Exploring Emotional and Cognitive Responses in Engineering Education: An Exploratory Study in Laboratory Learning Environments

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ABSTRACT

Emotional and cognitive responses shape learning experiences in engineering education, particularly within blended learning environments. This exploratory study aims to answer (RQ1) how students perceive their emotional and cognitive learning experiences when using laboratory kits in a blended learning environment compared to traditional in-person settings, and (RQ2) what key factors (instructional, emotional, and contextual) influence their engagement and persistence with laboratory kits in a blended learning environment. The study examines students' experiences using small-scale take-home laboratory kits for fluid flow (FLU) and heat exchanger (HEX) experiments over four weeks of online instruction, followed by one week of in-person laboratory work. Participants provided data through questionnaires and open-ended reflections. Preliminary results indicate that students valued the flexibility and autonomy of online labs but encountered challenges with troubleshooting and limited instructor support. Confidence in applying engineering concepts increased slightly, while anxiety decreased, particularly when transitioning from small-scale take-home lab kits to larger-scale equipment. Results from quantitative data showed a slight increase in confidence and a reduction in anxiety when compared before and after the study. While the qualitative results helped to understand the interplay and shift between emotional and cognitive responses. The findings highlight the importance of instructional clarity, hands-on engagement, and perceived real-world relevance in shaping students' emotional and cognitive experiences. These insights suggest that well-structured blended learning environments can enhance engagement and persistence; however, targeted scaffolding and instructional support are necessary to optimize learning and facilitate skill transfer in engineering labs and suggest directions for future research.

Keywords: *Emotional responses, Cognitive responses, Engineering education, Blended learning, Laboratory learning environments, Small-scale lab kits, Control-Value Theory (CVT), Educational Design Research (EDR), Student motivation*

1. INTRODUCTION

Emotional and cognitive responses are critical in shaping student's learning experiences and academic outcomes. Emotional intelligence, defined as the ability to recognize, understand, and regulate emotions, has been identified as a significant predictor of academic success [1], [2], [3]. Research shows that positive emotional responses, such as self-efficacy, motivation, and engagement, are essential contributors to effective learning and academic achievement [3], [4]. On the other hand, *cognitive responses*, including metacognitive strategies and self-regulation, play a crucial role in the learning process by enabling students to plan, monitor, and evaluate their progress, leading to improved academic performance [5].

While the importance of both emotional and cognitive factors in learning is well-documented, research exploring their combined impact in engineering laboratory settings remains limited. Most previous studies have concentrated on traditional classroom environments, creating a gap in understanding how emotional and cognitive dynamics operate in experiential learning contexts like engineering labs. Laboratory settings often demand active problem-solving, collaboration, and experimentation, which can amplify both emotional and cognitive demands [6]. This paper aims to address this gap by examining how emotional and cognitive responses intersect to shape learning outcomes, motivation, and engagement in engineering laboratories. A deeper understanding of these interactions is crucial for designing instructional strategies that support cognitive skill development while also promoting emotional well-being among engineering students and educators [7].

The purpose of this exploratory study is to investigate the emotional and cognitive responses of engineering students within a blended engineering laboratory learning environment. Engineering laboratories present unique challenges due to their hands-on nature, requiring both technical competence and emotional resilience for effective experimentation and problem-solving. While the existing literature has explored emotional factors such as anxiety, motivation, and engagement in relation to learning outcomes in STEM learning contexts [8], [9], limited attention has been given to how these emotional factors interact with cognitive processes in blended laboratory environments. By addressing this gap, the study aims to inform instructional practices that support both emotional regulation and cognitive growth in engineering education.

2. BACKGROUND

2.1 Emotional and Cognitive Responses. In engineering education, emotional and cognitive responses significantly shape students' learning experiences and academic outcomes. These responses are interconnected and influence key factors such as motivation, engagement, self-regulation, and persistence in challenging engineering programs [10]. Positive emotions, such as interest, curiosity, and enjoyment, promote deeper learning and sustained academic success in laboratory settings [11]. Conversely, negative emotions, such as anxiety, frustration, and boredom, impair performance, reduce engagement, and increase dropout rates, particularly in engineering laboratories that involve complex problem-solving or abstract theories (e.g., transport phenomena and thermodynamics) [12].

Within this context, cognitive processes like problem-solving, self-regulation, and critical thinking play a vital role. For instance, in engineering labs, students troubleshoot equipment issues, apply technical theories, and evaluate outcomes against expected results [13]. Effective problem-solving also encourages students to connect theoretical concepts, such as thermodynamics or fluid dynamics, to real-world applications, enhancing their understanding [14]. Critical thinking supports deeper engagement by encouraging students to examine underlying principles, moving beyond surface-level results [15].

