WIP: Tracking Cognitive Engagement via Micro-Facial Expressions during Engineering Problem-Solving

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Dr. Talha Naqash completed his doctoral studies in Engineering Education at Utah State University. With a diverse academic foundation, he also holds a Master's degree in Telecommunication and Networking. He is currently serving as a faculty member at Dickinson State University in the School of Applied Sciences. Dr. Naqash's research focuses on cognitive engagement analysis, assessment methods in engineering education, and the role of facial expressions and emotions in the learning process. His scholarly contributions include numerous publications and presentations at prestigious venues such as IEEE, ASEE conferences, and leading Wiley and Springer journals. He is an active member of several technical committees and serves as a reviewer for reputable journals and international conferences, including the ASEE and IEEE Transactions on Education. Dr. Naqash's dedication to advancing educational research, combined with his broad academic and professional experience, underscores his commitment to fostering innovation and excellence in engineering education.

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Zain ul Abideen holds a Ph.D. in Engineering Education from Utah State University, where he also served as a Graduate Researcher. He is a computer engineer and earned his bachelor's degree in computer engineering and master's degree in engineering, and brings over a decade of experience in teaching and research with undergraduate engineering students. He actively contributes to several technical committees and serves as a reviewer for leading journals and international conferences. His doctoral research focused on cognitive engagement, AI in education and engineering design, self-regulated learning, and mobile learning. His work seeks to deepen our understanding of how these elements influence learning and success in engineering education. With a strong commitment to educational advancement and a robust academic background, Zain is recognized as a dedicated and emerging scholar in the field of engineering education.

Waqas Ahmad, Utah State University

Waqas Ahmad is a doctoral researcher at Utah State University whose scholarly work explores cognitive engagement, learning processes, and the sociopolitical aspects of education. With over 20 years of teaching experience at the college and university level in STEM disciplines and a strong academic background, he integrates practice-informed insight into his research. His approach uses innovative methods to analyze observable signs of engagement during engineering problem-solving, while advocating for equitable practices through Indigenous perspectives in data science education and student agency. By combining a thorough analysis of complex learning tasks with a focus on social justice, his work promotes creative, evidence-based pedagogical frameworks.

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Assad Iqbal (Sid) is a Senior Lecturer at the Department of Engineering Education in the College of Engineering, Ohio State University. Assad has been working with the National Science Foundation (NSF) funded national collaboration research project, "Engineering For Us All (e4usa) since October 2022. The core mission of this project is to increase student and teacher access to engineering with a focus on reaching traditionally underrepresented populations in this field.

With a BS in Computer Information Systems Engineering, a Master of Science in Engineering Management, and a Ph.D. in Engineering Education, Assad's long-term research goal is to converge his varied research experiences and endeavors to explore the possibilities of an inclusive instructional design to promote self-directed, self-regulated, life-long learning among pre-college and undergraduate engineering students.

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Abstract

This work-in-progress (WIP) study examines the relationship between students' micro facial expressions and their level of cognitive engagement while solving two mathematical problems of varying degrees of difficulty. Cognitive engagement during problem-solving is a complex, dynamic, and multidimensional construct. Grounded in a constructionist perspective, this study conceptualizes cognitive engagement as context-dependent and shaped by learners' prior experiences and emotional responses. This mixed-methods study employed a participant-selection model to examine undergraduate engineering students' cognitive engagement during problem-solving. Students from multiple disciplines at a public land-grant research university completed two think-aloud problem-solving tasks, including an easier (linear algebra) problem and a more difficult (geometry) problem. These think-aloud sessions were audio-video recorded. Audio data were transcribed for detailed analysis. The facial expressions were captured using the Morphcast Emotional Tracking tool based on the Russell Circumplex Model. Transcripts were segmented into five-second intervals, coded for emotional valence and arousal, and triangulated with facial-expression data to identify patterns indicative of cognitive engagement.

