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# Engineering Competency Assessment through Virtual Reality Simulation and Artificial Intelligence

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***Abstract*– This paper presents TecDrone, an innovative educational strategy that integrates Virtual Reality (VR) and Artificial Intelligence (AI) to enable authentic assessment of engineering competencies in first-year students. The intervention was implemented in the "Electromagnetic Systems Analysis" course at Tecnológico de Monterrey, where students designed, assembled, and controlled drones in a virtual environment, justifying their technical decisions through interaction with an AI-powered avatar. Three institutional competencies were assessed: decision-making, demonstration of system functionality, and execution of technical actions. The methodology combined quantitative analysis (TAM survey and performance rubric) with qualitative analysis (thematic coding of argumentative responses). Results show significant improvements in students' understanding of system functionality and their ability to implement technical actions, along with high levels of perceived usefulness, ease of use, and autonomy. The experience proved to be replicable, engaging, and aligned with principles of active learning and authentic assessment. TecDrone emerges as an effective tool for transforming engineering education by bridging theory and practice through simulated environments. Beyond reporting learning outcomes, this study contributes an assessment-oriented VR–AI framework that operationalizes competency-based evaluation through observable performance, decision justification, and system-level reasoning in early-stage engineering education.***

***Keywords--Educational Innovation, Higher Education, Assessment, Evaluation, Learning.***

## I. Introduction

### *A. Background and related work*

Engineering education continues to face persistent challenges in preparing professionals capable of applying theoretical knowledge in real-world contexts [1]. Despite curricular advancements, many students experience a disconnect between classroom concepts and their practical application in professional settings. This gap has been widely documented in the literature, which highlights that traditional teaching and assessment methods—centered on written exams, standardized exercises, and limited hands-on practice—fail to foster complex competencies such as decision-making, critical thinking, and multidisciplinary knowledge integration [2],[3],[4].

Importantly, this disconnect is not limited to instructional practices, but extends to assessment systems that often privilege procedural correctness over functional understanding, thereby underrepresenting students' ability to reason, justify, and act within complex engineering systems.

Despite extensive curricular reforms and the adoption of active learning strategies, a persistent challenge remains in how engineering competencies are assessed, particularly during the early stages of professional formation. This challenge is especially critical in first-year engineering courses, where assessment practices strongly shape students' epistemological beliefs about what it means to "know" and "do" engineering.

In response to this issue, pedagogical approaches promoting active learning, problem-solving, and authentic assessment have emerged. Authentic assessment is defined as the evaluation of student performance in tasks that simulate real professional situations, requiring not only technical knowledge but also analytical, argumentative, and execution skills [5]. Rather than replacing conceptual instruction, this approach complements theoretical learning by focusing on functional understanding, applied reasoning, and evidence-based justification of technical decisions. From a competency-based perspective, authentic assessment enables the observation of integrated performance, where cognitive, procedural, and metacognitive dimensions converge within a single evaluative episode. This type of assessment aims to measure meaningful performance beyond rote memorization or mechanical repetition. Such performance-oriented assessment is particularly relevant in engineering domains characterized by dynamic systems, multivariable trade-offs, and uncertainty.

However, designing authentic assessment experiences that are simultaneously immersive, scalable, and capable of capturing both performance and technical reasoning remains a methodological challenge in engineering education.

Within this context, emerging technologies such as VR and AI have begun to transform engineering learning environments [6]. VR enables immersive simulations where students interact with complex systems, manipulate variables, and observe outcomes in real time, all within a safe and controlled setting [7]. These experiences enhance motivation, conceptual understanding, and knowledge transfer to professional contexts [8]. Beyond engagement, VR environments afford the externalization of system behavior, allowing learners to observe causal relationships that are otherwise abstract or mathematically opaque in traditional instruction.

AI, on the other hand, has been used in education to personalize learning, provide immediate feedback, and foster metacognitive reflection [9]. Intelligent avatars, in particular, can simulate technical conversations, request justifications, and evaluate the quality of student responses, thereby promoting argumentative skills and critical thinking [10]. When embedded within assessment contexts, AI-driven dialogue can function as a cognitive elicitation mechanism making students' implicit reasoning explicit and therefore assessable.

Several studies have explored the impact of these technologies on STEM education. For instance, research on virtual lab simulators has demonstrated improvements in understanding physical phenomena, concept retention, and the development of practical skills [11]. Similarly, AI-based tutoring has shown positive effects on student autonomy and the quality of feedback received [12].