2.2 Emotional Dynamics in Learning. Positive emotions, such as enjoyment and interest, mediate the relationship between self-efficacy and academic success, while negative emotions, such as anxiety, hinder cognitive processes and lead to poorer outcomes [5], [16], [17]. Students experiencing positive emotions are more likely to adopt adaptive strategies, whereas negative emotions can impair cognitive engagement and motivation [18], [19]. Achievement goals also influence emotional responses: mastery-oriented goals foster positive emotions and better outcomes, whereas performance-oriented goals increase anxiety and hinder performance [16], [19]. These findings highlight the importance of fostering a positive emotional climate in engineering education to enhance student motivation, engagement, and academic success [20], [21]. Engineering labs present unique challenges and opportunities due to their hands-on, collaborative nature. These settings demand high cognitive engagement, problem-solving, and the application of theoretical knowledge, often intensifying emotional responses [22]. Exploring emotional and cognitive responses in blended lab environments is essential for adapting teaching methods to better support students' emotional regulation and cognitive engagement.

2.3 Blended Learning in Engineering Laboratories. Blended learning, which combines online and in-person components, presents unique challenges to emotional and cognitive engagement. Students experience greater autonomy, which can enhance motivation and self-regulation but may also result in feelings of isolation and anxiety due to the lack of immediate instructor support [23]. These emotional dynamics significantly influence cognitive processes, including engagement, motivation, and problem-solving, in laboratory settings. Understanding how students navigate these experiences can inform instructional practices that promote both emotional resilience and academic persistence. In engineering education, acknowledging this relationship allows educators to design learning environments that encourage curiosity and reduce anxiety, thereby optimizing students' cognitive engagement and academic performance.

2.4 Theoretical Foundations. As illustrated in Figure 1, this study employs the Control-Value Theory (CVT) [9] to elucidate the dynamic relationship between learning environments, emotional and cognitive processes, and academic outcomes. This framework underscores the iterative nature of instructional design, highlighting how sociocultural and organizational factors shape learning experiences and affect students' emotional and cognitive engagement.

The conceptual model begins with the *Learning Context*, which encompasses the organizational and socio-cultural factors influencing learning outcomes and instructional methods. In engineering laboratories, for instance, the hands-on nature of problem-solving and experimentation creates unique cognitive and emotional demands. From there, students engage in *Appraisal-Oriented Regulation*, where they assess their level of control over tasks and the perceived value of the learning activity. These appraisals lead to *Emotion-Oriented Regulation*, characterized by emotional states such as curiosity, frustration, or anxiety. These emotions affect how students allocate cognitive resources and manage their motivation during learning activities, a process referred to as *Problem-Oriented Regulation*. Ultimately, these interconnected processes shape *Instructional Phenomena*, which include observable behaviors and outcomes such as self-regulation, motivation, and academic achievement. *Data Collection* serves as a feedback loop, allowing educators and researchers to systematically study these phenomena and refine instructional strategies based on evidence.

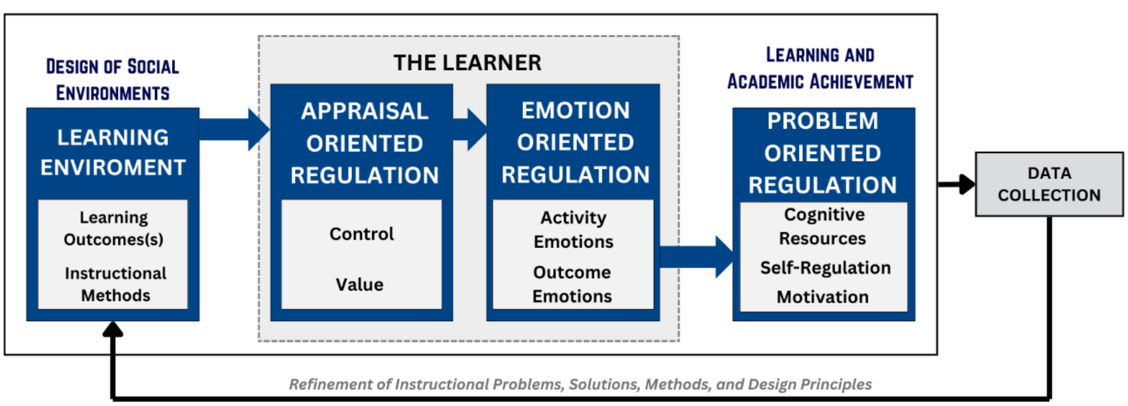

Figure 1. Research to practice conceptual model using Control-Value Theory. adapted from Pekrun,[24].

This framework establishes a foundation for understanding the emotional and cognitive responses of engineering students in blended laboratory environments. By integrating insights from CVT, this paper seeks to inform instructional practices that strengthen emotional resilience and cognitive engagement, thereby addressing the complex demands of engineering education.

3. METHODOLOGY

3.1 Research Question. Guided by the literature on cognitive and emotional responses and building on our previous work exploring the use of laboratory kits in blended learning environments [25], this research study aims to address the following research questions as part of a larger project:

RQ 1. How do students perceive their emotional and cognitive learning experiences in different instructional environments, specifically when using laboratory kits in blended learning versus traditional in-person laboratory settings?

RQ 2. What key factors (instructional, emotional, and contextual factors) do students perceive as influencing their engagement with laboratory kits in a blended learning environment, specifically during the HEX and FLU module?

