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Quantitative Analysis of Self-Regulation in Engineering and Mathematics Education

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Quantitative Analysis of Self-Regulation in Undergraduate Engineering and Mathematics Education

Abstract

This paper shares the initial findings of a three-year research project. Quantitative methods were used to develop coarse-grained understandings of undergraduate students' self-regulation of cognition (SRC) and self-regulation of motivation (SRM) during academic problem-solving activities in two undergraduate engineering and mathematics (EM) courses. Two research questions were constructed to guide this study: (1) How are SRC and SRM strategies related to each other while solving EM problems?; and (2) How do students perceive their SRC and SRM strategies for problem-solving activities in EM courses?

Two 2nd year EM courses, Engineering Statics and Ordinary Differential Equations, were purposefully selected as the contexts of the study. There were a combined total of 142 students (120 male and 20 female), across both courses, that participated in quantitative data collection using two validated surveys during spring 2022. Quantitative data were collected using two self-report surveys: Brief Regulation of Motivation Scale (BRoMS), and the Physics Metacognitive Inventory (PMI). Although PMI was initially designed for Physics, it can be used to assess students' metacognition for problem solving in other knowledge domains by simply revising the word "physics" to another domain knowledge. Both descriptive and inferential statistics were conducted to analyze the collected quantitative data.

During data analysis we found: (1) a significant relationship between students' strategies to self-regulate their cognition and motivation during EM problem-solving activities; (2) no significant difference between male and female's self-regulation of cognition (SRC) and self-regulation of motivation (SRM); (3) no significant difference of SRM between students who engaged in Engineering Statics and Ordinary Differential Equation problem-solving activities; and (4) a significant difference of reported strategies in interpreting problem and evaluating strategies between those who engaged in Engineering Statics and Ordinary Differential Equation problem-solving activities. Participants reported using certain SRM strategies, such as "If I need to, I have ways of convincing myself to keep working on a tough assignment" more frequently than other strategies during problem solving.

Keywords: engineering education, mathematics education, self-regulation of cognition, self-regulation of motivation.

A. Introduction and Brief Literature Review

This paper shares the initial quantitative findings of the second of three components of a three-year research project. The three components are (1) Component 1: Development, field-testing, and refinement of qualitative data collection instruments used for qualitative research; (2) Component 2: Mixed-methods research data collection and analysis; and (3) Component 3:

Integration of self-regulation within engineering and mathematics (EM) courses and workshops. The major objective of the project is to advance engineering and mathematics (EM) education theory and practice related to students' self-regulation, which includes how students adapt their cognitive processes (SRC) and motivation (SRM) during problem-solving activities. The expected outcome of Component 2 is the advancement of the knowledge base related to students' use of self-regulation during problem-solving activities in EM academic settings.

Problem solving is an effort to bridge the problem space to the solution space. Simon claimed, "solving a problem simply means representing it so as to make the solution transparent" (p. 153) [1]. This claim suggests that students start with what they know about the task, and then add relevant concepts and then strategies that are needed to solve the problem. Inadequate understanding of pre-requisite knowledge leads to weak interpretation of task and ultimately lead to errors in mathematics problem solving (e.g., [2], [13]). Similarly, in engineering problem solving, research has found that a significant difference between the instructor's and students' task interpretation of the assigned problems (e.g., [4], [5]). Student's ability to control motivation, thoughts and actions helps students accurately solve problem (e.g., [6], [7]).

The concept of self-regulation emphasizes the agentic role of the learners in their own learning [8], [9]. Historically, a focus on self-regulation is rooted, in part, in developmental psychology and behavioral interventions. People were taught techniques to self-regulate or modify negative behaviors to achieve more positive life experiences. From an educational perspective, the model of SRL was developed over the past 30 years to understand how to support greater academic success.

According to Zimmerman [10], self-regulated learners are "metacognitively, motivationally, and behaviorally active participants in their own learning process" (p. 329); therefore, self-regulated learners are skilled in goal setting, self-monitoring, self-instruction, and self-reinforcement [11]. During problem-solving engagement in EM, students set a goal, act on that goal, assess the outcome, and adapt their behavior to achieve the goal, processes which require significant regulation of cognition (e.g., [12], [13], [14]) and motivation (e.g., [15]).

