Board 193: Adaptive v. Faulty Adaptive Learning: The Interplay Between Knowledge About Task and Self-Regulation

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Abstract

This paper reports preliminary findings from a National Science Foundation (NSF) funded research targeting enhancing Engineering and Mathematics (EM) education. The project's central objective is to explain the critical role of students' metacognitive knowledge about task (MKT) and self-regulation in action (SRA) during problem-solving activities. This research paper seeks to understand the interplay between MKT and SRA, and how it leads to their problem-solving performance in two second-year engineering and mathematics (EM) courses, Engineering Statics and Ordinary Differential Equations.

Qualitative data were collected through one-on-one interviews before, and think-aloud verbalization while, solving problems. Qualitative data were generated with 20 undergraduate students (i.e., 7 females, and 13 males) across both courses (i.e., 11 and 9 students from mathematics and engineering, respectively) through one-on-one interviews before, and think-aloud verbalization while, solving problems. During data generation, each student engaged in four EM content-driven problem-solving activities of varying levels of difficulty. Data generation resulted in a total of 80 problem-solving qualitative data generation events with 20 unique participants. The qualitative data is analyzed using systematic and iterative techniques based on constant comparative analysis (CCA). Further, the analysis involves the deployment of initial and focused level codes, where initial codes directly reflect the raw data, while focused codes refine the seven significant problem-solving cases or patterns observed across the dataset.

Based on the analysis, the seven cases were clustered into four quadrants based on their low/high MKT level and low/high SRA levels. Each case describes a unique interplay between students' knowledge about tasks and self-regulation. In this paper, we focus on two possible cases belonging to the second quadrant (i.e., Adaptive Learning, and Faulty Adaptive Learning). In the adaptive learning environment, effective self-regulating deployment could enhance students' inadequate metacognitive knowledge about tasks to achieve satisfactory task performance. Faulty adaptive illustrates a problem-solving episode where adequate self-regulating strategies with a lack of metacognitive knowledge about tasks could also potentially lead to unsatisfactory task performance. A brief discussion is included at the end of the paper.

I. Introduction

To be effective problem-solvers, students must understand the relationship between task characteristics and associated processing demands such as monitoring and evaluation (M/E) throughout the problem-solving activities. The individual's knowledge about the problem-solving task is known as metacognitive knowledge about the task (MKT) [1]. The MKT that students develop helps them interpret tasks, and to bridge the gap between mental representations of the problem and effective solution strategies. According to the generative learning theory, the effective comprehension of a complex subject requires learners to actively engage in the process. Learners are urged to selectively focus on appropriate activities and establish meaningful links between new information and metacognitive knowledge [2]. The core idea of this theory highlights the importance of learners independently building meaning by incorporating new information with their prior knowledge [3]. It would be essential that students participate actively in this practice and that the learning approaches they select should be related to their attempts to incorporate new knowledge into their pre-existing metacognition framework [4]. Through the learner's cognitive engagement, the stress is on developing a thorough comprehension of the subject matter and establishing meaningful connections between new and former knowledge.

According to the generative learning theory, students might become more competent at solving problems and completing them when they take part in metacognitive activities such as monitoring their understanding of a problem and evaluating their advancement (e.g., [5]). Students who are aware of their cognitive activities are better able to identify mistakes, adjust their tactics, and make the required adjustments, which ultimately results in successfully solving the problem [6]. Metacognition is the study of information at the meta-level and the mental operations that direct cognitive methods. The process of monitoring and modifying one's cognitive techniques for solving problems is known as metacognitive regulation [7]. For example, writing is a cognitive function, but the act of taking notes is regarded as a metacognitive action.

Several studies exhibit the important interaction between cognitive and metacognitive actions and approaches, emphasizing the critical role that both play in successful problem-solving (e.g., [8]). Because the problem-solving approaches uncover beneficial outcomes need the harmonic coordination of cognitive acts and metacognitive processes, which is not only helpful but also essential [9]. Cognitive actions drive progress for problem-solving but also lay the foundation for the metacognitive processes which create a web of metacognitive activities that closely complement cognitive actions, participants engage in thoughtful observation, planning, evaluation, and monitoring (M/E) [10]. This complex interaction between MKT and M/E is essential to addressing problems successfully. The participants combine cognitive and metacognitive components and make sure that each one smoothly adds to the problem-solving process [11] that focuses on the ongoing and reciprocal interaction of their components which ultimately highlights the cyclical character of the problem-solving paradigm. Several investigations have shown that students' capacity to solve mathematical puzzles is improved by metacognitive instruction (e.g., [12]).

The focus is on the realization that metacognitive processes which include monitoring, evaluation, and regulation are an important component to make students better problem solvers, especially when it comes to mathematics (e.g., [13]). This research takes an applied approach to metacognition, concentrating on evaluation and monitoring while problem-solving activities. It creates opportunities for improving interventions, instructional techniques, and environment building that support and help students become skilled problem solvers.