This study examined four undergraduate participants as part of a larger investigation into affective markers of cognitive engagement in engineering problem solving. Preliminary video and emotion-tracking analyses showed that 3 of 4 participants who successfully solved the tasks exhibited predominantly positive affect, such as happiness, confidence, and curiosity despite brief moments of frustration. In contrast, the participant who struggled with both tasks displayed more frequent confusion and anxiety alongside intermittent positive states. Engagement-over-time visualizations revealed stable attention patterns among higher-performing participants, while the lower-performing participant demonstrated markedly variable attention. These early findings suggest that positive affect and curiosity, as reflected in facial expressions, may serve as preliminary indicators of higher cognitive engagement. This work contributes to ongoing efforts in affective computing for education and supports the development of real-time metrics to inform adaptive learning systems and targeted pedagogical interventions in engineering education.

Introduction & Brief Literature Review

Cognitive engagement is a multifaceted construct central to how students process information and persist through complex tasks. While cognitive engagement itself cannot be directly observed, recent research has shown that facial expressions can provide valuable insight into learners' emotional states, which often interact with and influence cognitive processes during problem solving [1],[2]. This study focuses on examining the relationship between cognitive engagement and facial expressions, with the aim of identifying non-verbal indicators that may signal heightened engagement during engineering problem-solving activities. A substantial body of literature highlights the relevance of facial expressions in understanding students' affective responses during problem solving and learning. Sathik et al. (2013) showed the wide applicability of facial expression recognition systems across fields such as psychology and education [1] and emphasized the importance of analyzing emotional cues in both human-computer and human-human interactions [2]. Researchers have also demonstrated how instructors can use students' facial expressions to enhance teaching and learning [6]. Automated analysis of facial movements during computer-mediated instruction has been shown to predict engagement, frustration, and problem-solving performance, as demonstrated in the work of Grafsgaard and colleagues (2013) [4]. Additional studies have linked facial expressions to heightened emotional states [5], with task demands and interaction contexts influencing the types of expressions displayed [6]. For example, research on collaborative programming teams has shown that high performing groups exhibit diverse emotional responses, ranging from confusion and frustration to delight and neutrality, throughout the coding process [7].

In recent empirical work, a consistent theme emerges that cognitive engagement can be inferred from observable behavioral and emotional cues, including facial expressions, however, existing evidence remains limited and warrants further investigation. For example, Sharma et al. (2021) found that children's facial expressions during collaborative coding systematically differentiated high- and low-performing teams, with high performers showing more transitions from confusion and frustration into delight, whereas low performers exhibited more boredom, suggesting emotion patterns may signal differences in engagement during problem-solving tasks [8]. Similarly, Li et al. (2021) demonstrated that students' facial behaviors could reliably predict cognitive-engagement states using machine-learning models, particularly Support Vector Machine (SVM), although high- and low-performing students did not differ significantly in overall engagement levels, highlighting both the promise and the current limitations of automated facial-analysis approaches [9]. Helme and Clarke (2001) provided foundational classroom-based evidence showing that cognitive engagement can be identified through linguistic and behavioral indicators, but their work did not incorporate affective or facial-expression data, leaving a gap regarding how emotional cues correspond with cognitive processes [10]. Complementing the existing machine-learning-driven approaches, De-Carolis and colleagues demonstrated that behavioral indicators, such as head movements, facial expressions, and gaze, can be automatically analyzed and linked to self-reported engagement using the psychological construct of flow [11]. Their work, however, examined only four dimensions of engagement (focus, interest, stress, relaxation), capturing only a subset of the broader construct. More comprehensive frameworks, such as those grounded in facial fiducial point analysis and the Facial Action Coding System (FACS), offer additional insight by connecting specific facial action units to behavioral and emotional dimensions of engagement [12]. Taken together, these studies underscore both the potential and the need for further research to determine whether facial-expression analysis can validly and reliably capture cognitive engagement, particularly in complex engineering problem-solving contexts.

