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BOARD # 37: Work-In-Progress: Understanding How Undergraduate Biomedical Engineering Students Use Metacognition to Approach Problem Solving

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Introduction

Despite the efforts of undergraduate biomedical engineering (BME) programs to prepare students with skills needed to make them competitive candidates for professional careers post-graduation, employers continue to voice that newly hired engineering graduates lack the analytical and critical thinking skills needed to be immediately successful in the workplace [2]. Meanwhile, as the field continues to grow [5] to meet current healthcare demands, the need for biomedical engineers is expected to increase substantially from the current 19,700 biomedical engineers reported to be employed in the United States as of 2023 [1]. The growth of this field warrants the attention of not only industry employers, but institutional BME departments at the undergraduate level to equip students with the specific skills and tools needed to be successful in professional practice. Inspired by this ongoing issue to prepare the future generation of BME students, and the exploration of the many factors that contribute to the development of a successful engineer, this WIP focuses on the significance of metacognitive skills in preparing students. This exploratory qualitative WIP seeks to explore how students currently make use of their own metacognitive skills through self-reporting and intends to expand on instructor-guided future implementation of pedagogical interventions that support student's metacognitive skills.

Theoretical Framework

This study is grounded in the theoretical framework presented in *Fostering Metacognition to Support Student Learning and Performance* [4], which defines metacognition as an individual's awareness and understanding of their own cognitive processes. Metacognition is conceptualized in two interrelated domains: (1) metacognitive knowledge, which encompasses declarative, procedural, and conditional knowledge, and (2) metacognitive regulation, which involves the processes of planning, monitoring, and evaluating one's cognitive strategies. This framework provides a foundational lens through which to examine the role of metacognitive skills in student learning and performance, particularly within the context of biomedical engineering education. Metacognitive knowledge refers to a person's perception of their knowledge, while metacognitive regulation refers to a person's ability to monitor their learning and address problems they encounter when learning. While the two categories and respective subcategories are important to a student's ability to solve problems, there is limited understanding of how metacognition or its constituents play a role in learning in the BME field or a BME learning environment. To further build on this framework, we posit that learning is actively constructed through interactions with the environment and reflection on those experiences. In this context, metacognitive regulation aligns with the notion of reflective abstraction, where learners assess and refine their cognitive strategies through experience. In BME education, where complex problem-solving and critical thinking are integral to the learning process, the dynamic interplay between metacognitive knowledge and regulation becomes essential. As students engage with challenging engineering problems, their ability to reflect on and adjust thinking is critical not only for retaining technical content but also for applying skills in the real-world. Thus, this framework allows for a deeper exploration of how metacognitive strategies can be nurtured and leveraged to improve both learning outcomes and professional development in the BME field.

Methodology

This work in progress study sought to answer the following research question, "How does metacognition play a role in a student's approach when solving tissue mechanics problems?" We followed a qualitative research approach to produce a case study to better understand the ways in which students engaged in developing their own metacognitive skills as they worked on solving problems in a biomedical engineering course. We paid particular attention to the subcategories of metacognitive knowledge and metacognitive regulations to understand how students adapted their metacognition to solving problems. To address the research question, the study focused on a sample of students enrolled in an elective biomedical engineering (BME) course at an R1 institution in South Central Texas. Given the specific nature of the course, the sampling frame was limited to one group, with participants recruited through a public announcement made within the course. This method resulted in a sample size of three participants (10% of class), each represented by pseudonyms: James, Stacy, and Jake. For data collection, semi-structured interviews were conducted by a graduate student to capture students' reflections on their problem-solving strategies and learning experiences. The coding process involved the use of an *a priori* coding approach, where initial codes were developed (Appendix 1) based on pre-established theoretical concepts related to metacognition [4]. After transcribing and listening to interview audio recordings, these codes were systematically applied to identify patterns and themes in how students described their metacognitive processes in problem-solving.

Human Subjects & Ethics Approval Statement: This study was found to be IRB exempt after review by the university IRB.

Preliminary Findings and Discussion

The preliminary findings from the participant interviews reveal that while students report having established routines for problem-solving, they also exhibit a high degree of adaptability when encountering unfamiliar content or challenges. This suggests that their metacognitive skills are actively engaged as they reflect on their learning process and adjust strategies accordingly. The patterns observed in the interviews with Jake, James, and Stacy align with the two key components of metacognition outlined in the theoretical framework: *metacognitive knowledge* (i.e., understanding of one's strengths and limitations) and *metacognitive regulation* (i.e., the ability to plan, monitor, and adjust strategies)For instance, the following excerpt highlights Jake's metacognitive knowledge (described below as routine knowledge) and regulation (described below as adaptation):

- <u>Routine:</u> "I learned I'm a hands-on learner. So, I mean, I can learn visually, like look at the PowerPoints, but I have to kind of apply it physically."
- <u>Adaptation:</u> "OK, so we'll go over the slides that don't relate to the back to the book, which is not my preferred method, but sometimes I do it like that"

Jake demonstrates awareness of his preferred learning style ("hands-on learner") and can reflect on how he best processes information (i.e., metacognitive knowledge). When faced with content that does not align with his learning preferences, he adjusts by engaging with the material in a less preferred but necessary manner, indicating a use of metacognitive regulation to plan and monitor his learning process. Similarly, James' description reflects both metacognitive knowledge and regulation:

- <u>Routine:</u> "So I'm very much like a just start off with the first thing that comes to mind. So, like I guess for tissue mechanics, like I don't remember what it was, it was something with flow. The first thing that came to my mind, I just kind of threw at it, it didn't work, period. And then I start to like deduce from there."
- <u>Adaptation:</u> "OK, we didn't go over that. Then of course, I'll just look for a new one."