II. Goal and Research Questions

The primary goal of this research is to investigate the impact of adaptive learning on students' problem-solving outcomes concerning their metacognitive knowledge, self-regulation deployment, and the role of prior knowledge. Specifically, we aim to identify key factors influencing students who, despite utilizing less prior knowledge, successfully solve problems through high monitoring and evaluation. Moreover, we seek to understand instances where adequate monitoring and evaluation, coupled with limited metacognitive knowledge, lead to unsuccessful problem-solving activity. The following two research questions will guide the research:

1. How does effective self-regulation deployment, coupled with limited metacognitive knowledge about tasks, contribute to successful problem-solving outcomes?
2. How does insufficient metacognitive knowledge about tasks influence students' problem-solving capabilities even by employing high monitoring and evaluation resulting in unsuccessful problem-solving outcomes?

III. Methodology

A total of 142 students enrolled in each EM course actively participated in the quantitative data collection phase, utilizing two validated surveys then by employing the purposive sampling technique, 20 participants were purposefully selected (9 from mathematics and 11 from engineering courses) for the subsequent qualitative data collection part. Qualitative data were generated through one-on-one interviews and think-aloud protocols (TAP) with 20 students from the EM course. In the TAP sessions, each student was involved in four problem-solving activities, including one easy and one difficult problem at the start and end of the semester respectively. This approach ensures a comprehensive assessment of their problem-solving abilities across varying levels of difficulty throughout the academic term. This process yielded a comprehensive dataset of 80 qualitative events, capturing students enacted self-regulation of cognition (SRC) and self-regulation of motivation (SRM) during problem-solving activities. To investigate the qualitative data, the responses of the selected twenty participants were precisely coded and classified according to the components of MKT and SRA [14].

IV. Results /Analysis

Students' MKT is a vital facet of extensive understanding of task purpose, structure, and components. A comprehensive and precise metacognitive awareness of these three characteristics is necessary for effective problem-solving [14]. In the context of Self-Regulated Learning (SRL), broadly defined as a multifaceted source of knowledge and skills for planning, implementing, monitoring, evaluating, and continually refining the learning method, research indicates that improving SRL abilities contributes to reinforced learning skills, improved academic success, and fosters a sense of responsibility and knowledge about one's cognition [15]. The metacognitive knowledge about the task and self-regulation in action in the context of monitoring and evaluating, play fundamental roles in successfully solving the problems. However, the analysis exhibits a complex relation between these elements. For example, for a student who may be lacking in MKT, the practiced SRA can potentially compensate for this shortfall in successfully solving the problem.

A. Adaptive Learning

In adaptive learning, participants with a lack of MKT but high M/E strategies successfully solve problems despite initially having less understanding of the task. One of the participants exhibited a lack of prior knowledge in their ability to complete the work, the student did not have sufficient knowledge about the task’s purpose, structure, and components. For instance, a participant articulated:

" *I would need the law of the transpose and the science, not the science. That's the wrong word. But the theories behind matrix multiplication, the dot product* ".

In a similar vein, another participant demonstrates a deficiency in prior knowledge when addressing the problem, stating:

"I don't know how important it is that I redraw the free body diagram. This one's pretty good. Other than just the tension which I'll just add as 6 kilonewtons, and then just the theta, which is just 30 degrees. I don't know ".

These patterns highlight the importance of prior knowledge about the task that can help students to improve their understanding and how should they approach the problem to successfully solve it; also, by addressing these shortcomings, we can make their problem-solving skills better [16]. The expressions of confusion and uncertainty (as expressed by the participants in their statements) highlight the need for targeted interventions aimed at developing a deeper understanding of task purposes, structures, and components. Moreover, it becomes apparent that when students, despite lacking prior knowledge, employ high monitoring and evaluation strategies during problem-solving, they can compensate for their initial deficiencies and successfully solve the tasks. This emphasizes the key role of effective M/E in preventing gaps in metacognitive knowledge and fostering a successful problem outcome. Even with the lack of prior knowledge, an interesting shift happened when a student actively employed a high level of M/E strategy while problem-solving tasks.

"*Now I just want to go back and make sure what I did was correct. So, I had my 6 kilonewton 30. Okay? Yeah. I was going to check that I added those right 3 plus 4 root 2 and, 3 root 3. Minus 4 root 2. That's about the same thing. Well, you know, I did make a mistake".*

This persistent M/E strategy acted as a coping mechanism for their limited MKT. It enabled them to control their cognitive processes, identify possible mistakes or misunderstandings, and make real-time adjustments to improve their problem-solving approach.

" *I'm trying to remember if I did it right the first time or if I messed up when I was calculating how the matrices would multiply together. And see because this is the first row. Oh, okay. So, I did the math a little wrong. So, the first row is just a 2".*

This study revealed that participants are making a conscious effort to evaluate their performance and modify the problem-solving approach, which showed a clear awareness of the participant's activities throughout the problem-solving activity and frequently monitoring the progress by scrutinizing each step and continually trying to enhance their problem-solving strategies. Though the student has a shallow awareness of and understanding of their task's purpose, structure, and components (e.g., [17]), their SRA strategies enabled them to effectively navigate the problem-solving task and achieve a high level of accuracy (e.g., [18]).