Purpose and Research Question

Against the backdrop, the present study extends existing affective analytics research by adopting a theory-driven, performance-anchored interpretation of facial affect grounded in Russell's Circumplex Model of Affect. Unlike prior work focused on classification or development of machine-learning models, this study is situated within engineering education research and investigates how valence-arousal dynamics may relate to cognitive engagement during authentic engineering problem-solving tasks. By situating facial-expression analysis within pedagogical and instructional design contexts, this work contributes towards developing richer, contextually grounded understandings of cognitive engagement that may inform future adaptive learning systems and educational interventions. Students exhibit distinct patterns of engagement in problem-solving tasks across various learning environments, encompassing traditional face-to-face settings and the increasingly prevalent online modalities. Our goal is to discern potential variations in the dynamics of cognitive engagement and corresponding facial expressions within these distinct learning scenarios. Many scientific justifications have been offered to explain the link between students' cognitive engagement levels, facial expressions, and the impact of diverse emotions (e.g., happiness, sadness, neutrality, frustration) on cognitive engagement during problem-solving tasks [13]. This awareness is crucial for identifying individual cognitive styles and learning tendencies. This study is guided by two research questions: (RQ1) Are there specific facial expressions that are consistently associated with high cognitive engagement in problem–solving? (RQ2) How can the findings of this study be applied to enhance educational practices or interventions aimed at fostering deeper cognitive engagement and more effective problem–solving strategies among students?

Participants

Four undergraduate students (two male & two female) with diverse engineering backgrounds participated in this pilot phase of the study. The females had backgrounds in civil engineering and mechanical engineering. On the other hand, the males specialized in mechanical engineering and aerospace engineering.

Methods

The study used a convergent mixed-method design with concurrent collection of both qualitative and quantitative data. Qualitative data were collected using the Think-Aloud Protocol (TAP) to assess student cognitive processes during problem-solving tasks. Quantitative data were analyzed using the Morph Cast Emotional Tracking tool [14]. This tool analyzes videos to identify specific micro-expressions, or small facial movements, as indicators of emotions. The purpose of the concurrent qualitative and quantitative data was to assess students' cognitive engagement through qualitative think-aloud data and correlate it to the associated facial expressions through analyzing quantitative facial action units data.

Data Collection & Analysis

There are two distinct phases involved in this study. The two phases allow researchers to fully capture the participants' problem-solving behaviors in addition to how these are reflected in their facial expressions. The first phase of the study involves the participants working through a series of two questions, beginning with an easy one, followed by a more challenging one. While solving the problem, participants practiced Think Aloud by verbalizing their thoughts, which allowed investigators access to their cognitive processes while involved in the problem-solving. Both sessions were audio- and video-recorded, with the HD camera placed to capture facial expressions during the problem-solving sessions. In Phase Two, video data from Phase One were analyzed using the MorphCast emotional tracking tool [14], which detects micro-expressions (subtle facial muscle movements associated with affective states). The extracted emotional features were subsequently interpreted within the framework of Russell's Circumplex Model to classify affect along valence and arousal dimensions. Through extensive analysis by the Morph Cast, the facial expression video data were converted into quantitative data, allowing for further analysis [15]. Simultaneously, the audio portions of the recordings were transcribed and divided into five-second segments. This data will be used for further comparison of the participants' facial expressions and micro-expressions during future analyses in Phase Two. *For this Work-in-Progress study, the focus is limited to results derived from video data analysis.*

Preliminary Results: Video Data Analysis- Easy & Difficult Problem–Solving Task

Video recordings of problem-solving sessions (both easy and hard problems) were processed and analyzed using Morph Cast to record participants' problem-solving time and their facial expressions to identify emotional cues and the degree of accuracy with respect to micro-expressions [15, 16]. This methodology included examining the frequency of facial expressions that corresponded with increased cognitive engagement in the problem-solving tasks [17]. All the participants' solutions were checked by the course instructor (Table 1) and marked as correct if the attained marks were more than 8 out of 10, partially correct if the attained marks were between 6 to 8, and incorrect if the marks were below 5.