Self-Regulation of Cognition (SRC), also known as self-regulation in action (SRA) or strategic action (SA), is the basis of self-regulated learning (SRL). SRC is comprised of iterative and recursive cycles of interpreting requirements, planning (e.g., resources, time, strategies), implementing cognitive processes, monitoring progress, evaluating progress against internal and external standards, and continually refining approaches to better achieve goals (see Figure 1) [16]. This iterative process continues until a problem is solved or the student abandons the goal.

As students manage their activities in tasks, they engage in iterative cycles of strategic activity, including actively interpreting requirements (i.e., interpreting task), developing a plan of action (i.e., planning), acting on a developed plan, and monitoring progress and results (i.e., evaluating and monitoring) and adjusting approaches (i.e., adjusting) as necessary. Despite its difficulty, the development of an accurate problem representation is the key to EM problem solving in that it guides the process of generating a possible solution. Representation and a step-by-step solution are interactive and may lead to corresponding changes in the solution method followed. The model explains how students' cognitive processes are situated within cycles of strategic activity (i.e., shaped by their choices of effective learning approaches in each situation).

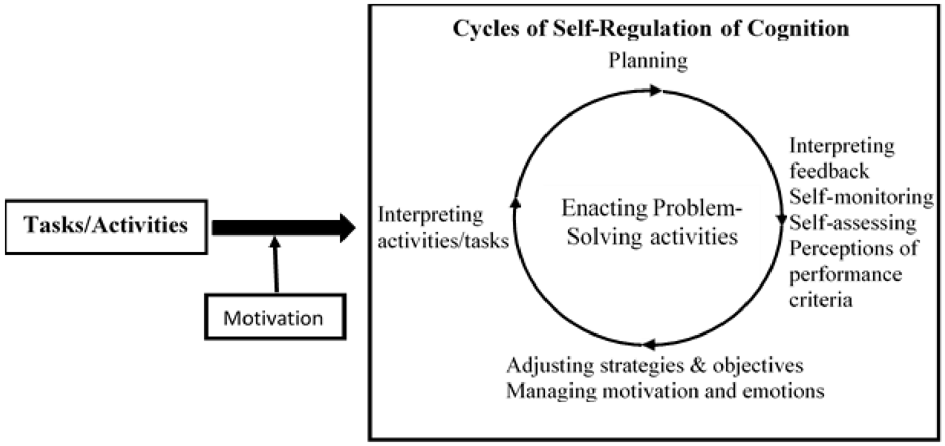

Figure 1. Interaction between Task and Self-regulation of Cognition

Besides cognitive processes, research also suggests that decisions to engage in problem-solving may be affected by individual students' motivation, including their goals for engaging in problem-solving activities, beliefs about their abilities and the nature of the problem to be solved, and the value they place on task [17]. In theoretical models of SRL, "…motivation is the primacy of metacognition in the regulation of cognitive processing" [18, p. 64]. This motivational aspect plays an important role in learning engineering (e.g., [19]), and mathematics (e.g., [20]). Wolters (2003) conceptualized self-regulation of motivation (SRM) as deliberately influencing one's own motivation [21]. In an academic arena, students are supposed to initiate, maintain, and even enhance their level of motivation regarding a particular activity.

B. The Study

The purpose of this research is to advance the knowledge of self-regulation of cognition and motivation as well as students' use of self-regulation during problem-solving activities in EM academic settings at the first year of undergraduate program.

2.1.Contexts

The setting for the study comprises two second-year engineering and mathematics (EM) courses offered at a midsize, public, and land grant university. As a land grant institution, the university is fully committed to providing accessible and affordable postsecondary education for all its state citizens. The national movement to improve undergraduate diversity, persistence, and retention in STEM majors [22] has led to broad reforms in undergraduate instruction, opportunities for student engagement (i.e., undergraduate research), and extracurricular supports, including bridge programs, tutoring services, and mentoring activities. Reforms and supports, however, have tended to focus within first-year courses to help students succeed in prerequisite STEM courses and maintain and/or build interest in STEM-related careers. We purposefully selected two foundational *second-year year* EM courses (i.e., Engineering Statics and Ordinary Differential

Equations) as the context for this study in order to deepen the knowledge base in this less studied year of undergraduate engineering education.