While previous studies have explored VR as a learning environment and AI as a tutoring or feedback mechanism, the novelty of the present work lies in conceptualizing their integration as an assessment framework. Rather than focusing on technology adoption itself, TecDrone operationalizes competency-based assessment through observable performance, decision justification, and system-level reasoning within a single evaluative experience. The contribution therefore resides in the assessment architecture that connects task design, evidence generation, and competency classification.

Regarding technology acceptance, the Technology Acceptance Model (TAM) has been widely used to assess user perceptions [13]. According to this model, perceived usefulness (PU) and perceived ease of use (PEOU) are key factors influencing attitudes toward technology and future usage intentions. In educational contexts, TAM has helped identify which features of a technological tool support its adoption by students [14].

In assessment-driven innovations, technology acceptance becomes a critical enabling condition, as tools perceived as opaque or misaligned with learning goals risk rejection regardless of their pedagogical potential.

Despite these advances, few studies have integrated VR and AI into a single authentic assessment experience in engineering, particularly in first-year courses. Most research has focused on technical simulations or automated tutoring, without exploring the combined potential of both technologies to assess complex competencies [15].

Specifically, there is a lack of empirical frameworks that operationalize VR–AI integration for the systematic assessment of institutional engineering competencies. Moreover, existing studies tend to prioritize learning outcomes or user experience, rather than the systematic evaluation of decision-making processes, system-level understanding, and execution of technical actions aligned with institutional competency frameworks.

In addition, there is a need to design educational experiences that combine innovation with replicability and scalability, while remaining explicitly aligned with institutional learning outcomes.

While prior studies have examined VR as a learning environment and AI as a tutoring or feedback mechanism, few have conceptualized their integration as an assessment instrument capable of eliciting, observing, and classifying engineering competencies in a single evaluative episode. In particular, there is limited empirical work operationalizing decision-making, system functionality, and technical execution as assessable constructs within immersive simulations at the first-year level.

In this framework, the present study introduces TecDrone, an educational strategy that integrates a virtual drone design lab with AI-driven interaction, aiming to assess engineering competencies in first-year students. TecDrone is conceived not merely as a learning activity, but as an assessment-oriented instructional system explicitly designed to elicit, observe, and evaluate competency-based performance within a simulated engineering context. This study contributes an integrated VR–AI assessment framework for first-year engineering education, providing empirical evidence on competency development and proposing a replicable instructional model aligned with authentic assessment principles. The proposal is grounded in principles of authentic assessment, active learning, and technology acceptance, and seeks to contribute to the body of knowledge on pedagogical uses of emerging technologies in higher education.

### B. *The proposal*

This proposal is conceived as an assessment architecture rather than a standalone instructional activity, in which engineering competencies are elicited through a structured sequence of preparation, simulation, and AI-mediated reflection. Each phase is intentionally aligned with observable evidence sources, enabling traceability between task design, student action, and competency evaluation.

*TecDrone* is an authentic assessment experience designed for first-year engineering students enrolled in the "Electromagnetic Systems Analysis" course. Given the university-level context, the instructional design aligns with principles of andragogy and active learning, emphasizing learner autonomy, relevance of tasks, and problem-centered challenges connected to real engineering practice. The strategy is structured into three phases: (1) a preliminary activity involving theoretical research on quadcopter dynamics, (2) a virtual reality simulation where students design, assemble, and test drones, and (3) a reflective phase involving interaction with an AI avatar that prompts students to justify their technical decisions, see Fig. 1.

During the simulation, students select components such as propellers, batteries, and frames, considering performance, autonomy, and stability criteria. They then execute maneuvers in the simulator, manipulating the drone's degrees of freedom (yaw, roll, pitch, throttle). The AI avatar interaction enables assessment of technical reasoning and knowledge integration.

The experience is complemented by a TAM-based survey to evaluate perceived usefulness, ease of use, and motivation. Additionally, performance records and argumentative responses are collected for quantitative and qualitative analysis. The goal is to assess three institutional competencies: decision-making (SIIT0302A), demonstration of system functionality (SIIT0102A), and implementation of technical actions (SIIT0303A).


Fig. 1. Students interacting with an AI avatar for instruction and decision-making.