3.2 Study Setting and Learning Context. This study was conducted as part of an extended exploratory research project during the summer of 2024, with participant recruitment starting in the spring of 2024. To recruit participants, a pre-survey was administered to undergraduate sophomore year engineering students enrolled in Chemical, Mechanical, and Biomedical Engineering courses. To ensure broad outreach, faculty members from each department assisted in distributing the survey. The target population consisted of students enrolled in engineering majors, as their foundational knowledge aligned with the study's instructional modules. The survey asked students if they were interested in participating in a study using take-home lab kits for experiential learning. Students who responded to the survey and provided consent were invited to participate in the intervention. Upon reviewing the survey responses, no students from the Chemical Engineering department expressed interest in participating. However, 11 students volunteered to participate in the study, including 10 from the Mechanical and Aerospace Engineering departments and 1 from Biomedical Engineering.

The intervention lasted five weeks, during which students were expected to spend a total of 10 hours per week engaging with the simulated learning environment. Each week consisted of two synchronous sessions: the first focused on helping students individually set up the lab kits and troubleshoot, while the second emphasized teamwork and collaboration. Additionally, students were estimated to spend approximately two hours independently setting up the lab kits and completing weekly deliverables. A small token of appreciation was provided for their time.

3.2.1 Learning Modules and Timeline. The study uses a blended learning approach, combining online and in-person components to enhance experiential learning. Approximately 60% of the content is delivered online, enabling students to engage with home-lab kits in a remote setting before transitioning to in-lab experiments. The study starts with a prelab/ in-person orientation session (**Week 1**), where students receive an overview of the program, complete consent forms, and collect their lab kits while learning about their assembly and operation. Students also receive operational instructions and instructional videos via the Canvas learning management system, enabling them to independently set up and use their lab kits effectively.

In **Weeks 2 and 3**, students participate in online modules focused on fluid dynamics (FLU) and heat exchangers (HEX), conducting hands-on experiments at home using the lab kits. Before each online session, students allocated approximately one hour for pre-setup, ensuring they had the necessary materials and workspace arranged for the upcoming experiment. Each synchronous online session lasted one hour, followed by two to three hours of group work in breakout rooms, where students set up experiments, conducted trials, and collected data collaboratively. This structured peer interaction facilitated collaborative problem-solving and enabled students to share insights on experimental challenges. **Week 4** introduces a transition modality, where students engage in an online session covering safety protocols and experimental procedures in preparation for in-person laboratory work. Finally, in **Week 5**, students apply their knowledge in a laboratory setting, conducting pilot-scale experiments with pipe networks and heat exchangers, connecting their remote learning experience with hands-on laboratory practice. After completing each module, students submitted a data report to the instructor and completed a 20-minute survey reflecting their cognitive and emotional responses. This was followed by a one-hour focus group discussion with an external facilitator, where students shared their thoughts on the experiment and its challenges.

Table 1. Study description, general schedule/ distribution of study in 5 weeks.

Module	Learning Activities
Week 1: Orientation week	In-person: Program overview, consent form, initial survey. Kit pickup Instruction of assembly and operation
Week 2: Mini Fluid Flow	Online: Experiments on fluid dynamics using home take-lab kits.
Week 3: Mini Heat Exchangers	Online: Using Home-take lab kits
Week 4: Scale up and modality transition	Online: Session on safety protocol engineering labs and experimental procedures.
Week 5: In-lab FLU & HEX	In-person: Experimentations with Pilot-scale pipe networks and walk-through heat exchangers.

3.3 Data Collection. Data collection employed a mixed-methods approach, integrating both quantitative and qualitative methods to provide a comprehensive analysis of students' experiences. The quantitative component included multiple-choice and Likert-scale questions that captured students' perceptions of engagement, instructional effectiveness, and emotional responses. The qualitative component included open-ended questions that allowed for a deeper exploration of students' cognitive and emotional experiences. A survey was designed by integrating three validated instruments:

- Achievement Emotions Questionnaire (AEQ) – 11 items assessing students' emotional and control experiences related to learning as outlined by CVT [26].
- Community of Inquiry (CoI) Questionnaire – 15 items evaluating cognitive presence, teaching presence, and social presence [27].
- Technology Acceptance Model (TAM) – 30 items measuring students' perceptions of ease of use and usefulness of the blended learning environment [28] [29].

Each survey was conducted after both online and in-person experiments, evaluating students' interactions with instructional methods, learning modalities, and teacher/social presence. Additionally, pre- and post-tests were given to assess students' perceptions before and after participating in the blended learning environment. The study also included focus groups; however, they fall outside the scope of this paper. In the final post-evaluation survey, students were asked two open-ended questions about their perceptions: (a) online engineering laboratory experience and (b) whether it affected their ability to learn engineering principles and skills. The quantitative responses were used to describe preliminary patterns, while the open-ended responses were examined through the lens of Control-Value Theory (CVT) to categorize students' emotional and cognitive dimensions, focusing on appraisals of control, task value, and associated emotional responses.