B. Faulty adaptive learning

In faulty adaptive learning, individuals with low MKT but high monitoring and evaluating (M/E) strategies, but the ineffective deployment of M/E strategies leads to problem-solving failure. Both scenarios highlight the intricate dynamics between MKT and M/E strategies in determining problem-solving outcomes. Before the student dives into solving the question, the student shows they have a poor awareness of and understanding of their task purpose, task structure, and task component. For example, the student says,

> "*I'll probably go home and look up the parallelogram law or triangular rule because I'm not 100% sure what those are.*"

This indicates that the student is unfamiliar with the parallelogram law or triangular rule, which may lead to a problem when the student starts to solve the problem. In another example, the student does not know what is given or what is unknown in their question. Also, the student is unsure what theories and formulas to use in solving this question. The student's shallow understanding of the MKT might become an obstacle and holdback for them in finishing solving the problem accurately. the lack of MKT was expressed by stating:

> *"I'm just drawing still, okay, I don't know what I'm finding*"

which proved the limited understanding of the task and provoked us to investigate it. The student frequently evaluates, monitors, and adjusts their procedures during the problem-solving activity. For example, the student verbalized,

> "*I really want the x-axis label. So, I just cannot find X. still cannot find it. So maybe it's just not there. I mean, technically, there are, like, conventions in which we can draw your diagram. Just, this is all weird, so I guess I'll just leave this one x."*

It shows that the student did not use the M/E effectively because the participant stated later:

> *"I could not find x, maybe it's just not there".*

The examples provided underscore the student's inadequate awareness and understanding of task elements, leading to challenges during problem-solving. The expressed uncertainty about concepts and the struggle to identify given information further emphasize the impact of insufficient MKT on problem-solving proficiency [19]. Regardless of the student's continuous efforts to monitor and adjust their problem-solving approach, the ineffective employment of M/E strategies reflects consistently unsatisfactory results which highlights the need for a comprehensive reassessment and improvement of M/E methodologies to provide timely and tailored support for students facing challenges in their academic pursuits. Because it holds particular significance in the context of the growing emphasis on aiding students in SRL [20], it is vital to empower students to appropriately employ the M/E strategy while engaging in problem-solving activities because the analysis of the current study shows that the proficiency utilization of M/E during problem-solving leads to enhanced accuracy and ultimately improve performance. Inversely, when M/E is not effectively exercised, the results in problem-solving activities tend to be poor. Therefore, adopting effective M/E practices appears as an important element in improving students' problem-solving capabilities. The complex dynamics between MKT and M/E strategies highlight the importance of considering both aspects to gain a general understanding of how students approach and perform problem-solving tasks by actively engaging in self-evaluation besides the quality of their work focuses attention on task criteria and promoting the construction of MKT [14].

Conclusions

The complex dynamics of adaptive learning, emphasize the fundamental role of metacognitive knowledge about tasks and the effective deployment of self-regulation in action components, particularly monitoring and evaluating strategies. The findings underline the transformative potential of metacognitive awareness and self-regulation in shaping the outcomes of problem-solving activities, demonstrated through the distinctive narratives of adaptive learning and faulty-adaptive learning setups. In the domain of adaptive learning, participants with an initial lack of MKT demonstrated an outstanding capacity to compensate through the active utilization of monitoring and evaluating strategies. Despite their inadequate understanding of the problem at the start, these individuals effectively employed SRA methods, allowing them to navigate the complexities of the activity. The study highlights the dynamic relationship between low MKT and high M/E, ultimately leading to exceptional precision. The ability to actively analyze performance, engage in deep practices, and make essential adjustments illustrates how individuals, even with inadequate metacognitive knowledge, can manage their cognitive processes to achieve optimal outcomes.

Conversely, the exploration of faulty-adaptive learning stresses the risks of lacking MKT, even when participants exhibit relatively high M/E approaches. In these cases, the failure to deploy M/E approaches effectively failed to solve the problem. The study underlines that the lack of effective metacognitive awareness and self-regulation can considerably hinder an individual's ability to approach and successfully solve tasks. The student's high M/E, while indicative of a capacity for self-monitoring and evaluation, proved inadequate in the absence of a solid foundation of prior knowledge. The study supports the importance of a holistic approach, stressing the indispensable role played by both metacognitive knowledge and self-regulation in attempting tasks successfully.

The research explains the vital role of effective self-regulation in action, particularly monitoring and evaluating, as a powerful tool for overcoming the challenges posed by low metacognitive knowledge. The complex relation between MKT and SRA underlines the nuanced nature of adaptive learning and faulty adaptive learning, providing valuable insights for educators, learners, and researchers seeking to enhance the application of metacognitive approaches in educational contexts. Moreover, this underscores the significance of developing both MKT and SRA for a general and vigorous approach to adopting effective learning approaches and academic success.

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