### C. *Research Questions and Hypotheses*

Based on the intervention design and study objectives, the following research questions were formulated:

- R1: To what extent does the *TecDrone* experience improve student performance in competencies SIIT0302A, SIIT0102A, and SIIT0303A?
- R2: What are students' perceptions regarding the usefulness, ease of use, and motivation associated with *TecDrone* as an assessment tool?
- R3: What argumentative patterns emerge, and how do these patterns reflect system-level reasoning and applied electromechanical understanding during AI-mediated assessment?

The corresponding hypotheses are:

- H1: The TecDrone experience leads to measurable improvements in student performance in the SIIT0102A competency compared to traditional methods.
- H2: Students perceive *TecDrone* as a useful, easy-to-use, and motivating tool, with average scores above 4.2 on the Likert scale.
- H3: Interaction with the AI avatar promotes well-founded technical arguments, demonstrating applied understanding of torque dynamics and design decisions.

## II. Methodology

This study was conducted using a mixed-methods approach, integrating both quantitative and qualitative techniques to evaluate the impact of the *TecDrone* educational strategy on the development of engineering competencies in first-year students. It follows an exploratory and evaluative design aimed at examining the feasibility and educational impact of an integrated VR–AI assessment strategy**.** The mixed-methods design was selected to capture both observable performance outcomes and the underlying technical reasoning processes elicited during the assessment experience. The intervention took place in the "Electromagnetic Systems Analysis" course at Tecnológico de Monterrey, involving a sample of 54 students. The sample size (n = 54) consists of exploratory mixed-methods studies in first-year engineering education, where the primary objective is to examine feasibility, implementation quality, and emerging performance trends rather than to establish population-level generalizations. Accordingly, the study prioritizes internal coherence and analytic transparency over statistical generalization. The objective was to assess three institutional competencies (SIIT): SIIT0302A (decision-making), SIIT0102A (demonstration of engineering system functionality), and SIIT0303A (implementation of technical actions), which are referenced throughout the study using their institutional codes for consistency, through a virtual reality (VR) simulation experience complemented by interaction with an artificial intelligence (AI) avatar. These competencies were selected because they can be directly observed and operationalized within a simulated electromechanical system.

### A. *Intervention Design*

The *TecDrone* strategy was structured into three pedagogical phases:

1) Preliminary Activity: Students conducted structured theoretical research on torque moments associated with yaw, roll, and pitch, as well as throttle control mechanisms in quadcopters, drawing on course materials and guided academic sources. This phase aimed to activate prior knowledge while reinforcing key electromechanical principles related to force distribution, rotational dynamics, and system stability. By engaging with these concepts before entering the virtual environment, students were better prepared to interpret simulator feedback and to make informed technical decisions during the subsequent design and testing phases.

2) VR Simulation: In an immersive virtual environment, students designed, assembled, and tested drones based on specifications provided by a fictional client. The platform allowed them to select components such as propellers, batteries, and frames, considering performance, autonomy, and stability criteria. Technical decisions had to be justified within the system, promoting critical thinking and the application of electromechanical principles. In addition to component selection, the simulation required students to iteratively test and refine their configurations under performance constraints imposed by the virtual environment. These constraints simulated realistic engineering trade-offs related to stability, energy consumption, and maneuverability. By exposing students to iterative testing cycles, the platform encouraged experimentation, error analysis, and corrective decision-making, reinforcing the connection between theoretical electromechanical concepts and observable system behavior.

3) Evaluation and Reflection: Upon completing the simulation, students interacted with an AI avatar that requested explicit technical justifications for their design choices and executed actions. This dialog-based interaction encouraged students to reflect on causal relationships between their decisions and observed system behavior, thereby fostering metacognitive processes and deeper conceptual articulation. In parallel, a Technology Acceptance Model (TAM)-based survey was administered to assess perceived usefulness (PU), perceived ease of use (PEOU), and motivation. Previously defined constructs were employed to ensure conceptual consistency and to avoid redundancy across sections.