Table 1: Initial Results of Problem-Solving Activity

Participant No	Problem 1 (Easy)		Problem 2 (Difficult)	
	Completion time (min)	Problem Solved Status	Completion time (min)	Problem Solved Status
1	26.41	Correct	53.52	Partially Correct
2	13.00	Incorrect	24.29	Incorrect
3	6.11	Correct	24.47	Correct
4	32.55	Incorrect	13.49	Partially Correct

The study examined the relationship between positive emotional valence and cognitive engagement during problem-solving. Positive emotional states are considered particularly important because they are associated with sustained attention, increased persistence, and deeper cognitive processing, whereas prolonged negative emotional states may correspond with cognitive disengagement or reduced task performance. Cognitive engagement emerged as the strongest predictor of problem-solving performance and was associated with positive emotional valence. Participants spent most of their time in the upper-right quadrant of Russell's Circumplex Model [18], reflecting positive valence and moderate arousal. Participants 1, 3, and 4 demonstrated high cognitive engagement and strong performance. They reported confidence, curiosity, and interest with controlled arousal levels. Brief increases in arousal and negative emotions (e.g., frustration or confusion) occurred during challenging tasks, but participants generally regulated these states and returned to positive valence. .

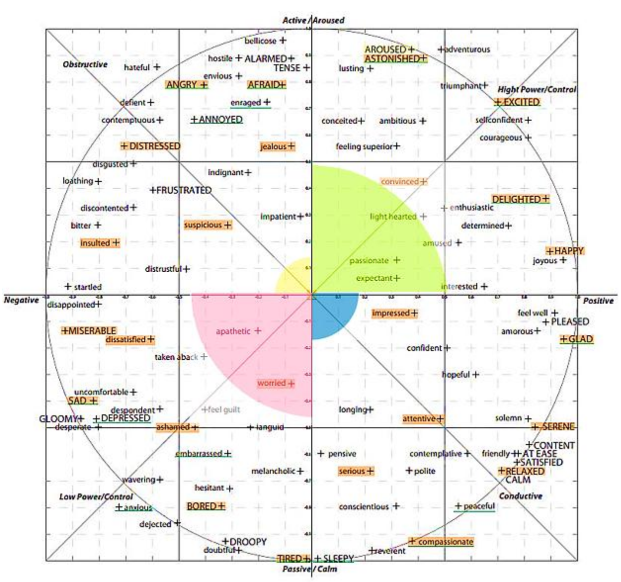

Figure 1: Emotions Exhibited by participant 1 while solving the Easy question

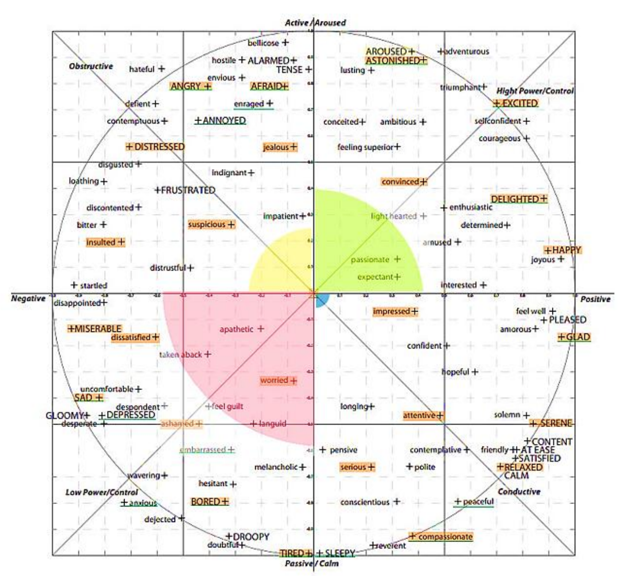

Figure 2: Emotions Exhibited by participant 1 while solving Difficult question

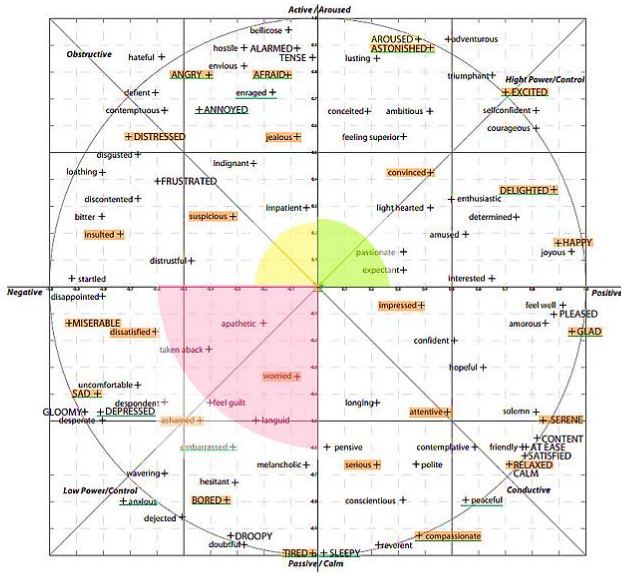

Figure 3: Emotions exhibited by participant 2 while Solving Easy question

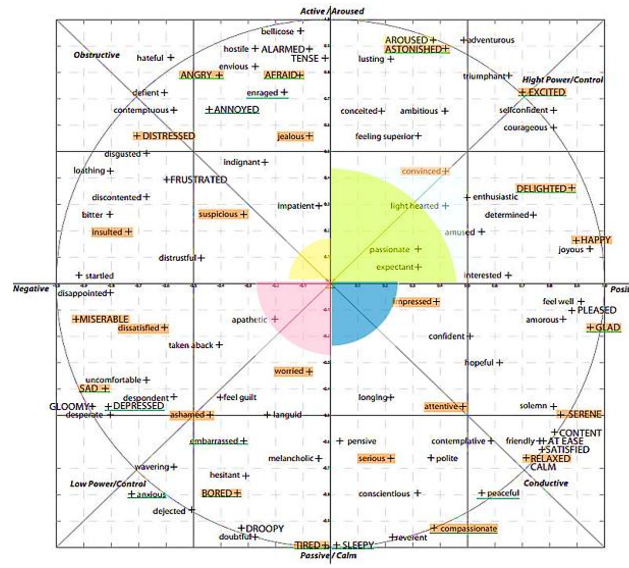

Figure 4: Emotions exhibited by participant 2 while solving the difficult question