3.4 Study Limitations: This paper presents quantitative data from a broader study involving 11 students who participated in an intervention. The study employs a small sample size, which is appropriate given its longitudinal and exploratory nature. Longitudinal studies require sustained engagement over time, making smaller cohorts more feasible for tracking cognitive and emotional shifts in depth [30]. Prior research in engineering education has shown that smaller, focused samples can yield rich, actionable insights into instructional interventions, particularly in mixed-methods research [31].

Participants received compensation for their time, which may have influenced their decision to opt in. Compensation-based participation might have favored students already confident with experimental interventions, potentially excluding those with higher academic anxiety or fewer resources for extracurricular engagement. This selection bias is an important factor to consider when interpreting the findings.

The quantitative data in this study were analyzed using descriptive statistics, which help summarize patterns and trends within the dataset. However, these findings are not intended to predict outcomes or infer conclusions beyond the sample itself. As an exploratory study, the primary objective is to examine research questions in depth, identify emerging trends, and generate hypotheses for future research, rather than achieve broad statistical generalizability [32]. Exploratory research prioritizes depth over breadth, offering a granular understanding of student experiences in blended learning environments.

While these findings may not be broadly generalized, they provide valuable insights that can be transferable to similar engineering education settings. These results lay the groundwork for future large-scale studies with broader and more diverse participant samples, ensuring greater external validity.

4. RESULTS AND DISCUSSION

4.1 Study Participants: This exploratory study included 11 students. Table 2 provides an overview of the participants' gender distribution and academic disciplines. In terms of gender, the sample closely aligns with the national average National Science Foundation's 2013 report with 18% to 28% of women and approximately 72% to 82% men participation in engineering at the undergraduate level [33]. Most participants were from the Mechanical and Aerospace Engineering disciplines. The group also included 1 international student, 1 transfer student, 2 junior and 9 senior level undergraduates.

Table 2. Study demographics

Total Participants	*11*
Female	27%
Male	73%
Biomedical	9%
Mechanical & aerospace	82%

4.2. Results for RQ 1: Perceptions of Their Learning Experiences. Figure 2 presents pre-study survey responses, showing that most students felt confident engaging with blended learning environments using take-home kits and online components. Ten participants agreed or strongly agreed that they trusted their ability to learn effectively in an online and self-paced format, with one participant remaining neutral. All participants expressed confidence in their ability to learn at their own pace using take-home kits. When asked if the course content was relevant to their future careers, nine participants agreed, while two responded neutrally. However, contrary to this, some participants were neutral, and one disagreed when asked if they felt prepared to handle larger-scale engineering equipment, suggesting a need for additional instructional support to help bridge the gap between small-scale and real-world applications.

According to Control-Value Theory (CVT), these findings could suggest that students had high control appraisals regarding their ability to learn independently but lower control appraisals when applying their skills to larger-scale equipment [34], [35]. This discrepancy indicates that while students felt competent in small-scale tasks, they may be unsure how well these skills would transfer to more complex engineering environments.

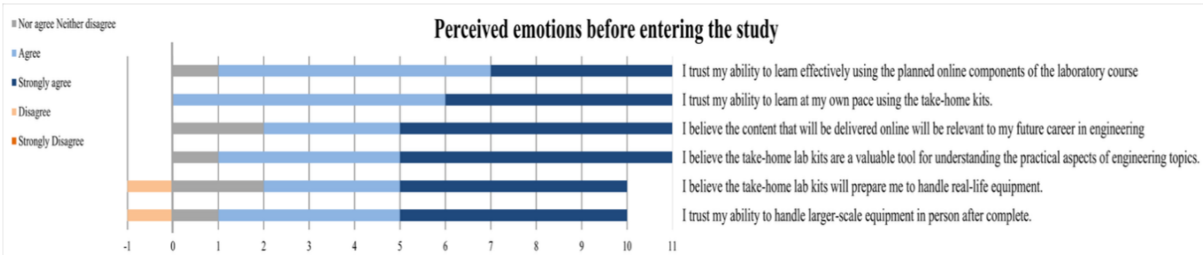

Figure 2. Pre-Survey: Students' perceptions before participating in the exploratory study.

In Figure 3, the post-study survey responses indicate that 10 participants agreed or strongly agreed that the take-home kits helped them prepare to handle real-world laboratory equipment. Most participants also reported feeling confident applying their learning to engineering tasks. Additionally, with only one participant disagreeing, the other students continued to express trust in their ability to learn in an online, self-paced format, suggesting comfort with the blended learning approach. From a CVT perspective, these findings may indicate an increase in perceived control as students gained confidence in transferring their skills to larger-scale equipment.