### B. *Assessment Instruments*

The following instruments were used for data collection:

- TAM Survey: Adapted for the educational context, including items that evaluate PU, PEOU, learning autonomy, and clarity of instructions. A 5-point Likert scale was used. This instrument measured student acceptance of the tool.
- Argumentative Prompts: Embedded in the AI avatar interaction, aimed at assessing technical decision-making and knowledge integration. Responses were recorded for qualitative analysis.
- Performance Records: Extracted from the *TecDrone* platform, including data on functional drone assembly, compliance with client specifications, and execution of maneuvers in the simulator.
- SIIT Competency Rubric: A rubric was developed to classify student performance into "Emerging" and "Outstanding" levels for each competency, based on observable evidence during the simulation. The "Emerging" level corresponds to partial or guided execution with limited technical justification, whereas the "Outstanding" level reflects consistent, autonomous performance supported by coherent technical explanations aligned with institutional competency descriptors.

Each instrument was explicitly aligned with the assessed SIIT competencies to ensure consistency between learning objectives, assessment criteria, and collected evidence.

### C. *Assessment Validity Considerations*

Assessment validity was addressed through alignment between competency definitions, task design, and evidence sources. The assessed competencies (decision-making, system functionality, and technical action implementation) were operationalized through observable behaviors within the simulation and through AI-mediated justification prompts. This alignment supports construct representation by ensuring that the collected evidence reflects the intended competency domains. Decision accuracy was strengthened through the use of multiple evidence sources, including simulator performance records, argumentative responses, and rubric-based classification, allowing triangulation across complementary indicators.

### D. *Intervention Procedure*

The intervention was carried out over three consecutive sessions. In the first session, the design challenge was introduced, and the preliminary activity was conducted. In the second session, students accessed the virtual lab to configure and test their drones. The third session involved interaction with the AI avatar and administration of the TAM survey. The entire process was supervised by the instructor, who provided technical and pedagogical support as needed. Instructor intervention was limited to technical facilitation and did not include guidance on decision outcomes.

Data were collected digitally, ensuring traceability of technical decisions and simulator performance. Argumentative responses were stored in text format for subsequent qualitative analysis.

### E. *Quantitative Analysis*

Consistent with the exploratory nature of the study, quantitative analyses were limited to descriptive statistics aimed at identifying performance distributions and emerging trends across assessed competencies, rather than establishing causal or inferential claims. No inferential statistical tests were conducted, as the study was not designed to test causal hypotheses.

Quantitative data were processed using descriptive statistics, including measures of central tendency (mean) and dispersion (standard deviation, minimum, and maximum). TAM survey results and performance level distributions for each SIIT competency were analyzed.

For example, in the SIIT0102A competency (demonstration of system functionality), 45 students achieved the "Outstanding" level, while only 9 remained at the "Emerging" level. This analysis helped identify the differential impact of the tool across competencies.

Item averages from the TAM survey were also calculated, with values exceeding 4.4 for perceived usefulness and autonomy, indicating high acceptance of the tool.

### F. *Qualitative Analysis*

Qualitative analysis was conducted through thematic coding of argumentative responses. Patterns were identified in technical reasoning, use of electromechanical concepts, and the ability to justify decisions under uncertainty.

The coding process followed three stages: open reading, axial categorization, and thematic synthesis. Triangulation criteria were applied across performance records, argumentative responses, and survey results to strengthen the validity of the analysis.

Key findings include students' appreciation of the experience as an opportunity to apply torque concepts in practice, and the AI avatar interaction as a catalyst for critical reflection on their decisions.

Special attention was given to the coherence between students' verbal justifications and their recorded actions within the simulation. This alignment allowed the identification of discrepancies between intended decisions and executed behaviors, providing additional insight into students' conceptual understanding. The qualitative analysis thus complemented quantitative performance data by revealing how students articulated causal relationships between design choices, system responses, and performance outcomes.

This qualitative approach allowed for an in-depth examination of how students articulated causal relationships between design decisions and system behavior.

### G. *Ethical Considerations*

The study adhered to the ethical principles established by the institutional review board at Tecnológico de Monterrey. Informed consent was obtained from all participants, who were briefed on the study's objectives, the voluntary nature of participation, and data confidentiality.

All data were anonymized before analysis, and participation in the activity did not negatively affect students' academic evaluation. Formative feedback was provided at the end of the experience to promote reflective learning.

This study does not aim to establish causal effectiveness through experimental comparison, but to examine the feasibility, internal coherence, and assessment sensitivity of an integrated VR–AI evaluation strategy. Accordingly, the methodological focus is placed on performance traceability, competency observability, and alignment between design intent and evaluative evidence, rather than on inferential comparison.