2.2.Research Questions

Two research questions were constructed to guide this study: (1) How are undergraduate student self-regulation of cognition (SRC) and self-regulation of motivation (SRM) strategies related to each other while solving EM problems? and (2) How do undergraduate students perceive their self-regulation of cognition (SRC) and motivation (SRM) skills for problem-solving activities in EM courses?

2.3.Data Collection and Analysis

One hundred forty-two students from engineering statics and ordinary differential equations courses participated in quantitative data collection using two validated surveys, revised PMI and BRoMS. All quantitative data were generated and collected using an ad-hoc web-based survey tool called Qualtrics.

The revised Physics Metacognition Inventory (PMI) was developed, revised, and validated by Taasoobshirazi and Farley [23] to assess students' SRC while solving problems. The PMI is one of the first instruments developed to measure metacognition during problem solving [24]. Although PMI was initially designed for Physics, it can be used to assess students' metacognition for problem solving in other knowledge domains by simply revising the word "physics" to another domain knowledge [25]. The revised PMI includes 26 items that assess 7 components of metacognition for problem solving. Since this study investigates students' SRC during problem-solving activities in two specific EM courses, we used the five regulation of cognitions scales: interpreting task, planning, monitoring, evaluating, and adjusting components, a total of 16 items (see Table 1). Thus, each participant was requested to respond to a total of 16 PMI items on a 5-point Likert scale ranging from 1 (never true of myself) to 5 (always true of myself). Instruments will be tailored by restating discipline specific terms (i.e., "Physics" was restated as "Engineering Statics or "Ordinary Differential Equations") to reflect the appropriate EM courses context.

Table 1. Revised Physics Metacognition Inventory (PMI)

SRC Features	Number of Items
Interpreting Task	2
Planning	3
Evaluating	5
Monitoring	3
Adjusting	3

Eight BRoMS items are measured on a 5-point Likert scale ranging from 1 (never true of myself) to 5 (always true of myself). BRoMs was developed and validated by a group of researchers led by Wolters [26] to assess students' regulation of motivation while learning. The BRoMs instrument was selected for this study because it (1) includes substantially fewer items than other measures of regulation of motivation; (2) assesses students' overall tendency to respond to the cued motivational challenges in a way meant to sustain or improve their motivation rather than their reported use of particular regulation of motivation strategies; and (3) samples a broad set of motivational challenges to ensure that they are salient when students respond to each item [27] (see Table 4 for those 8 BRoMS items).

Quantitative data from questionnaires (PMI and BRoMS) were analyzed through descriptive statistics to create students' self-regulation of cognition and motivation profiles for the complete sample of both courses. Furthermore, data collected within each course and from both questionnaires were evaluated by computing the statistical mean (M) and standard deviation (SD) to describe how participants within each course plan, monitor, evaluate, and regulate their cognition and motivation in generic problem-solving activities (to answer research questions). Pearson correlation tests were used to evaluate any associations between students' SRC and SRM. To ascertain any consistency of the results, potential differences of students' SRC and SRM between gender and between the two courses were evaluated using both parametric (t-test) and a non-parametric test (Mann-Whitney test).

C. Findings

Our analyses are organized and presented in association with the two research questions.

3.1. Research Question 1: How are undergraduate student self-regulation of cognition (SRC) and self-regulation of motivation (SRM) strategies related to each other while solving EM problems?

Through a Pearson correlation test, a moderate positive relationship was found between the students' SRM and SRC, across genders, and courses, see Table 2.

Table 2. Correlation between SRM and SRC

Control Variables	Correlation Coefficient between SRM and SRC
Combined	.531**
Gender	.527**
Course	.530**

**Correlation is significant at 0.01 level (2-tailed).

Further analysis was conducted to evaluate the degree of relationship between individual SRC features and SRM. Our analysis showed that moderate associations existed between Evaluating and SRM, between Monitoring and SRM, and between Adjusting and SRM. Weak associations were indicated between the Interpreting Task and SRM strategy reported, and between Planning strategy and SRM reported (see Table 3).

