Routine vs. Non-Adaptive Learning: Examining the Impact of Metacognitive Knowledge and Self-Regulation on Problem-Solving

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Abstract

This study presents findings from a National Science Foundation (NSF) funded project aimed at exploring how students apply monitoring and evaluation (ME) processes in conjunction with their metacognitive knowledge of tasks (MKT). The research focused on problem-solving activities in engineering and mathematics courses, specifically Ordinary Differential Equations and Engineering Statics, which were chosen to represent different yet interconnected fields in the second-year engineering curriculum. Twenty undergraduate students (7 female, 13 male) from these courses at a land-grant university in the western United States participated. Data were collected through semi-structured, one-on-one interviews conducted before and after problem-solving sessions, with a think-aloud protocol employed during the sessions. Each student solved two problems of varying difficulty, resulting in a total of 80 qualitative data points.

The qualitative analysis of the semi-structured interview data provided insights into the students' understanding of tasks prior to engaging in problem-solving. Comparative Content Analysis (CCA) was used to systematically examine and compare qualitative data segments from the two courses, as well as the varying difficulty levels of the tasks. This approach enabled a detailed analysis of similarities, differences, and trends in students' metacognitive knowledge about the tasks. The Think-Aloud Protocol (TAP) data offered further insight into students' self-regulation in action during problem-solving. From this data, seven distinct problem-solving learning episodes were identified and categorized into four quadrants, each representing different interactions between students' metacognitive knowledge about the task and their self-regulation (monitoring/evaluation) during problem-solving activities.

In this paper, we focus on two learning episodes within the fourth quadrant (Routine Learning and Non-Adaptive Learning), where students possess adequate metacognitive knowledge about the task but do not employ sufficient monitoring and evaluation (M/E) strategies. This discrepancy leads to either successful or unsuccessful outcomes. In Routine Learning, participants demonstrate low levels of M/E strategies but high levels of metacognitive knowledge about tasks (MKT). They are familiar with the problem's context and have a strong understanding of it, allowing them to solve it successfully despite using fewer M/E strategies. In contrast, participants in Non-Adaptive Learning share similar characteristics but fail to solve the problem, even though they initially have a reasonably good understanding of it.

The study discussed how different episodes of problem-solving activities can shape students' perceptions of their task performance, either positively or negatively, and how these experiences influence their deeper understanding of the subject matter. It also examined the critical roles of metacognitive knowledge about tasks (MKT) and monitoring and evaluation in enhancing the teaching and learning processes within mathematics and engineering education, highlighting their impact on students' ability to navigate complex tasks and refine their problem-solving skills.

I. Introduction and Brief Literature Review

The problem-solving process holds significant importance for Science, Technology, Engineering, and Mathematics (STEM) education. Studies indicate that numerous STEM graduates exhibit noticeable challenges in their problem-solving abilities. These challenges are caused partially by cognitive processing [1] and motivational regulation [2] during problem-solving tasks. Our preliminary findings indicate that reviewing solutions after completing problem-solving tasks had a minimal impact on enhancing students' understanding, particularly when tackling challenging problems [3]. To become effective problem-solvers, students must grasp the connection between task characteristics and the processing demands required during problem-solving activities. Metacognitive knowledge about task (MKT) captured this concept helping students in interpreting tasks and bridging the gap between their conceptual representation of a problem and effective solution strategies. Generative learning theory emphasized engagement of the learners for comprehending complex tasks by constructing meaningful connections between new information and existing metacognitive knowledge [4]. Students' active participation in this process is crucial, and the learning strategies they adopt should align with their efforts to integrate new knowledge into their existing metacognitive frameworks [5]. To achieve this, students must actively participate in the learning process, ensuring that their approaches align with their efforts of incorporating new knowledge into their existing metacognitive frameworks [4]. This cognitive engagement fosters a deeper understanding of the subject matter and creates meaningful links between new and prior knowledge.

Metacognitive awareness, the understanding of one's cognitive processes, helps students identify mistakes, adapt strategies, and improve outcomes. Metacognition involves understanding knowledge at a higher, meta-level, along with the mental operations that guide cognitive strategies [6]. The act of overseeing and adjusting one's cognitive approaches during problem-solving is referred to as metacognitive regulation. The process of applying self-regulation to learning is complex, as it involves not only the awareness and use of learning strategies but also deep reflection and self-awareness. Self-regulated learners excel at monitoring their learning and understanding, which directly influences every stage of the self-regulation process. Accurate monitoring of learning can influence self-regulation at every stage of the learning process [7].

Self-regulated learning is an active and constructive process that involves various levels of control. To ensure effective self-regulation, students must possess knowledge about how they are learning. Moreover, they need to apply self-regulation strategies effectively throughout the learning process [8]. Zimmerman's [9] three-step academic learning cycle begins with forethought, which involves goal setting and self-efficacy. The second step is performance and volitional control, guided by self-monitoring. The final stage is self-reflection, where students assess their success or failure and adjust their self-efficacy. To be an effective self-regulated learner, a student must utilize metacognitive knowledge to guide this process, adjusting goals, judgments of learning, self-efficacy, and task selection. This three-year project seeks to enhance the theory and practice of engineering and mathematics (EM) education by focusing on students' self-regulation of cognitive and motivational skills during problem-solving activities. Self-regulation encompasses students' metacognitive knowledge about tasks (MKT) and their ability to self-regulate cognition (SRC). The research emphasizes the importance of metacognitive processes of monitoring enhancing students' problem-solving abilities. It takes an applied approach, focusing on evaluation and monitoring during problem-solving, with the goal of improving interventions, instructional methods, and environments to help students become better problem solvers. 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. Purpose, Goals, and Significance