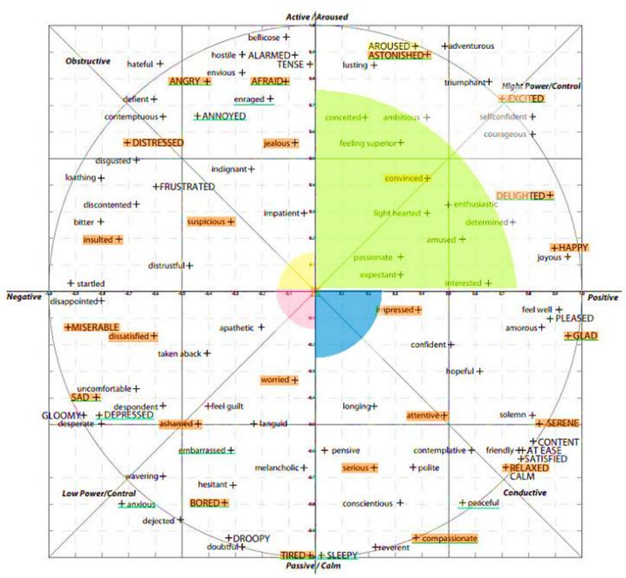

Figure 5: Emotions Exhibited by participant 3 while Solving Easy question

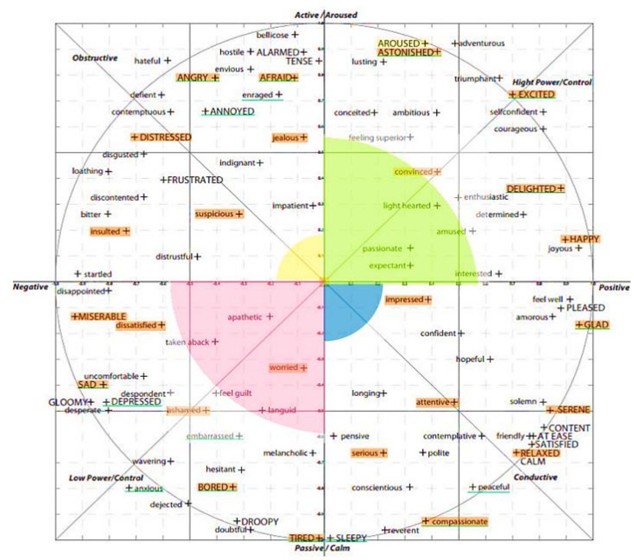

Figure 6: Emotions Exhibited by participant 3 while solving Difficult question

Participant 2 exhibited higher levels of negative valence than any of the other participants. Therefore, while maintaining high positive valence/supportive emotion, participants experienced periods of unstable emotion patterns as the arousal continued to decrease to neutral. Research questions identified the interaction of emotional valence/arousal dynamics and cognitive engagement in student learning. Research question 2 focused on educational practices and strategies to support student emotional management. The identified patterns of augmented engagement identify the impact of facilitating cognitive engagement through emotional intelligence in developing students' self-regulation skills and knowledge.

