis has been used to predict behavioral traces, and thus, it is difficult to compare our results to the prior literature.

Compared to the relatively robust literature displaying that students who set adaptive goals tend to be more strategic during performance (Schunk and Swartz 1993) our study is one of the first microanalytic studies to illustrate a strong link between strategic planning during forethought and the use of strategies during task performance. That is, students who think more strategically just before a task tended to use more strategies during the task. From our perspective, this link is important given that strategic planning measures have been, to date, the strongest microanalytic predictors of achievement (Cleary and Callan 2017). Although we did not directly test this hypothesis, our results suggest that strategic planning may have a direct effect on achievement as well as a mediated effect through strategy use.

Some research has contrasted our findings regarding the link between strategic planning and strategy use. For example, in a study targeting reading and studying behaviors, researchers found that high school students who identified more strategies within their plans before reading and studying text about tornadoes, *were not* more likely to report using task-relevant strategies during the actual study session than those who developed less robust plans ($r = .08$; DiBenedetto and Zimmerman 2013). The discrepancy between our results and the findings of DiBenedetto and Zimmerman (2013) may to be due to differences in the microanalytic measures. Specifically, in our study, strategic planning and strategy use measures both were aligned with a single task (i.e., completing mathematics problems) whereas in DiBenedetto and Zimmerman (2013), the planning measure was administered with respect to a study session while the strategy use measure was linked to test taking. Thus, the observed connection between planning and using strategies in our study was more direct.

A key finding in our study, however, was that forethought phase processes did not predict all types of performance phase processes. Specifically, neither forethought process related to metacognitive-monitoring. In fact, metacognitive-monitoring did not correlate with any other SRL process in the study. The weak relations between metacognitive-monitoring and SRL processes from both forethought and self-reflection phases in our study contrasts some prior research. For example, teaching students to self-record their approach during dart-throwing has been shown to relate to more strategic attributions, improved motivation (i.e., self-efficacy and interest), and satisfaction (Kitsantas and Zimmerman 1998; Zimmerman and Kitsantas 1997). Further, monitoring the use of strategies or process has been shown to influence the type of reflective judgments and reactions that students make (Cleary et al. 2006).

An important distinction between these prior studies and the current study is that our study measured monitoring via performance estimations whereas prior studies emphasized monitoring of specific processes. Moreover, most of the SRL processes targeted in our study pertained to strategic thinking or action, with the metacognitive-monitoring measure being the notable exception. Thus, it makes sense that these other SRL processes typically converged in expected ways whereas metacognitive-monitoring did not. An important line of future research may be to examine the cyclical relations of SRL processes while measuring multiple forms of self-monitoring including performance estimates and process monitoring measures.

Some research using metacognitive-monitoring measures similar to the one we used, support the notion that metacognitive-monitoring may not be causally linked to other SRL processes in all situations or for all students (Dinsmore and Parkinson 2013; Tuysuzoglu and Greene 2015). One explanation for this lack of convergence is that metacognitive-monitoring is more stable or trait-like in nature whereas other SRL processes differ more across contexts. For example, students tend to report similar levels of metacognitive-monitoring across a variety of domains, but strategy use tends to vary across contextual factors (Greene et al. 2015; Lodewyk et al. 2009).

In contrast, other research suggests that metacognitive-monitoring is influenced by both traits and contextual factors. Specifically, Dinsmore and Parkinson (2013) asked college students to read a passage of text and answer a series of questions about the text. Participants ranked their confidence for each question and explained the reasons for their ratings with an open-ended response. Results indicated that confidence ratings were based on personal factors, such as prior knowledge, as well as contextual factors such as the text features. Thus, differences in monitoring and other SRL processes are not simply explained by their situational specificity.

Another explanation is that the link between metacognitive-monitoring and other SRL processes varies across student achievement level. That is, high achievers link metacognitive-monitoring with other SRL processes whereas lower achievers do not. For example, when high achievers detect ineffective learning through monitoring, they adjust their use of strategies, but lower achieving students fail to do so (Tuysuzoglu and Greene 2015). Although we did not examine this question in our study, high and low achieving students in our sample may have displayed a similar pattern of results, but when aggregated, these processes did not relate.

