Beyond Cognition: The Role of Emotions in Engineering Students' Problem-Solving

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Introduction

A student rewrites the same line of code for the fourth time. The logic appears sound, yet the program crashes again. Confusion rises, frustration follows, and hesitation settles in. In this moment, the student's emotional response, rather than the technical content of the algorithm, determines what will happen next. Scenes like this are common in engineering classrooms and laboratories, yet the emotional processes behind them often remain unexamined. In engineering education, where students routinely face complex problems, emotions are rarely treated as central to learning. Instead, engineering problem solving is often framed as a purely technical activity, grounded in logic, formulas, and procedures. This contrast between what research reveals and how engineering problem solving is commonly understood highlights the need for a closer examination of the emotional dimensions of engineering learning.

Emotions are multifaceted experiences that involve cognitive appraisals, affective feelings, physiological responses, motivational tendencies, and expressive behaviors [1] [2] [3]. Unlike moods, which can persist for extended periods without a clear cause, emotions are typically short and intense responses to specific events or situations [4]. They can be described along two key dimensions: valence, which refers to whether an emotion is experienced as positive or negative, and activation, which reflects the level of energy or arousal associated with the emotion [5]. In learning contexts, emotions often emerge when goals are blocked, plans fail, or expectations are violated. During engineering activities, these emotional responses can arise consciously, but they may also occur without students' full awareness, shaping attention and behavior in subtle ways [6].

Since emotions are closely tied to how students interpret challenges, the ability to regulate emotions plays a critical role in problem solving. Emotion regulation refers to the processes through which individuals influence which emotions they experience, when they experience them, and how those emotions are expressed [7]. Some regulation strategies aim to prevent unproductive emotions by changing how a situation is interpreted, while others focus on managing emotional reactions after they arise. In engineering education, effective emotion regulation is increasingly understood as a form of meta affective competence. Students who can view frustration, confusion, or discomfort as natural elements of problem solving are more likely to persist when tasks become difficult. This capacity is essential because emotion dysregulation has been shown to interfere with attention, reasoning, and strategic thinking, ultimately impairing problem solving performance [8].

Problem-solving in engineering is particularly demanding because it rarely follows a fixed procedure. Engineering problems often involve ambiguous information, competing constraints, and uncertain outcomes [9]. Students must identify relevant variables, make assumptions, evaluate tradeoffs, and manage risk. These features are especially prominent in complex problem-solving tasks, which are dynamic and involve many interdependent variables that change over time. Such tasks require students to actively engage with the problem, monitor their

understanding, and adapt strategies as new information emerges. As a result, engineering problem solving places heavy cognitive and emotional demands on learners.
Despite growing interest in emotions within engineering education, the literature remains fragmented and uneven. Many studies focus narrowly on constructs such as anxiety or emotional intelligence, while broader theoretical perspectives on emotion receive little attention. Research on emotions during laboratory work and hands on activities is especially limited, even though interaction with physical tools and materials is central to engineering practice [10]. Methodologically, much of the existing research relies on self-report measures collected after tasks are completed, which limits insight into how emotions evolve during the problem solving process [11]. There is a need for studies that capture emotional trajectories in real time, particularly during ill-defined engineering tasks that more closely resemble professional practice.

Together, these gaps demonstrate that existing research has not yet provided a comprehensive understanding of how emotions shape engineering students' thinking and learning during problem solving. Although individual studies have shown that emotions influence attention, strategy use, persistence, and performance [12], the field lacks of which emotions arise, how they unfold over time, and how students regulate them. This is especially important because engineering students are expected to confront uncertainty, navigate shifting constraints, and make judgment calls that involve risk and potential failure.
Given the significance of these gaps, this literature review examines the emotional experiences of engineering students during problem solving and the ways emotion regulation shapes their approaches and outcomes. More specifically, the review is guided by two central research questions:
1. How do engineering students experience and express emotions during problem-solving tasks?
2. How do emotions and emotion-regulation strategies influence engineering students' problem-solving approaches and performance?

Methods

The purpose of this review was to examine how emotions and emotion-regulation processes influence engineering students' problem-solving approaches and performance. Because the term "emotions" can refer to a wide range of specific emotional states such as happiness, frustration, excitement, or sadness, relying on the single keyword "emotions" risked missing relevant studies. At the same time, it was not feasible to list every individual emotion term in the search strings. To address this issue, we expanded our search to include the broader term "affect" and "feeling", following the view that this concept closely align with the construct of emotion [3]. This approach increased the likelihood of capturing studies that addressed emotional experiences even when specific emotion labels were not used.