## III. Results

The implementation of the *TecDrone* strategy enabled the assessment of three engineering competencies within a virtual simulation environment, complemented by interaction with artificial intelligence. The results are presented in two dimensions: competency performance and student perceptions of the tool, integrating both quantitative and qualitative analyses. Results are reported descriptively, consistent with the exploratory design of the study.

### A. Competency Performance

Performance records extracted from the *TecDrone* platform were classified into two levels—Emerging and Outstanding—based on the institutional SIIT rubric. The distribution by competency was as follows:

- SIIT0302A – Decision-Making: 26 students were classified as Emerging and 28 as Outstanding. This relatively balanced distribution suggests a moderate impact of the experience on the development of this competency, with a slight trend toward improvement.
- SIIT0102A – Demonstration of Engineering System Functionality: A significant improvement was observed, with only 9 students at the Emerging level and 45 at the Outstanding level. This result indicates that the virtual environment effectively facilitated the understanding and technical explanation of the electromechanical systems involved in drone design.
- SIIT0303A – Implementation of Technical Actions: 15 students were classified as Emerging and 39 as Outstanding. The improvement observed reflects that participants were able to apply concrete actions in the simulator, likely due to the practical and interactive nature of the experience.

Beyond the numerical distribution of performance levels, observational data revealed that students classified as "Outstanding" consistently demonstrated anticipatory reasoning, adjusting parameters proactively based on expected system behavior. In contrast, students at the "Emerging" level tended to rely on trial-and-error strategies with limited explanatory justification. This distinction illustrates qualitative differences in decision-making strategies rather than mere differences in task completion. These qualitative distinctions support the validity of the competency rubric and reinforce the interpretive value of combining performance metrics with contextualized observation.

These results demonstrate that the *TecDrone* virtual lab supports the development of complex competencies, particularly those related to functional understanding and technical execution in a simulated context. Fig. 2 provides a visual summary of the distribution of student performance levels across the three assessed competencies, highlighting the contrast between Emerging and Outstanding classifications.

These findings directly address RQ1 by providing empirical evidence of differential competency development across decision-making, system functionality, and technical execution.

Rather than indicating mere task completion, the observed performance distributions suggest differential levels of anticipatory reasoning and system awareness, supporting the rubric's capacity to discriminate between surface execution and integrated understanding.

### B. Student Perceptions and Technology Acceptance

Student perceptions of the *TecDrone* tool were assessed through a survey grounded in the Technology Acceptance Model (TAM), involving 54 participants. Using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree), the results indicated a high level of acceptance across key dimensions. All reported values correspond to item-level descriptive statistics. Table I presents a summary of the TAM survey findings, highlighting students' positive views on the tool's usefulness, ease of use, and its role in supporting practical learning and assessment in engineering education.

High Perceived Usefulness (PU): Students found TecDrone to be a highly useful tool for their learning. The average response score for usefulness-related items was 4.5 out of 5, indicating strong perceived alignment between the tool and assessment goals. In particular, the question, "I consider *TecDrone* to be more effective than traditional exams (like written tests) for evaluating my practical competencies," received an average score of 4.6, which shows that students value its effectiveness as an authentic assessment method.

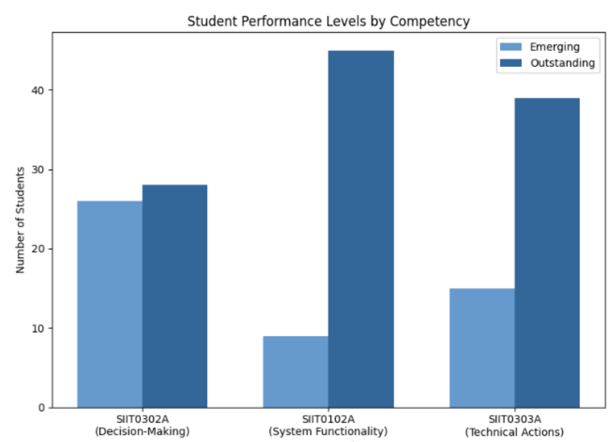


Fig. 2. Student performance in three competencies, showing strong gains in functionality and technical actions, and moderate gains in decision-making.