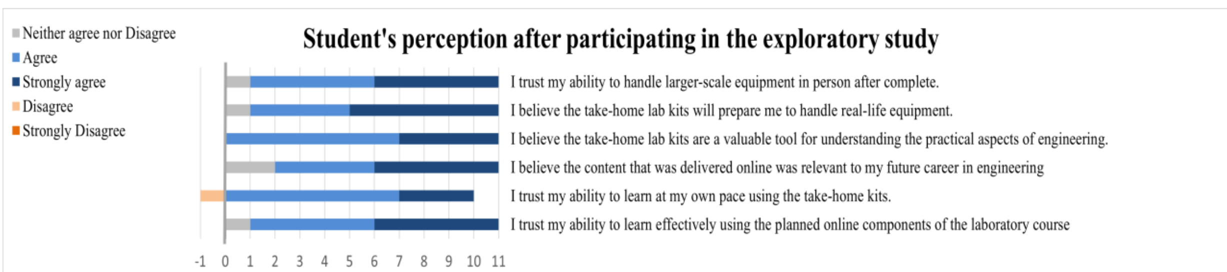

Figure 3.Post-survey: Students' perceptions after participating in the exploratory study.

While these findings may not be statistically significant, they suggest that the blended learning experience could help students develop confidence in their laboratory skills, particularly when transitioning to larger-scale equipment. To further support students, future course iterations could enhance instructional scaffolding by explicitly connecting take-home lab activities to professional engineering applications [9], [36].

Figure 4a captures students' initial emotional responses toward the online laboratory environment and take-home kits. Among the 11 participants, seven expressed excitement, indicating a positive initial motivation toward blended learning. However, one student reported anxiety, and three students expressed neutral or uncertain feelings, reflecting mixed reactions to this approach. Regarding take-home kits, seven students were excited about the flexibility and independence they provided, while three students expressed anxiety about troubleshooting challenges and limited instructor support. When considering larger-scale equipment, responses were more divided: six students expressed anxiety about applying skills learned with small-scale kits, while five felt confident or excited about the transition.

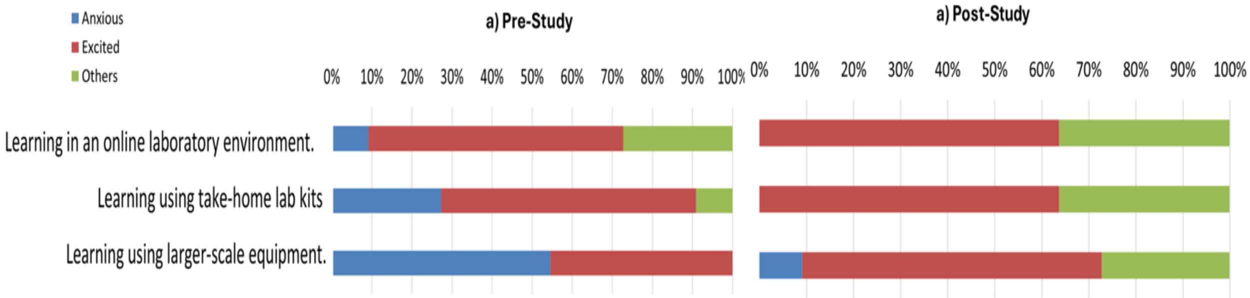

Figure 4. Students' perceived feelings about the online laboratory environment before and after completion of the study.

These findings provide some insights into the dual role of emotions in engineering education. While excitement can foster curiosity and engagement, anxiety about larger-scale applications highlights the need for structured preparation and instructional scaffolding. According to Control-Value Theory (CVT), negative emotions such as anxiety can increase cognitive load, potentially hindering learning and engagement [24]. To mitigate these concerns, future instructional designs could incorporate virtual simulations, clear communication of expectations, and structured feedback mechanisms to bridge the gap between small-scale laboratory activities on take-home lab kits and real-world engineering applications [36].

Figure 4b illustrates a shift in students' emotional responses after completing the exploratory study. For online labs and take-home kits, no students reported anxiety, and seven maintained excitement. Four described feeling "prepared" and "comfortable" regarding larger-scale equipment, only one student still expressed anxiety, while seven reported excitement and three felt prepared. This shift may suggest that the blended learning approach could help enhance students' sense of control and competence, as described by CVT. The reduction in anxiety and the increase in confidence and preparedness to use larger-scale equipment reflect greater perceived control and task value, both of which are critical to self-efficacy and cognitive engagement. Engaging with take-home lab kits and independently troubleshooting tasks likely contributed to stronger feelings of preparedness, reinforcing positive learning experiences [8].

4.3. Results for RQ 2: Perceived Influencing Factors. The results presented in Tables 3, 4, and 5 highlight key factors influencing students' experiences with laboratory kits in a blended learning environment. These findings, analyzed through the lens of Control-Value Theory (CVT), suggest that students' perceived control and task value significantly shaped their emotional and cognitive engagement in both online and traditional lab settings [9].

The findings reveal a range of emotional and cognitive responses to online laboratory environments and take-home lab kits, highlighting the importance of addressing both positive and negative emotions in engineering education. Excitement, reported by the majority of students, highlights motivation and openness to these innovative approaches. This aligns with the motivational dimensions of Pekrun's Control-Value Theory (CVT), which links positive emotions to higher engagement and deeper cognitive processing [9]. Students' excitement was primarily driven by the perceived value of hands-on experiments and their relevance to real-world engineering concepts, reinforcing the importance of task value in fostering meaningful learning experiences. Students' excitement was primarily driven by the perceived value of hands-on experiments and their relevance to real-world engineering concepts, reinforcing the importance of task value in fostering meaningful learning experiences [37].