To address the research questions, we developed three search strings: ("emotions" OR "affect" OR "feeling") AND ("problem solving"); ("problem solving") AND ("engineering students" OR "engineering education"); ("emotions" OR "affect" OR "feeling") AND ("engineering students" OR "engineering education"). These strings allowed us to locate literature focused on emotional processes in problem solving, engineering contexts, and the intersection of both areas. Searches were conducted in six major databases: SCOPUS, ERIC, APA PsycInfo, IEEE Xplore, EBSCO, and ScienceDirect. Because our interest extends beyond engineering education to the broader

cognitive and psychological foundations of emotions, we did not limit our search to engineering specific studies. Instead, we included research from general education and psychology and then examined how these findings connect to engineering problem solving. We also included studies from STEM education to expand the scope of contexts related to engineering learning.
The search process using the three strings produced a total of 1,107 papers. We then removed duplicates and excluded articles that were not written in English. Screening proceeded in three stages: abstract screening, full-text sifting, and full-text review. No publication date limits were applied because foundational theories of emotions remain valuable for contemporary research and many influential studies were conducted several decades ago. After completing all stages of screening and hand selection of relevant sources, 33 papers were retained for the final review.

Findings

How do engineering students experience and express emotions during problem-solving tasks?

Engineering students experience a broad range of emotions during problem solving, and these emotions shift as they move through different phases of the task. Research across engineering education, psychology, and cognitive science shows that the emotions students feel are not random; instead, they are closely tied to the cognitive demands of the problem, moments of uncertainty, the presence or absence of feedback, and students' beliefs about their own capability.

The Predominance of Epistemic and Process-Related Emotions

Across studies in engineering, mathematics, programming, and physics, epistemic emotions are the most reported. These are emotions that arise from intellectual effort and meaning making. Confusion, curiosity, frustration, boredom, anxiety, and moments of enjoyment appear far more frequently than basic emotions such as fear or sadness [5], [11], [13]. For example, engineering students working on programming tasks reported frustration more often than any other emotion, usually when they encountered syntax errors or unexpected results [4]. In engineering design settings, the pattern varies depending on students' beliefs about knowledge [14]. Students who believe knowledge can be justified in different ways tend to experience more positive engagement, while students who expect fixed and certain answers are more likely to feel bored or discouraged when tasks require judgment or interpretation.

Forethought Phase: Novelty, Anxiety, and Relief

Students' emotions begin shifting the moment they encounter a new problem. During this initial stage, their reactions are influenced by how difficult the task appears, how familiar the topic feels, and how much control they believe they have [11]. Ill-defined or open ended tasks often provoke anxiety, uncertainty, and hesitation, particularly when students are unsure where to begin or how much prior knowledge they need [13]. Physiological studies show that emotional arousal is often highest before students begin working, which indicates that anticipation and concern can be strong even before any calculations or reasoning occur [15]. Although some students experience relief when a task appears manageable at first glance, this sense of ease usually fades once they begin solving the problem. Students often describe a feeling of discomfort when they realize that a problem requires them to make assumptions instead of applying a clear formula [4]. This discomfort highlights the uncertainty that characterizes real engineering work.

Performance Phase: The Cycle of Confusion and Frustration

During the performance stage, when students begin calculating, coding, experimenting, or designing, their emotions become more intense and more closely tied to the cognitive difficulty of the task. Confusion becomes one of the dominant emotions [13]. It often arises when students encounter contradictions, errors, or unexpected results. While confusion can guide students to reflect, reconsider strategies, and deepen understanding, it can also become exhausting. The literature describes a critical transition point here: if confusion is resolved through metacognitive activities, it can transition into positive emotions like curiosity or delight; however, if the impasse remains unresolved, confusion frequently transitions into frustration or boredom [1][16]. These emotions make it harder for students to concentrate and reduce their willingness to persist through difficulty. Studies show that frustration increases when students face repeated failure or slow progress, as is common during debugging or complex mathematical reasoning. Students often describe an emotional back and forth between hope and discouragement depending on whether small successes appear along the way. In laboratory environments, physical interaction with tools and materials can also provoke emotional reactions. Students handling unfamiliar or potentially risky equipment, such as radioactive samples, often feel nervous at the beginning, but this apprehension usually shifts toward confidence as they become more comfortable with the tools and procedures [17].

Emotional responses during problem solving are also shaped by cognitive load and the degree to which students can regulate their emotions [18], [19]. Tasks that require students to track several ideas at once or apply multiple steps in sequence place heavy demands on attention. Students with weaker emotion regulation skills are more likely to feel overwhelmed during these tasks. Research with undergraduate students shows that poor emotion regulation is closely associated with weaker problem solving performance and greater feelings of hopelessness, which can undermine students' ability to think clearly and make reasoned decisions [8]. Cognitive theories of emotion explain these patterns by showing that emotions emerge from the way students interpret and evaluate a situation [7]. When students view a problem as threatening or unmanageable, their emotional responses become more intense, which further disrupts problem solving processes such as planning, evaluating alternatives, and maintaining focus

Reflection Phase: Attribution and Outcome Emotions

At the reflection stage, after the task is complete or feedback is received, students experience a different set of emotions tied to their interpretation of the outcome [20]. When they believe they performed well, they often feel pride, relief, and happiness, particularly when they attribute success to their own effort or strategies. Pride is especially strong when students solve problems independently or understand concepts that seemed confusing at first. When students believe they have performed poorly, they tend to experience disappointment, shame, anger, or renewed frustration. Research in mathematics education shows that students with positive emotions demonstrate stronger abilities in organizing information, identifying problems, selecting strategies, and generalizing solutions. Students with recurring negative emotions are more likely to struggle with these same skills and to withdraw from the task altogether [1], [14] . Boredom during reflection is especially concerning because it often reflects a deeper belief that the activity lacks value, which can lead to long term disengagement from learning.