TABLE I. SUMMARIZES THE DESCRIPTIVE STATISTICS OF THE TAM SURVEY ITEMS, SHOWING CONSISTENTLY HIGH MEAN VALUES ACROSS ALL DIMENSIONS, WHICH INDICATES STRONG STUDENT ACCEPTANCE OF THE TECDRONE PLATFORM.

| TAM Survey Results Summary | | |
|---|---|---|
| ***Question ID*** | ***Mean*** | ***SD*** |
| Q1 | 4.46 | 0.84 |
| Q2 | 4.26 | 0.99 |
| Q3 | 4.28 | 1.0 |
| Q4 | 4.43 | 0.9 |
| Q5 | 4.57 | 0.84 |
| Q6 | 4.5 | 0.84 |
| Q7 | 4.39 | 0.92 |

Q1-*TecDrone* allowed me to apply what I learned in situations similar to real-world contexts.
Q2-I consider *TecDrone* more effective than traditional exams (such as written tests) for evaluating my practical competencies.
Q3-The *TecDrone* interface was intuitive and easy to use.
Q4-*TecDrone* enabled me to carry out learning activities independently, without constant assistance.
Q5-The instructions provided by *TecDrone* were clear and easy to follow.
Q6-*TecDrone* adequately assessed my ability to demonstrate the operation of engineering systems and devices.
Q7-The *TecDrone* tool managed to keep my interest during its use.
Q8-Do you consider *TecDrone* a resource that supports the evaluation of your learning?

High Perceived Ease of Use (PEOU): The tool's interface and design were perceived as intuitive. The average score for the ease of use items was 4.7 out of 5, with a score of 4.8 on the question, "The *TecDrone* interface was intuitive and easy to use for me," indicating a smooth and frustration-free user experience.

High Autonomy and Engagement: The survey also revealed that the tool fosters learning autonomy (average of 4.4) and maintains student interest (average of 4.6). This data suggests that the platform is not only accepted and easy to use but is also a motivating resource that facilitates independent learning.

Furthermore, 94% of the students affirmed that the tool aids in the evaluation of their learning, which underscores its perceived value as an innovative and effective alternative to traditional assessment methods. These findings confirm that *TecDrone* successfully overcomes technological acceptance barriers, a critical factor for the success and scalability of educational innovation strategies.

## IV. DISCUSSION

From a broader perspective, TecDrone illustrates how immersive environments can reposition assessment as a knowledge-generating activity rather than a terminal measurement. By making decision processes explicit through AI-mediated dialogue, the strategy contributes to ongoing discussions on transparent, competency-based assessment in engineering education, particularly in early curricular stages where epistemological beliefs are still forming.

The central contribution of TecDrone is not the technological integration itself, but the assessment framework enabled by that integration. VR provides access to observable engineering actions, while AI-mediated dialogue makes reasoning processes explicit. Together, these elements create an assessment architecture capable of generating evidence about decision-making, system understanding, and technical execution that would be difficult to capture through conventional examinations.

The findings from the TecDrone implementation underscore the efficacy of Virtual Reality (VR) and Artificial Intelligence (AI) environments in supporting authentic assessment of engineering competencies. While the results demonstrate clear benefits within a first-year engineering context, they should be interpreted as context-specific rather than universally generalizable. This contextual framing is consistent with the exploratory and design-oriented nature of the study. The contribution of this study lies in presenting a replicable instructional design that can be adapted to similar educational settings. More specifically, the contribution resides in operationalizing assessment within an integrated VR–AI environment rather than treating these technologies solely as instructional supports. The marked improvement in SIIT0102A (Demonstration of Engineering System Functionality), with 83% of students reaching the Outstanding level, indicates that immersive simulations can significantly enhance conceptual understanding and the ability to articulate technical processes.

These findings align with prior research indicating that immersive simulations support applied understanding and decision-making in engineering education [7], [11]. Unlike traditional laboratory activities constrained by time or resources, the virtual environment allowed repeated experimentation without physical risk, fostering deeper engagement with system dynamics. This affordance is particularly relevant for early-stage learners who are still developing mental models of system behavior. This flexibility may explain the strong gains observed in competencies related to system functionality and technical execution.

Performance gains in SIIT0303A further suggest that the interactive nature of the virtual lab promotes the execution of concrete engineering decisions. Importantly, the strategy emphasizes functional understanding and technical justification rather than isolated mastery of abstract physical theory, positioning simulation as a complementary layer to conceptual instruction, reinforcing the value of experiential learning in simulated environments. This shift supports assessment practices that privilege integrated performance over procedural recall.. Although SIIT0302A (Decision-Making) showed a more balanced distribution, the upward trend reflects the potential of *TecDrone* to foster analytical thinking.