Table 3. Themes and analysis of student perceptions of laboratory kits in blended learning environments

Theme 1: Perceived Clarity of Instructions Supports Control and Reduces Anxiety	
<u>Analysis:</u> Students found the instructional materials, including videos and manuals, clear and concise, which enhanced their sense of control over the learning process and reduced anxiety allowing them to focus on the experimental tasks.	<u>Example Quotes:</u> • "The lab instructions were clear and concise, allowing for ease of use for the lab kit." • "Instructions were very clear and to the point."
Theme 2: Hands-on learning was helpful in conceptual understanding	
<u>Analysis:</u> The hands-on nature of the kits helped students visualize abstract fluid mechanics concepts, increasing the perceived value of the tasks. This alignment with real-world applications fostered emotional engagement and curiosity.	<u>Example Quotes:</u> • "I loved being able to see the difference in pressure losses in real-time and then connecting that to the diameter of the pipe." • "It's great to visualize concepts."
Theme 3: Autonomy in Troubleshooting Builds Perceived Control and Fosters Motivation	
<u>Analysis:</u> The independence required for assembling and troubleshooting the kits contributed to students' perceived control over their learning. This autonomy encouraged persistence and deeper involvement with the material, even when challenges arose.	<u>Example Quotes:</u> • "It is helpful to have to work through issues on my own, because it makes me much more involved in the course material." • "I had to experiment to learn that."
Theme 4: Design Limitations Challenge Perceived Control and Increase Cognitive Load	
<u>Analysis:</u> Certain logistical constraints, such as cramped setups, missing components, or space issues, created barriers to learning. These challenges occasionally reduced students' sense of control and increased frustration, highlighting areas for improvement in kit design.	<u>Example Quotes:</u> • "There were too many tubes sticking out of the base, and they were too close to one another." • "The biggest restriction was the gallon of water/container."
Theme 5: Compact and Practical Design Increases Control and Encourages Engagement	
<u>Analysis:</u> Students appreciated the compactness and ease of use of the kits, which supported their ability to independently collect and analyze meaningful data. These features enhanced their perceived control and engagement in the learning process.	<u>Example Quotes:</u> • "The compactness is very valuable, and it feels very within the user's control." • "The data is relatively easy to obtain and compare."
Theme 6: Emotional Responses Reflect Appraisals of Control and Task Value	
<u>Analysis:</u> Students reported a mix of emotions, ranging from excitement (positive appraisal of task value and control) to frustration (challenges to control). Positive emotions, such as excitement, supported engagement, while frustration due to setup challenges motivated problem-solving when scaffolded effectively.	<u>Example Quotes:</u> • "It was a great experience. I enjoyed playing with the tubing." • "I was stressed because water made a mess, and I am not the best with small kits."
Theme 7: Real-World Relevance Increases Task Value and Motivates Engagement	
Students connected the experimental tasks to theoretical concepts and recognized their practical applications. This alignment of tasks with future engineering practices increased their perceived value and strengthened emotional engagement.	• "It's a good way to learn Bernoulli's equation as it feels apparent how this would apply to the lab kit." • "Doing this in a lab setting is better than a whiteboard."

However, anxiety, especially concerning the transition to larger-scale equipment, points to concerns about the adequacy of preparation provided by the kits. CVT posits that negative emotions like anxiety can increase cognitive load, impairing performance in high-stakes environments like engineering laboratories [9]. This was reflected in themes such as design limitations and practical challenges, which students noted as barriers to their confidence and success. To address these challenges, instructors could implement scaffolding strategies, such as virtual simulations of large-scale equipment or more structured, frequent feedback during the transition phases. These adjustments could help bridge the gap between small-scale experimentation and real-world applications, reducing anxiety and reinforcing perceived control.

Neutral and uncertain responses further suggest that some students were still forming their perceptions of the blended learning approach. This aligns with the emotional responses theme, where students expressed mixed emotions during the initial stages of engagement. According to CVT, a lack of clarity about the learning process or its relevance can undermine task value and reduce trust in the instructional method. Clear communication about course objectives, benefits, and real-world applicability is essential for addressing these uncertainties. Providing transparent expectations can foster trust and help students see the utility of these innovative approaches. Providing transparent expectations can foster trust and help students see the utility of these innovative approaches [37].

For the post-survey question (b), participants were asked to reflect on how completing an engineering laboratory online influenced their ability to learn engineering principles and skills. The thematic analysis is summarized in Tables 4 and 5, which capture students' perceptions across key areas. The results highlight a complex interplay of control, task value, and emotional responses in online labs. Students valued hands-on experience and real-world relevance, which enhanced the perceived value of tasks and engagement. Autonomy and adaptability were linked to increased confidence and self-regulation, though challenges such as equipment limitations and a lack of support sometimes reduced perceived control. Anxiety and uncertainty were mitigated by structured instructional materials and the flexibility of online labs, which provided opportunities for self-paced exploration.