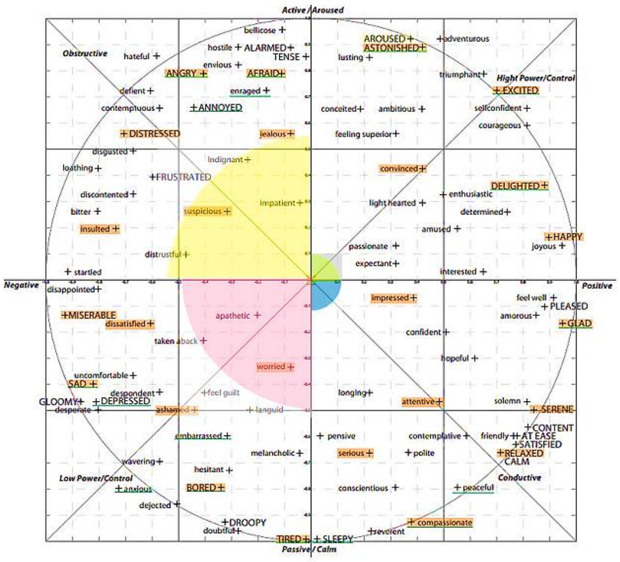

Figure 7: Emotions Exhibited by participant 4 while Solving Easy question

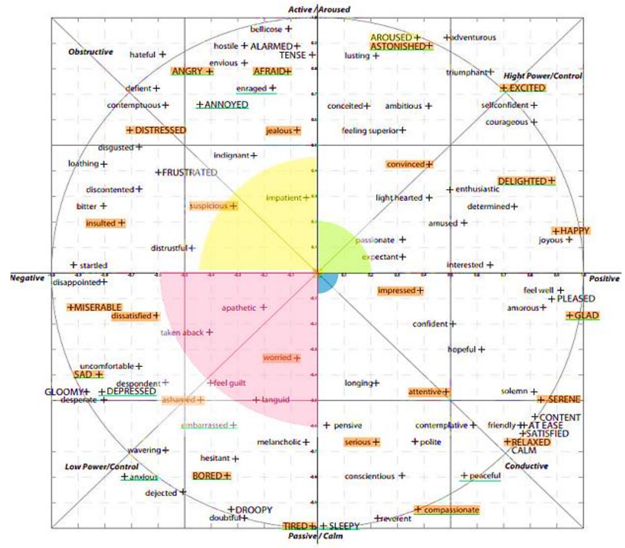

Figure 8: Emotions Exhibited by participant 4 while solving difficult question

Implementation of programs supporting exploration, response to confusion, and support for timely feedback will provide opportunities for students to maximize the effectiveness of emotional intelligence when working through problem-solving tasks. Additionally, technology integration to monitor facial expressions associated with various emotional states will allow teachers toto identify when learners are operating within negative emotional valence states of confusion and/or distress that exhibit excessive levels of arousal. Teachers should implement corrective support (i.e., modifying student tasks, feedback, and supportive strategies) to encourage students to return to a state of optimal engagement. This method will provide great benefit to students who experience emotional management challenges while attempting problem-solving tasks.

Conclusion

Preliminary findings suggest a systematic association between cognitive engagement and affective states characterized by valence and arousal as conceptualized in Russell's Circumplex Model. Patterns observed in facial expression data indicate that sustained positive valence combined with moderate-to-high arousal tends to co-occur with higher levels of cognitive engagement during problem-solving. In contrast, consistently lower or fluctuating valence appears to align with reduced engagement and comparatively weaker performance indicators. These relationships are exploratory and correlational in nature; therefore, no causal inferences are made. Nevertheless, the emerging patterns provide an initial foundation for further investigation into affect–engagement dynamics in engineering learning contexts. Emotional management is crucial in student learning processes and provides a foundation for researchers to create and validate therapeutic tools to recognize and manage emotional responses to learning experiences. An important implication is the potential integration of affect-aware analytics into learning management systems, where students' facial expression patterns could provide instructors with real-time insight into cognitive engagement. Such information may support educators in tailoring instructional strategies not only at the course level but also at the topic level. Future research will expand the dataset and validate this multimodal engagement framework.

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Appendix A

Problem 1: (Linear Algebra)

This problem tests the fundamental ability to translate a physical or logical system into a matrix equation $Ax=b$.

The Scenario: A small drone (Aero/CS) or a static joint (Civil/Mech) is held in place by two cables. To maintain equilibrium, the horizontal and vertical forces must sum to zero.

- Cable 1 exerts a force vector $f1=\langle 1,2\rangle$ multiplied by an unknown tension T1.
- Cable 2 exerts a force vector $f2=\langle -1,1\rangle$ multiplied by an unknown tension T2.
- The total external load (gravity/wind) is a constant vector $b=\langle 2,10\rangle$.

Your Task:

1. Set up the 2×2 system of linear equations:

$$T_1-T_2=2$$
$$2T_1+T_2=10$$

2. Solve for T_1 and T_2 using Cramer's Rule or Substitution.
3. If the computer returns a solution where T1 is negative, what does that physically imply about the "cable"?

Problem 2: Geometry

The Scenario: A flat solar panel (The Plane) is mounted on a roof.

- The Plane (Π) contains the point $A(1,2,3)$ and has a normal vector $n=\langle 2,-1,2\rangle$.
- A support beam (The Line) is modeled by the equation $r(t)=\langle 0,1,1\rangle+t\langle 1,1,1\rangle$.

Your Task:

1. Find the Equation of the Plane: Write the scalar equation of the plane in the form $ax+by+cz=d$.
2. Find the Intersection: Determine the specific point $P(x,y,z)$ where the support beam (the line) passes through the solar panel.
3. Calculate the Angle: Find the angle ϕ between the beam and the plane's normal vector n
4. Reflect: If $\phi=0^\circ$, is the beam perpendicular or parallel to the panel? If you were "rendering" this panel, would the beam be visible if the camera is at (0,0,0)?