The primary goal of this research is to explore how students apply monitoring and evaluation (M/E) processes in conjunction with their metacognitive knowledge of tasks (MKT) during problem-solving in engineering and mathematics courses, specifically Ordinary Differential Equations and Engineering Statics. The study aims to identify key factors influencing students' problem-solving outcomes when they possess adequate metacognitive knowledge about the task but fail to employ sufficient monitoring and evaluation strategies. Moreover, the research seeks to understand the impact of this discrepancy on students' ability to solve problems successfully or unsuccessfully, based on two key learning episodes: Routine Learning and Non-Adaptive Learning. The following research questions will guide the study:

1. How does high metacognitive knowledge about tasks (MKT), when combined with inadequate monitoring and evaluation (M/E) strategies, influence students' problem-solving outcomes in engineering and mathematics courses?
2. How do different problem-solving episodes, such as Routine Learning and Non-Adaptive Learning, shape students' perceptions of their task performance?

III. Methodology

This study followed a qualitative methodology to explore the utilization of monitoring and evaluation(M/E) processes and metacognitive knowledge of tasks (MKT) during problem-solving activities. Twenty undergraduate students (7 female, 13 male) enrolled in Ordinary Differential Equations and Engineering Statics courses at a second-year engineering level at a land-grant university in the western United States were purposefully selected to represent a diverse group based on gender and academic background within the engineering discipline. All participants provided informed consent before participation. Data were collected through semi-structured, one-on-one interviews, conducted before and after students engaged in problem-solving sessions. Each participant was asked to solve two problems of varying difficulty, designed to assess their problem-solving approach in both simple and complex scenarios.

During these problem-solving sessions, a think-aloud protocol was used, encouraging participants to verbalize their thoughts, strategies, and reasoning as they worked through the problems. This approach allowed for the direct observation of how students applied MKT and M/E strategies in real-time. Each session was recorded, and a total of 80 qualitative data points were gathered, two problems per student, with each problem-solving session yielding a set of detailed verbalizations. The tasks were chosen to represent different levels of difficulty, with one problem being simple and the other more complex. The simple problem was intended to test students' familiarity and comfort with standard procedures, while the complex problem aimed to challenge their ability to apply advanced strategies and think critically.

IV. Results and Findings

Students' metacognitive knowledge about tasks (MKT) is an important element in understanding a task's purpose, structure, and components. A deep and accurate awareness of these aspects is essential for effective problem-solving. Research suggests that enhancing self-regulated abilities strengthens learning skills, boosts academic performance, and promotes a sense of responsibility and awareness of their cognition. Both metacognitive knowledge of the task and self-regulation in action, particularly in monitoring and evaluating, are key to successful problem-solving. However, the relationship between these elements is complex. Comparative Content Analysis (CCA) [10] was employed to methodically analyze and contrast qualitative data segments from the two courses, considering the different levels of task difficulty. By identifying and contrasting patterns, themes, or behaviors in the content, CCA provides a deeper understanding of how students approach problem-solving in different settings. Emerging themes and inconsistencies were analyzed in-depth through multiple rounds of discussion among the researchers, ensuring a comprehensive and rigorous examination of the data.

Routine and Non-Adaptive Learning

Routine Learning episodes involve individuals with strong metacognitive knowledge about tasks but weaker monitoring and evaluation skills. Although they had good prior knowledge about the task, their monitoring and evaluation was below average to effectively assess their progress, but they made necessary adjustment in task may result in satisfactory outcomes. While non-Adaptive Learning episode leads to unsatisfactory results as individuals fail to adjust their strategies, despite having sufficient metacognitive knowledge. The study results have shown that sufficient metacognitive knowledge about a task, without adequate monitoring and evaluation, can lead to both successful and unsuccessful outcomes. In "Routine Learning" individuals with strong prior knowledge may not need extensive monitoring to achieve success, with problem-solving strategies becoming automatic. This was observed in math tasks, but not in engineering statics. In contrast, "Non-Adaptive Learning" occurs when individuals fail to adjust their strategies despite adequate knowledge, often leading to failure. Routine Learning was seen in math tasks where students used most of the recommended task interpretation activities, while Non-Adaptive Learning involved lower levels of task interpretation and monitoring. Students using Routine Learning completed tasks more efficiently and were better at assessing the quality of their solutions. When individuals are in a Non-Adaptive Learning state, it is crucial to help them improve their monitoring, evaluation and adjusting strategies and to encourage the development of Routine Learning episodes.

Our findings indicate that strong proficiency in MKT increases the likelihood of achieving satisfactory solutions. This highlights the need to foster metacognitive awareness in students. Educators can support this by incorporating explicit instruction and reflection to deepen students' understanding of problem-solving tasks and approaches. By developing metacognitive skills, students can become self-regulated learners capable of effectively monitoring and evaluating their progress, as seen in the Routine Learning episode.

V. Conclusions

This study examined the relationship between participants' metacognitive knowledge about tasks (MKT) and their monitoring and evaluation (ME) processes during problem-solving. The findings emphasize the role of MKT in guiding effective problem-solving strategies, highlighting areas where targeted interventions can improve metacognitive abilities, self-regulation, and problem-solving performance. The study also underscores the complexity of problem-solving, noting that success is not guaranteed in all learning episodes. The research emphasizes the need for students to develop both task knowledge and the ability to monitor, evaluate, and adapt their approaches to achieve optimal outcomes. Further exploration of the impact of teaching practices on problem-solving in mathematics and engineering is planned for future research.

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