The findings from Tables 4 and 5 highlight both the strengths and challenges of using online laboratory kits in blended learning environments. Students recognized the real-world relevance and hands-on experience provided by the kits, which enhanced task value and engagement. Confidence in managing and troubleshooting the kits independently reflected high perceived control, though challenges such as equipment limitations and the lack of immediate instructor or peer support occasionally undermined this control. While online labs required greater self-discipline, they were also seen as opportunities for growth, fostering self-regulation and critical thinking. Compared to traditional labs, online labs offered flexibility and creative exploration but lacked the collaborative benefits and direct guidance of in-person settings. Anxiety was present across both modalities, but online labs sometimes alleviated social pressure, offering a more individualized learning experience. Overall, students believed that the fundamental learning objectives could be achieved in both settings, but online labs posed additional cognitive and logistical challenges that required enhanced instructional support and scaffolding.

Table 4. Thematic Analysis of Preliminary Perceptions of Students About Completing an Engineering Laboratory Online.

Theme 1: Online labs provide real-world relevance.	
Analysis: Students recognized that online labs act as a foundation for understanding larger-scale engineering tasks.	Example Quote: "The online laboratory operates as a mini version of the experiment, making it easier to understand the landscape of what you're doing in the pilot scale version."
Theme 2: Hands-on experience enhances learning.	
Analysis: The assembly and use of kits helped students engage deeply and develop a detailed understanding of engineering concepts.	Example Quote: "I think having to assemble the lab kit myself really makes me think about the engineering principles in more detail."
Theme 3: Challenges with online labs hinder control.	
Analysis: Equipment limitations and lack of immediate peer or instructor support created barriers to achieving optimal learning outcomes.	Example Quote: "The equipment isn't as reliable as the equipment in traditional laboratories... using ice for the heat exchanger was probably less reliable than using scalding water from a tap."
Theme 4: Students express confidence in managing kits.	
Analysis: Students felt confident in handling and troubleshooting the equipment independently but raised concerns about the depth of learning.	Example Quotes: "I will be able to manage the equipment and troubleshoot by myself, with some help." "I completed EEL3003 (baby circuits class) online last summer. The course used the Arduino kit, which I thought actually decreased the educational value... I think an online lab could be very beneficial for learning."
Theme 5: Learning autonomy fosters self-confidence.	
Analysis: Independent learning fostered confidence but raised skepticism about whether online labs matched traditional ones in quality.	Example Quotes: "I learn really well on my own... but I am concerned about the applicability of the online course, and if it's as quality as a real class." "Completing an online laboratory class will enhance my self-learning abilities as I will be placed in the position to problem solve independently."
Theme 6: Online labs require discipline for success.	
Analysis: Students believed that online labs demand a higher level of self-discipline but saw this as an opportunity for growth.	Example Quote: "It will require a bit more discipline from the student, but I think at the end the effort... gives them real power to shape their own learning."
Theme 7: Online labs can boost motivation and critical thinking.	
Analysis: Students anticipated gaining critical thinking skills, reflecting a growth mindset and a focus on academic development.	Example Quote: "I think completing an online engineering laboratory course will increase my ability to learn engineering principles and skills... and critical thinking to solve problems."
Theme 8: Anxiety persists in online settings.	
Analysis: Some students expressed anxiety about online labs, particularly due to technical limitations, but noted that individualized learning reduced social pressure.	Example Quote: "I think it will be a little harder than if it was in person, but I also get anxious in the labs sometimes with other people so maybe it will be better."

Table 5. Thematic Analysis of Comparative Perceptions: Traditional vs. Online Engineering Laboratories

Theme 1: Online labs foster self-reliance.	
Analysis: Students acknowledged the need for greater independence in troubleshooting and problem-solving during online labs.	Example Quote: "There will be more reliance to problem solve independently rather than immediately going to my instructor if something were to go wrong."
Theme 2: Anxiety affects both lab formats.	
Analysis: Anxiety was present in both settings, but online labs sometimes reduced social anxiety in group environments.	Example Quote: "I really don't know because I think that in person is better, but I also get anxious around people at the lab classes sometimes."
Theme 3: Instructional materials determine success.	
Analysis: The quality and clarity of online lab kits and instructional resources were seen as critical for successful outcomes.	Example Quote: "If the kit is very well-thought-out, practical, exciting, with clear instructions, I think an online lab could be better than traditional."
Theme 4: Direct interaction supports learning.	
Analysis: Traditional labs were valued for providing direct instructor guidance and opportunities for peer collaboration.	Example Quote: "I feel more competent in a traditional class because of the close instructor interactions and the help from peers."
Theme 5: Online labs offer flexibility for exploration.	
Analysis: Students found online labs adaptable, allowing for creative engagement with the kits.	Example Quotes: "I think it will be more interesting because of the thought put into the kits… students can mess with and play with their kits a bit more."
Theme 6: Online labs require additional guidance.	
Analysis: Online labs were perceived as requiring more detailed instructions and visual demonstrations to compensate for the lack of in-person support.	Example Quote: "It will require more explanation and visual demonstration through the camera for each component to make sure the processes are done correctly."
Theme 7: Learning outcomes are comparable, but processes differ.	
Analysis: Students believed the fundamental objectives of both lab formats could be met, but online labs posed more challenges in execution.	Example Quote: "The end result of the lab will be the same between online and in-person labs, but I think it will be more difficult online than in person."