Taken together with prior findings, our results are important and suggest that researchers and educators should not expect that teaching students to set goals and plan strategically will translate into improvements in metacognitive-monitoring for all students. In addition, students who metacognitively-monitor accurately may not adjust their approach adaptively. From our perspective, it is important for researchers and educators to directly assess if their students link metacognitive-monitoring with other SRL processes and to intervene when they do not. That is, teaching students to utilize metacognitive-monitoring data may support achievement and help establish self-sustaining cycles of SRL.

We found some support that performance phase processes relate to self-reflection processes. Students who reported greater use of strategies were significantly more likely to attribute failure to inadequate use of strategies. Although the effect was small, these findings complement prior research showing that students who are trained to focus on the use of strategies during task performance are more likely to attribute performance outcomes to strategies (Cleary et al. 2006, 2017; Kitsantas and Zimmerman 1998). For example, when students were taught to focus on and monitor their use of a free-throw shooting strategy during a practice session, they were significantly more likely to make strategic attributions and strategic adaptive inferences following failed shooting attempts compared to students in a control group (Cleary et al. 2006). In addition, Kitsantas and Zimmerman (1998) showed that training students to set goals and to use a specific dart throwing strategy resulted in students making more strategic attributions following successes and failures. Given the descriptive nature of our study, it is important for future research to experimentally examine whether training students to focus on specific task strategies while solving mathematics problems leads them to attribute failure experiences to inadequate use of strategies rather than less desirable or uncontrollable factors (e.g., ability).

Adaptive inferences did not correlate positively with any of the SRL measures and correlated negatively with metacognitive-monitoring. These findings are consistent with some prior microanalytic research that has also found non-significant relationships between adaptive inferences and other theoretically linked SRL processes (Cleary et al. 2015). Measuring adaptive inferences poses several challenges. For example, we intended to measure how participants would approach similar mathematics problem in the future. Qualitative analysis of responses revealed that many participants' responses reflected statements about specific computational errors for the specific mathematics problem that they had just completed (e.g., "I should have added three"), rather than more broad conclusions about how their approach should be refined or modified to support future mathematics performance. Thus, we were not able to target the desired construct with all students.

SRL and practice session achievement

We also examined the extent to which forethought and performance phase SRL processes measured before and during the practice session predicted mathematics problem-solving achievement. Although prior achievement, strategic planning, strategy use (microanalysis and behavioral traces), and metacognitive-monitoring all correlated significantly and positively with mathematics performance, the strongest predictors were prior achievement, behavioral traces, and metacognitive-monitoring. Behavioral traces and prior achievement both uniquely explained a small amount of variation (4% for both) whereas metacognitive-monitoring accounted for a medium amount of variation (13%). A few points regarding these findings warrant further discussion.

First, multiple measurement methodologies (i.e., microanalysis and behavioral traces) were significant predictors of practice session achievement. These findings complement other research that has shown an added value to using multiple SRL measurement methodologies (Cleary and Callan 2014). For example, Cleary and Callan (2014), measured students' SRL with a self-report questionnaire and teacher rating scale and found that both measures contributed significantly to the explanation of achievement. Thus, researchers and practitioners may also benefit from utilizing multiple methods to measure SRL as well.

A second point is that multiple distinct SRL processes (i.e., strategy use and metacognitive-monitoring) uniquely and significantly predicted practice session achievement. These findings are consistent with prior research showing metacognition and strategy use to be strong predictors of mathematics (Montague 2008; Van der Stel and Veenman 2008; Van Luit and Kroesbergen 2006). Interestingly, metacognitive-monitoring was the strongest predictor of mathematics achievement even when compared to prior achievement on a standardized test, and strategy use was on par with prior achievement. These findings are provocative given that standardized tests receive far more attention in schools than the assessment of SRL processes (Cleary 2011). Thus, educators may also wish to also emphasize the measurement of academic enablers such as SRL. Moreover, these findings are encouraging because intervention programs are available to improve students' metacognitive-monitoring and strategy use (Dimmitt and McCormick 2012; Montague 2008; Zimmerman et al. 2011). It may be possible that the metacognitive-monitoring measure emerged as such a strong predictor because it was a narrow and achievement focused measure relative to the other measures.