Student perceptions, measured through the Technology Acceptance Model (TAM), revealed high levels of acceptance across all dimensions. Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) averaged above 4.5 on a 5-point scale, demonstrating that students found the tool both effective and intuitive. This level of acceptance is especially relevant given the assessment-oriented role of the platform. Additionally, the platform's capacity to promote autonomy and engagement was strongly affirmed.

The integration of AI avatars enabled students to justify technical decisions and reflect on their impact, introducing a metacognitive layer essential for complex problem-solving. By externalizing reasoning through dialogue, the AI interaction made students' decision processes observable and assessable. The three-phase pedagogical model (pre-task, simulation, reflection) proved effective in activating prior knowledge, applying skills, and fostering systems thinking.

### A. Practical Recommendations for Instructors

To effectively implement *TecDrone*-like strategies, instructors should begin by scaffolding theoretical foundations before moving into simulation activities, ensuring students can connect abstract concepts with applied tasks. Structured guidance during the VR phase is recommended, while leaving room for autonomy to promote critical decision-making and problem-solving. Instructors should leverage AI avatars not only for assessment but also as facilitators of reflective dialogue, encouraging students to justify their technical reasoning. Additionally, aligning tasks with institutional competencies ensures relevance and meaningful evaluation. Technical support and clear instructions are essential to minimize cognitive overload and maximize engagement. Finally, integrating formative feedback throughout the process can reinforce learning, helping students transfer skills to real-world engineering contexts.

These recommendations aim to support faithful implementation without over-constraining instructional flexibility.

### B. Study Limitations

This study presents several limitations that should be acknowledged. First, the experience was implemented in a single course with first-year engineering students, which constrains the scope of transferability. Second, competency assessment focused on observable performance and argumentation within a simulated environment, rather than on exhaustive measurement of conceptual physics knowledge. Third, the intervention duration limits conclusions regarding long-term retention or progression across curricular stages. Finally, the qualitative analysis was based on brief written responses, limiting the depth of interpretation despite triangulation with performance data.

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The competency rubric employed a binary classification scheme (Emerging and Outstanding) to facilitate implementation and interpretation. While this approach provided clear distinctions in performance, a more granular rubric including intermediate achievement levels could reveal subtler differences in competency development. Future research should explore whether multi-level classifications improve sensitivity to incremental learning gains and provide a more nuanced characterization of student performance trajectories.

## V. Conclusions

The *TecDrone* educational strategy demonstrated its effectiveness in assessing and fostering engineering competencies through immersive simulation and AI-driven interaction. The significant improvements observed in students' ability to demonstrate system functionality and implement technical actions highlight the pedagogical value of integrating Virtual Reality and Artificial Intelligence in first-year engineering education. The experience also showed moderate gains in decision-making, suggesting room for further enhancement in challenge design. These findings support the feasibility of competency-based assessment within simulated environments at early stages of engineering formation.

Students reported high levels of perceived usefulness, ease of use, and autonomy, confirming the tool's acceptance and its alignment with active learning principles. The AI avatar interaction added a reflective dimension, encouraging students to articulate and justify their technical decisions, thereby promoting metacognitive development. This dialogic component enhanced the transparency of the assessment process by making reasoning explicit.

The replicable three-phase model—preparation, simulation, and reflection—offers a scalable framework for authentic assessment across STEM disciplines. By bridging theory and practice in a controlled yet realistic environment, *TecDrone* contributes to the transformation of engineering education, preparing students to tackle complex, real-world challenges with confidence and competence.

From an instructional perspective, TecDrone demonstrates how assessment can be repositioned as a learning-centered process rather than a purely evaluative event. In this sense, assessment becomes an integral component of the learning experience rather than an external checkpoint. By embedding assessment within authentic tasks and reflective dialogue, the strategy supports continuous feedback and iterative improvement, which are central to competency-based engineering education.

Future implementations should explore longitudinal impacts, broader disciplinary applications, and strategies to enhance decision-making skills through more nuanced simulation scenarios.

The primary contribution of this work lies not in demonstrating technological novelty, but in operationalizing assessment within immersive environments in a manner that is pedagogically grounded, methodologically transparent, and institutionally aligned.

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