BOARD # 246: Impeccable Learning: Deep Understanding, Self-Evaluation, and Monitoring for Problem-Solving Success

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Abstract

This paper presents one of the findings from a National Science Foundation (NSF) funded research project aimed at enhancing engineering and mathematics (EM) education. The research project specifically focuses on the role that students' self-regulation in action (SRA) and metacognitive knowledge about tasks (MKT) play during problem-solving activities. To gain insight into academic problem-solving practices, the study examines how undergraduate students enrolled in second-year engineering and mathematics (EM) courses (Engineering Statics and Ordinary Differential Equations) use their MKT to navigate problem-solving challenges while concurrently monitoring and evaluating their cognitive processes.

Twenty undergraduate students (7 female and 13 male) from a land-grant university in the western United States participated in one-on-one semi-structured interviews and practiced the think-aloud protocol (TAP) during problem-solving sessions to generate qualitative data. The students were tasked to solve four subject-specific problems in engineering and mathematics (EM) courses. In total, twenty students generated eighty problems throughout the study, comprising forty problems (20 easy and 20 difficult) produced at the beginning of the semester and an additional forty problems (20 easy and 20 difficult) generated at the end of the semester that were analyzed using constant comparative analysis (CCA) technique.

The analysis included two coding phases: initial codes that represent the raw data and focused codes that reveal the seven key problem-solving patterns within the dataset. Based on this analysis, the seven patterns were organized into four quadrants, classified according to high/low levels of metacognitive knowledge about the task (MKT) and high/low levels of self-regulation in action (SRA). This paper specifically examines the first quadrant, which is indicative of impeccable learning episodes.

Students in this quadrant demonstrated a deep understanding of the tasks, accurate self-evaluation, and effective monitoring, leading to appropriate problem-solving strategies and successful results. These findings highlight that student who engaged in impeccable learning episodes demonstrated a thorough comprehension of the tasks, enabling them to effectively self-regulate their actions. These results have important implications for educational strategies meant to develop students' MKT and SRA to improve their problem-solving abilities. A brief discussion is included at the end of the paper.

I. Introduction and Brief Literature Review

Problem-solving lies at the heart of engineering education, serving as a fundamental skill that mirrors the challenges engineers confront in crafting innovative solutions. It encompasses a structured methodology for recognizing, evaluating, and addressing intricate problems across diverse engineering fields. Research has indicated that students frequently struggle to retrieve the necessary knowledge required for effective problem-solving in engineering education [1] and to foster increased motivation during problem-solving tasks [2]. Understanding the nature of the

problem is a critical first step in the process, providing the foundation for all subsequent efforts. Without a solid understanding of the problem, students cannot develop effective strategies to address it [3]. Students are encouraged to focus on relevant tasks and create significant connections between newly acquired information and their prior understanding of the task [4]. The accuracy of the solution in engineering problem-solving heavily depends on students' capability to actively monitor and assess their involvement in the problem. The process of monitoring and evaluation constitutes a crucial aspect of self-regulation in action [5]. The practice of self-regulation encompasses recurring and cyclical processes, including interpretation, detailed planning, active time management, and the adoption of strategic methods. It involves executing cognitive operations, tracking progress, assessing outcomes against internal criteria and external expectations, and continuously refining approaches to optimize the attainment of goals [6]. The ability to regulate motivation, cognition, and behavior plays a crucial role in self-regulation, contributing to precise problem-solving and fostering greater persistence among students as they work through problem-solving activities [7],[8]. Students with low motivation during problem-solving tasks can impact on their emotional states, such as frustration and disappointment, which may ultimately result in poor academic performance [9]. Continuous monitoring enables students to make adjustments, optimize their methods, and address unexpected challenges. Through critical evaluation of their progress, students can pinpoint weaknesses or areas that require improvement, ensuring their solutions align with standards of efficiency, functionality, and practicality. This ability to oversee and assess their problem-solving efforts equips students to produce innovative and impactful outcomes in engineering. Effective knowledge evaluation requires strong self-regulation and the skillful application of metacognitive strategies [10]. This work is funded by the National Science Foundation (NSF) under the Improving Undergraduate STEM Education (IUSE) program at Level 2, emphasizing its significance in advancing STEM education.

II. Objective

This study seeks to examine how students apply their metacognitive knowledge about tasks to address problem-solving challenges, while concurrently monitoring and evaluating their cognitive processes. The focus is on understanding this interaction within the realms of mathematics and engineering education. The primary objective is to explore how impeccable learning influences students' problem-solving outcomes in relation to their metacognitive knowledge, self-regulation in action, and the role of prior knowledge. Specifically, we aim to identify the key factors that contribute to students' success in problem-solving, even when they have limited prior knowledge, by effectively utilizing self-regulation through high monitoring and evaluation. Moreover, we seek to explore situations where adequate monitoring, coupled with metacognitive knowledge, leads to successful problem resolution.