Table 3. Correlation between SRM and individual SRC feature

SRC Feature	Correlation Coefficient between SRM and SRC Feature
Interpreting Task	.140
Planning	.272***
Evaluating	.444***
Monitoring	.327***
Adjusting	.397***

***Correlation is significant at 0.001 level (2-tailed)

3.2.Research Question 2: How do undergraduate students perceive their self-regulation of cognition (SRC) and motivation (SRM) skills for problem-solving activities in EM courses?

The SRM of students working on mathematics and engineering problem solving is similar ($p > .05$). Although lower mean scores for mathematics than engineering students on almost all survey items, no significant SRM difference was found between students on both courses. Similarly, male and female students reported similar SRM ($p > .05$) during problem-solving activities. Although lower mean scores were reported for female than male students on all survey items, no significant difference was found between them.

After calculating the mean and standard deviation values, we were interested in understanding how students used those SRM strategies specified in the survey. We found that the two of most popular SRM strategies deployed during problem-solving were: “If I need to, I have ways of convincing myself to keep working on a tough assignment” and “Even when studying is hard, I can figure out a way to keep myself going.” The two least used SRM strategies reported were “It's easy for me to make myself study, even if I would rather be doing something else” and “If studying gets too boring, I find a way to make it fun.” See Table 4 for a complete set of SRM strategies including information about their popular ranks (see Table 4).

Through paired *t*-tests, five clusters of SRM strategy were found. Significant differences were found between SRM 4 and SRM 7, between SRM 1, 2, 3 and SRM 4, between SRM 1, 2, 3 and SRM 6, between SRM 5 and SRM 6, and between SRM 5 and SRM 8, see Figure 2.

Table 4. Self-regulation of Motivation (SRM) strategies

BRoMS Item No	SRM Statement	*M* (*SD*)	Rank
SRM 7	If I need to, I have ways of convincing myself to keep working on a tough assignment.	3.94 (0.85)	1
SRM4	Even when studying is hard, I can figure out a way to keep myself going.	3.70 (0.93)	2
SRM1	I use different tricks to keep myself working, even if I don't feel like studying.	3.54 (0.99)	3

SRM3	If I feel like stopping before I'm really done, I have strategies to keep myself studying.	3.52 (0.95)	4
SRM2	If I lose interest in an assignment, I have ways to boost my effort to get it done.	3.50 (1.05)	5
SRM6	If what I am studying seems unimportant, I can still convince myself to stick with it.	3.19 (0.98)	6
SRM5	It's easy for me to make myself study, even if I would rather be doing something else.	2.92 (1.11)	7
SRM8	If studying gets too boring, I find a way to make it fun.	2.69 (0.96)	8

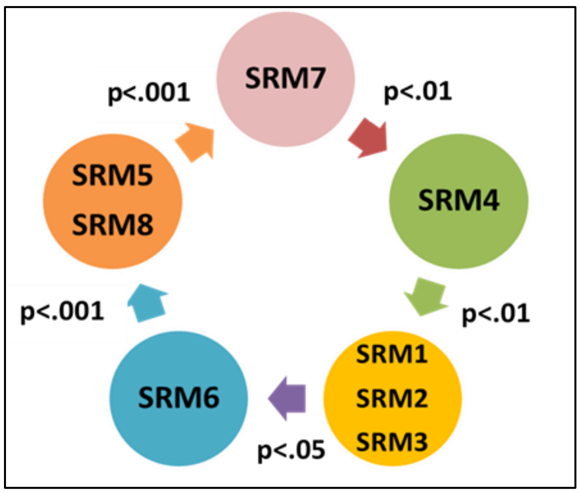

Figure 2. Significant level (p-value) between SRM (BRoMS) strategies

After conducting a series of two-sample *t*-test and a non-parametric test (Mann-Whitney test) on students' SRC, significant differences were found between students who worked on mathematics and engineering problem solving on two SRC features: "Task Interpretation" ($p < .001$) and "Evaluating" ($p < .05$) strategies. Students' "Task Interpretation" and "Evaluating" were found to be lower for those working on mathematics than those working on engineering problem-solving tasks. The reported use of other SRC features (i.e., Planning, Monitoring, and Adjusting) is similar ($p > .05$) among all students working on either mathematics or engineering problem solving (see Table 5).