Throughout all stages of problem solving, emotional awareness and regulation play important roles. Students who notice their emotional reactions and understand how these reactions affect their thinking are more capable of managing frustration and adjusting their strategies. Classic studies of affect in problem solving show that students who can monitor their emotional responses are better at deciding when to pause, seek clarification, or change approaches. Recent research reinforces this idea by showing that emotional stability supports better problem solving performance.

How do emotions and emotion-regulation strategies influence engineering students' problem-solving approaches and performance?

Emotions have a direct and measurable influence on how engineering students approach problem solving. They shape the strategies students choose, the depth with which they process information, and the consistency of their performance over time. The literature shows that emotions function as cognitive signals: they guide where students direct their attention, how much effort they invest, and the type of reasoning they use when confronted with uncertainty or difficulty.

Influence on Cognitive Strategies and Approaches

Positive activating emotions, especially curiosity and enjoyment, support the use of deep cognitive strategies. Students who feel curious tend to engage in exploration, elaboration, and metacognitive monitoring. This curiosity-driven behavior helps them search for missing information, question their assumptions, and avoid premature closure on a problem. Studies in complex problem solving show that curiosity encourages students to test alternative explanations or revise their approach, which leads to more adaptive reasoning [1]. In contrast, boredom consistently undermines strategic thinking. When students feel bored, their attention drifts, and they rely on surface-level processing rather than planning or critical evaluation. Boredom is also linked with disengagement in engineering design settings, where students who believe knowledge has a single correct form show fewer strategies and weaker persistence.
Negative emotions such as frustration play a more complex role. Mild frustration can alert students that a strategy is ineffective and that they need to rethink their approach. In this sense, frustration can act as a constructive signal that promotes strategy-switching. However, high levels of frustration tend to disrupt cognitive control. Research on emotional dynamics in problem solving shows that strong frustration lowers students' resolution level, meaning they process information in a more shallow and reactive manner [15]. Under these conditions, students are more likely to adopt impulsive strategies in which they take quick actions without anticipating consequences. This pattern is especially visible in programming tasks and in dynamic simulations, where frustrated students test random changes instead of following a systematic plan.

Influence on Performance Outcomes

Performance outcomes are strongly tied to students' emotional states. Curiosity is one of the strongest positive predictors of problem-solving success. Students who begin a task with a sense of curiosity are more likely to persist through uncertainty and eventually reach a correct solution. Positive outcome emotions also influence future performance. When students feel happy or relieved after solving one problem, they approach the next task with greater confidence and effort, creating a cycle in which success and positive affect reinforce one another. In contrast, negative outcome emotions, especially frustration after failure, can limit future performance. Students who dwell on previous mistakes often deplete the cognitive resources they need for the next task, which makes it harder for them to recover and perform well. Several studies show that emotional stability has a significant impact on performance. Students who maintain steady emotional patterns, with increasing positive emotions and decreasing negative emotions over time, consistently outperform students whose emotions fluctuate or become increasingly negative [21].

Emotion regulation strategies shape how strongly emotions affect performance. Students who are able to monitor, interpret, and manage their feelings engage more effectively with difficult tasks. This form of regulation, called meta-affect, involves recognizing emotions as part of the learning process rather than signs of failure [22]. For example, students who experience confusion or discomfort during engineering modeling tasks often make better progress when they interpret these emotions as normal features of open-ended problem solving. These students treat uncertainty as a challenge rather than a threat, which supports persistence and resilience. Different regulation strategies also lead to different performance outcomes. Research on complex simulations shows that active regulation strategies, such as confronting the source of frustration, reorganizing the problem space, or energetically removing obstacles, are associated with higher performance [23]. These active strategies help students maintain cognitive control. In contrast, passive regulation strategies, such as attempting to reassure oneself without changing behavior, are associated with weaker performance because they do not address the underlying cognitive difficulty. Social regulation is another important mechanism. Students often reduce anxiety by sharing concerns with peers, using humor, or confirming that others feel similarly confused [24]. These social interactions help students settle their emotions and return to the task with greater clarity.

Conclusion

This review highlights that emotions play an important role in shaping how engineering students engage with challenging problem-solving tasks. Emotional experiences influence how students respond to uncertainty, adapt their strategies, and persist through difficulty. Differences in emotional regulation help explain why students with similar technical knowledge may approach the same problem in very different ways.

These findings suggest several promising directions for future research. One important step will be to investigate how engineering students can learn to regulate emotions more intentionally and to clarify which strategies are most beneficial. Another need is to explore ways of embedding emotion-regulation support into engineering coursework so that it becomes part of students' regular problem-solving practice rather than an isolated intervention. This may involve designing learning environments that make space for emotional reflection or creating curricular activities that help students recognize emotions as informative signals rather than barriers.

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