III. Methodology

A total of 142 students enrolled in engineering statics and mathematics courses at a land-grant university in the western United States participated in the quantitative phase of data collection, completing two validated surveys. 20 participants (7 female and 13 male) were purposefully

selected using purposive sampling (11 from engineering courses and 9 from mathematics) for the qualitative data collection phase. Qualitative data was gathered through individual one-on-one interviews and think-aloud protocols (TAP) with the 20 selected students. During the TAP sessions, each student engaged in four problem-solving tasks, which included one relatively simple and difficult problem at the beginning and the end of the semester. The data collection resulted in 80 qualitative events, capturing students' self-regulation in action (SRA) during problem-solving activities. To analyze the qualitative data, the responses from the 20 participants were systematically coded and categorized based on the components of MKT and SRA [11].

IV. Results and Findings

Self-regulated learning, mostly understood as a complex set of knowledge and skills used for planning, enacting, monitoring, evaluating, and continuously enhancing one's learning approach, has been shown by research to strengthen learning abilities, promote improved academic performance, and cultivate a heightened awareness and accountability regarding one's cognitive processes [12]. Students' understanding of a task is a vital element of their overall comprehension of its purpose, structure, and components. A thorough and accurate metacognitive knowledge about tasks of these three aspects is essential for successfully solving the problem [11]. Metacognitive knowledge about the task and self-regulation in action, particularly in the areas of monitoring and evaluation, are key factors in effective problem-solving. Our analysis reveals that students with a high level of metacognitive knowledge about the task, combined with effective utilization of self-regulation strategies, particularly monitoring and evaluations, are more inclined to solve problems successfully. High metacognitive knowledge about the task enhances the ability to approach problems more strategically. In all problem-solving activities, students effectively translated theoretical concepts into practical applications by articulating specific laws or theories. For instance, they showcased their comprehension of both known and unknown variables by explicitly stating them. A student verbalizes the key information required to solve the problem, by stating:

> *"Okay, so these two uh, these two eigenvalues and these two eigenvectors are what I essentially needed to build this factorization matrix. I mean, the diagonalized matrix, that's the word for it. And so, from these, I can now build it."*

Furthermore, research participants explain a step-by-step approach for determining the unknown variables necessary to solve the problem, expressing:

> *"So I have one over negative one or essentially negative one times. And I have to flip these two. I flip the diagonal. So one, they're negative. Three, they're like that. And these both become negative. So I have a negative one, but then this one becomes a positive two"*

Participants with high metacognitive knowledge about the task significantly improve the task interpretation phase of problem-solving. In the impeccable learning episode, participants display high monitoring and evaluation skills, which play a vital role in improving their problem-solving outcomes. The interconnectedness of these processes greatly influences the results. Their capacity to monitor progress and regulate cognitive functions is essential for successfully solving the problem. This includes actively evaluating task understanding, choosing appropriate

strategies, and adjusting efforts based on real-time. These activities involve ongoing self-assessment, identifying errors, and refining strategies in a flexible manner. As one research participant rightly expressed:

> *"Going to double check this. I'm going to go three times a two, which is negative three minus eight should equal -17. So negative nine minus eight equals -17. Yeah, that's correct because this is 17."*

The participant's consistent monitoring, evaluation, and adjustment of problem-solving strategies highlight their expertise in self-regulation. This active engagement in monitoring, regulating, and evaluating strategies significantly contributes to successful problem-solving outcomes.

V. Conclusions

Quadrant 1, referred to as "Impeccable Learning" where both the problem-solving process characterized by high levels of metacognitive knowledge about tasks (MKT) and effective monitoring and evaluation (ME) and the resulting solution, reflected in outstanding task performance, are highly successful. In this context, students effectively employ monitoring and evaluation strategies, underpinned by high MKT. During an Impeccable Learning episode, individuals exhibit a profound understanding of the task, supported by their strong metacognitive awareness. Their skillful use of monitoring and evaluation techniques enables accurate progress assessments, facilitating the selection and implementation of appropriate problem-solving strategies, ultimately leading to successful outcomes. From an instructional standpoint, fostering impeccable learning experiences is essential for enhancing student engagement, effectiveness, and meaningful learning outcomes. These experiences are defined by the inclusion of well-structured instructional materials, clear explanations, interactive activities, and ample opportunities for practice and feedback. Such elements not only deepen students' comprehension of the subject matter but also encourage critical thinking and improve persistent knowledge retention.

Moreover, active student engagement through collaborative tasks, problem-solving exercises, and reflective discussions significantly aids in the internalization of concepts and their application to real-life scenarios. This active participation fosters a learning environment where students feel motivated and empowered to explore and question. As a result, educators must focus on designing and delivering impactful, engaging, and meaningful learning experiences. By doing so, they can maximize student achievement and ensure that learners are equipped to realize their full potential.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. 2110769 under the Improving Undergraduate STEM Education (IUSE) program at Level 2. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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