5. CONCLUSION

Overall, the quantitative results provide preliminary insights into how students perceive their learning experiences in blended laboratory environments compared to traditional in-person settings, directly addressing RQ1. Before the study, students expressed enthusiasm for blended learning but also uncertainty about troubleshooting and applying small-scale skills to larger equipment. Post-study responses indicate that engagement with take-home kits and structured online activities shows a slight improvement in students' confidence and preparedness, with a reduction in negative emotions and reinforcing their ability to transfer skills. The findings align with Control-Value Theory (CVT), as increased perceived control and task value led to greater emotional engagement and motivation. While the blended approach was effective in fostering confidence and adaptability, some students still desired stronger connections between small-scale experiments on take-home lab kits and real-world engineering applications. This highlights the importance of scaffolding and instructional support in bridging the gap between hands-on learning in blended settings and industry-scale applications. Thus, the study suggests that blended learning environments could support student learning and engagement, but future implementations should refine instructional strategies to further enhance learning transfer and real-world applicability.

The findings from the qualitative part answering RQ2, suggest that students' engagement was shaped by multiple factors, including the clarity of instructional materials, hands-on learning experiences, and the autonomy to troubleshoot and problem-solve. While students appreciated the flexibility and real-world relevance of the kits, challenges such as equipment, personal skill limitations and lack of immediate instructor support occasionally hindered their sense of control. These insights emphasize the need for well-designed scaffolding strategies to enhance students' confidence and ability to transition from small-scale take-home lab kits to larger-scale engineering applications.

The findings also suggest that online environments and take-home laboratory kits could serve as tools for enhancing students' emotional and cognitive engagement in engineering education. Students valued the clarity of instructions, hands-on learning, and opportunities for autonomy, which supported their confidence and motivation. However, challenges such as equipment limitations, lack of real-world connections, and anxiety over transitioning to larger-scale applications reveal critical areas for improvement and it provides actionable recommendations for refining instructional approaches in engineering education.

6. SIGNIFICANCE AND IMPLICATIONS FOR EDUCATORS

The findings show the potential of online laboratory environments and take-home kits to transform engineering education by fostering emotional resilience, cognitive engagement, and self-regulated learning. These insights carry several key implications for educators:

1. **Enhancing Task Value and Real-World Relevance**
   Students consistently emphasized the importance of connecting laboratory activities to real-world applications. Educators should design experiments that explicitly link small-scale tasks to industrial or professional engineering contexts. This alignment can enhance task value, increase motivation, and deepen students' understanding of engineering principles.
2. **Supporting Emotional Regulation and Reducing Anxiety**
   The study revealed that while students experienced excitement and motivation, some also faced anxiety due to equipment limitations and uncertainty about applying skills to larger-scale systems. Educators can mitigate these negative emotions by incorporating scaffolding strategies, such as virtual simulations, structured feedback, and additional resources to build confidence and reduce cognitive load.
3. **Promoting Self-Regulation and Learning Autonomy**
   The hands-on nature of the kits encouraged independence and critical thinking, aligning with the goal of fostering lifelong learning skills. Educators should continue to emphasize self-directed learning by providing opportunities for students to troubleshoot, problem-solve, and reflect on their learning processes. However, this autonomy must be balanced with adequate support to ensure that students do not feel isolated.
4. **Improving Instructional Design and Materials**
   Students highlighted the importance of clear, concise instructions and well-designed kits as critical factors for success in online labs. Educators should prioritize the development of high-quality instructional materials, including step-by-step guides, visual demonstrations, and troubleshooting resources, to maximize students' perceived control and engagement.
5. **Balancing Autonomy with Collaborative Opportunities**
   While online labs provided flexibility and creative exploration, students expressed a desire for more interaction with instructors and peers, as seen in traditional labs. Educators should

consider integrating hybrid models that combine the strengths of both modalities, such as collaborative in-person sessions alongside independent online experiments.

6. **Addressing Diverse Emotional Needs**
   The dual emotional responses observed such as excitement for self-paced learning and anxiety about technical challenges highlight the importance of tailoring instructional approaches to accommodate different student needs. Creating a supportive environment that includes opportunities for peer interaction, instructor feedback, and transparent communication can foster trust and emotional well-being.

7. **Bridging the Gap Between Online and Traditional Labs**
   Students believed that the learning outcomes of online and traditional labs were comparable, but online labs posed additional challenges in execution. Educators should work to bridge this gap by enhancing the usability of online kits and addressing logistical constraints, such as the reliability of materials and accessibility of resources.

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8. AUTHORS CONTRIBUTION

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