Table 5. Self-Regulation of Cognition across genders and courses

SRC Features	Across Courses *M*(*SD*)				Across Genders *M*(*SD*)			
	Math	Engineering	Combined	Sig. level	Female	Male	Combined	Sig. Level
Interpreting Task	3.83 (.72)	4.25 (.66)	4.10 (.72)	**	3.95 (.67)	4.09 (.72)	4.07 (.71)	NS
Planning	3.24	3.48	3.40	NS	3.17	3.42	3.38	NS

	(.75)	(.85)	(.82)		(.85)	(.81)	(.82)	
Monitoring	3.38 (.87)	3.27 (.93)	3.34 (.91)	NS	3.43 (.82)	3.31 (.91)	3.33 (.90)	NS
Evaluating	3.70 (.63)	3.94 (.71)	3.87 (.69)	*	3.93 (.59)	3.83 (.70)	3.84 (.69)	NS
Adjusting	3.64 (.76)	3.77 (.75)	3.74 (.76)	NS	3.45 (.85)	3.76 (.74)	3.72 (.76)	NS

* Significant at $p \leq .05$
** Significant at $p \leq .001$
NS Not significant

D. Conclusions and Brief Discussion

From the analyses, we concluded that there was a moderate positive association between self-regulation of motivation and self-regulation of cognition of second-year students working on mathematics and engineering problem solving. Significant associations between SRM and all SRC features, except Interpreting Task, were established. This implies that, when experiencing challenges, students with less ability to regulate their motivation are likely to be less skillful in planning, monitoring, evaluating, and making necessary adjustments needed to produce desirable solutions. This aligns with a growing consensus in neuroscience that SRC are dependent in part on the development of SRM and vice-versa (e.g., [28], [29]). Students who learn techniques to alter a situation such as interpreting the situation in a positive way (i.e., SRM) may also exercise and select a best-fitting strategy (i.e., SRC) that produces adequate outcomes.

Students' overall strategies to regulate motivation across genders were similar; motivation self-regulatory strategies reported by those who solved mathematics and engineering problems were also alike. Although similar, we found that certain SRM strategies were more popular than other strategies during problem solving.

In the self-regulation of cognition side, no significant difference was found in students' planning, monitoring, and adjusting self-regulatory strategies reported across genders and between those working on mathematics and engineering problem solving. Our analysis also indicates a significantly lower reported use of self-regulatory strategies during interpreting problems and evaluating their problem-solving activities by those working on mathematics than those working on engineering problem-solving tasks. The nature of mathematics problem-solving tasks involves mathematical symbolic language that often exhibits more explicit information than most engineering problem statements (e.g., story problems). As a result, interpreting mathematical problems may become more apparent and does not require a lot of effort to identify parts of the problem as in interpreting engineering problems. Different kinds of symbolic information require different kinds of processing and place different demands on the students [30]. Similarly, different success criteria for solving mathematics and engineering problem may require a different level of evaluating strategies. Solving an engineering problem often requires an understanding of the context, understanding the issues and ways to evaluate the process. Students need to identify more involved criteria and constraints in solving engineering problems.

The findings of the study may carry implications for teaching and learning improvement in an academic setting. For example, integrating group assignments, such as group homework assignments, may be considered in the teaching curriculum to help students with low self-regulatory of motivation keep up with their learning. Task Interpretation and Evaluation is critical for teachers to understand for 2nd year students. First year students, who have had mostly math and science courses, may not have engaged as much in these SRC activities. When they reach 2nd year engineering courses, they encounter difficulty because the need to engage in SRC activities is new and perhaps, not taught explicitly. Learning how to understand problems is as essential as getting the solutions. Allowing practice self-regulation through learning how to interpret problem, building a workable plan to solve the problem, monitoring, evaluating, and making relevant changes to produce desirable solutions, may need to be strategically built into the teaching curriculum and explicitly taught. Currently, qualitative analyses are in progress to understand how students' metacognitive knowledge about task (MKT) inform their self-regulation of Cognition (SRC) and how students' SRC dynamically evolve during problem solving.

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