The fact that strategy use and metacognitive-monitoring were both significant predictors of practice session achievement is especially pertinent when considered in conjunction with our findings regarding the cyclical relations of SRL processes. Specifically, strategy use was linked to goal-setting and planning during forethought and attributions during reflection, but metacognitive-monitoring was not positively related with other SRL processes. Therefore, these findings underscore that multiple aspects of SRL are important in explaining students' performance, but different procedures may be necessary to develop these skills. Specifically, teaching students how to set goals and plan may support their use of strategies during performance, but educators may need to emphasize direct instruction in metacognitive-monitoring and self-reflection to improve metacognitive-monitoring skills (Dimmitt and McCormick 2012; Zimmerman et al. 2011).

Limitations and future research

Although this study makes an important contribution to the literature, there are some limitations. First, as noted previously, given the correlational design, it is inappropriate to make causal inferences about the observed relations. Experimental research is needed to intervene with specific SRL processes and observe changes in subsequent SRL processes. However, the measures developed within this study may provide a tool for examining future experimental efforts, and our findings may serve to support future hypotheses. Another limitation was that a single practice session was used. Thus, we were unable to examine the influence of self-reflection processes on subsequent forethought during a second practice session. This study examined the cyclical relations among SRL processes within a single context, a mathematics task, and to date very few studies that have sought to examine the cyclical nature of SRL within other contexts. In addition, the participants in this study were middle school students from a large urban school district, who were primarily of minority ethnicities and eligible for free-reduced lunch. Thus, more research is needed to make broad generalizations about the nature of SRL during other activities, age levels, school types, student ethnicities, and socio-economic statuses. Also, given that the metacognitive-monitoring measure was achievement focused, additional research is needed to determine whether these findings generalize. Future research should also include motivational beliefs, such as self-efficacy or interest, and other SRL processes such as self-reflection satisfaction.

Conclusion

This study indicates some support for the cyclical assumption of SRL, especially the link between forethought processes and strategy use. In addition, students who self-reported using more strategies were more likely to identify insufficient strategies as a reason for failure. Our findings also suggest that the relations among some SRL processes may be more nuanced and complex than previously believed. Specifically, metacognitive-monitoring measures targeting performance estimates are important predictors of achievement, but the link with other SRL processes is not direct or clear at this time. Educators and interventionists are cautioned against the assumption that teaching students to plan or act more strategically will result in more accurate metacognitive-monitoring of performance. Finally, several SRL processes across multiple phases were shown to correlate to and predict achievement on the mathematics task and this prediction was enhanced with the use of multiple measurement formats.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Responses to SRL microanalysis items were coded regarding the presence of five different categories of mathematical problem solving (MPS) strategies. Definitions of each category can be found below.

Table 6 Coding categories

MPS strategy	Microanalysis	Behavioral traces
Identifying key information	Statements that indicated the isolation or identification of the most pertinent information in the problem by underlining, highlighting, and/or listing key information.	Text has been underlined, listed, and/or "highlighted" on the work paper.
Transforming or elaborating upon problem information	Statements that indicated re-writing or paraphrasing of the problem content or creating a similar/analogous problem. Statements that indicated the use of pictures or mental images to aid problem comprehension or solution.	A paraphrased statement, analogous problem, or drawing can be seen on the work paper.
Hypothesizing or estimating the answer	Statements that indicated the creation of a hypothesis or estimation about a potential answer to the math problem.	A written statement indicating an approximated answer such as "about 100" is present.
Developing an equation to facilitate problem comprehension or solution	Statements that indicated the development or use of a formula or equation as a means of guiding problem understanding or solution. Must be clearly separate from the mere completion of mathematical computations (e.g., "$x + 1 = y$").	An equation can be seen written on the work paper. Formula is either an algebraic formula with at least one unknown (e.g., "x") or is an identifiable formula ($a^2 + b^2 = c^2$).
Checking work, answers, or understanding	Statements that indicate checking the accuracy or appropriateness of operations, answer, and/or understanding of the problem objectives.	Work has been crossed out with adjacent reworking of the problem or redundant math operations are present (e.g., dividing to check multiplication).

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