James recognizes his tendency to rely on initial intuition ("the first thing that comes to mind"), which is an example of metacognitive knowledge. When his initial approach fails, he demonstrates metacognitive regulation by re-assessing the problem and adjusting his strategy to seek a more effective solution. This highlights how he actively monitors and modifies his cognitive approach during the learning process. Finally, Stacy tried to provide a description of her own metacognitive skills when taking quizzes and her ability to adapt when confronted with gaps in her understanding (metacognitive regulation). We opted for leaving Stacy's quote intact to show that describing metacognitive skills can often be messy for students because these skills involve complex internal processes that may be difficult to articulate.

- Routine: "I know what I have to do in order for me to grab better understanding of the concepts."
- Adaptation: "for example when we take the quizzes, and I don't have like the and the notes about it I just have to go back and kind of research and go into my notes and research locate kind of help me guide me through the question instead of just looking at my notes and writing everything down"

When she lacks specific notes or resources, she demonstrates metacognitive regulation by revisiting the material, researching additional information, and using her notes strategically to find a solution. This indicates a proactive approach to monitoring and adjusting her learning process to ensure comprehension.This trend of adaptive tendencies proposes that metacognition, specifically the subsection of metacognitive knowledge conditional knowledge, plays a role in how students approach problem-solving. The significance of this finding challenges the assumption that students have limited ability to problem solve at the undergraduate level, causing challenges during the school-to-work transition [3]. Nonetheless, the interpretation of this data suggests that research could facilitate a greater focus on leveraging the current presence of conditional knowledge in the classroom. This may include introducing activities of different modalities, following up with students in a qualitative assessment, and conducting a quantitative assessment to determine if there is a possible correlation with grades (content retention). The participants' responses reveal that metacognition is not a static process; rather, it involves ongoing reflection and adaptation. In terms of metacognitive knowledge, all three participants displayed an understanding of their preferred learning strategies, such as Jake's hands-on learning, James's initial reliance on intuition, and Stacy's strategic use of notes. This knowledge shapes how they approach problems and guides their learning. However, the more critical insight lies in how the participants regulate their learning when faced with obstacles. Whether it's Jake's adjustment to non-preferred learning methods, James's shift in strategy after his first attempt fails, or Stacy's resourceful use of alternative materials, each participant demonstrates metacognitive regulation in action. This regulatory aspect of metacognition—planning, monitoring, and adjusting—is key to solving complex problems, particularly in a demanding field like biomedical engineering, where students are often required to engage with unfamiliar and challenging content. These findings underscore the dynamic relationship between metacognitive knowledge and regulation. Students' ability to adapt their strategies based on real-time reflection suggests that fostering both components of metacognition can enhance problem-solving skills and learning outcomes.

Conclusion

To conclude, the preliminary data conveyed in this paper demonstrates metacognition's role in undergraduate BME's approach to problem-solving in their major-specific learning environment. Additionally, the interpretation of student interviews established a possible trend in using the subcategory of metacognitive knowledge, conditional knowledge. Moreover, it suggests that incorporating and developing metacognitive skills may enhance the preparedness of students leading to graduation, thus bridging the gap between the scholastic and work performance of future graduates. The next steps of this study include increasing the sample size of participants and observations to confirm the role of metacognition through qualitative and quantitative analysis.

Appendix 1:

Code Name	Definition
Systematic	Structured approach to a problem.
Reassurance	To remove doubt of conceptual understanding
Recollection	Memory of content
Trial and Error	Experimentation to find success
Routine	Regular/ 'fixed' procedure to approach problems
Adaptive	Change for different situations.
Attentive	Actively paying close attention.

Appendix 2:

Question Category	Interview Question
Declarative Knowledge	Do you think you know yourself as a 'learner'? If you think you do, does that help you learn different topics/ complete different assignments in tissue mechanics?
Procedural Knowledge	Do you have a specific learning strategy that you use prefer to learn different topics/ complete different assignments in tissue mechanics? Can you explain your process of learning this strategy if you have one, or explain why you do not have a preferred approach?
Conditional Knowledge	Can you think of a time when you used a different strategy than you're used to, and you struggled with being successful when completing different assignments/ learning different topics in tissue mechanics?
Planning	Do you find planning to be necessary to solve problems develop a further understanding of content in this tissue mechanics course?
Monitoring	Do you monitor your understanding and progress while studying or working on an assignment in tissue mechanics? (Ex: Setting a goal for the number of assignments you wish to complete). Can you explain how you monitor?
Evaluating	Do you ever pause to check if you understand what you are doing? What questions do you ask yourself if you take pauses?

R**eferences:**

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