AI-ENHANCED GAMIFICATION IN ERP SIMULATION: THE MxREP AND VIRTUAL PLANT APPROACH

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ABSTRACT
The growth of Artificial Intelligence (AI) has profoundly impacted educational innovation, particularly in teaching complex, integrated industrial concepts such as Enterprise Resource Planning (ERP) and supply chain dynamics, which traditionally require extensive practical experience. Tecnologico de Monterrey and Mälardalen University jointly developed an AI-enhanced gamified simulation infrastructure centred on the MxREP ERP process simulator. As equal partners in design, implementation, and evaluation, the two institutions built a system capable of operating across their differing curricular structures. The simulator models assembly processes within a fictional manufacturer and incorporates Virtual Reality and Augmented Reality modules (collectively referred to as the Virtual Plant) to capture rich, granular data on student behaviour, including assembly sequences, task completion times, and demand-forecasting decisions. The collaboration's core objective is to transform simulation data into actionable learning intelligence. AI serves a dual function: predictive modelling, exemplified by refining demand-prediction algorithms and anticipating quality failures; and providing a personalised learning experience by comparing student performance against expert benchmarks. The embedded AI provides adaptive feedback, suggesting optimal strategies and highlighting subtle decision signals frequently overlooked in traditional instruction. The system evaluates the application of both disciplinary and transversal competencies during decision-making. The research validates that AI-enhanced gamification, coupled with the Virtual Plant simulation, improves undergraduate engineering learning outcomes by transforming a passive tool into a dynamic, adaptive resource that bridges theoretical knowledge with the practical development of professional competencies.

Keywords: Gamification, ERP simulation, artificial intelligence, extended reality, engineering education

1 INTRODUCTION
The learning styles of engineering students born after 2000 differ substantially from those of previous generations. Where earlier cohorts developed competencies through textbooks, physical laboratories, and proximity to industry-experienced instructors, today's students arrive with high expectations for immersive, technology-mediated engagement. This reality places new demands on instructional design, particularly in Industrial and Systems Engineering (ISE), where core concepts such as Enterprise Resource Planning, supply chain optimisation, quality control, and manufacturing dynamics have traditionally required hands-on experience in industrial facilities to be learned effectively.
The global pandemic accelerated the search for credible alternatives. In response to this shared challenge, this research collaboration gave rise to the MxREP ERP process simulator, extended through XR modules into what the team terms the Virtual Plant. The environment was designed from the outset to function across both institutions' curricula, within Tecnologico de Monterrey's TEC21 challenge-based model and Mälardalen University's engineering design programmes, and this dual-institution scope shaped its modular architecture. Student teams manage a fictional manufacturing firm, configure production lines, manage inventory, respond to demand variability, and assemble physical products in VR, while competing on real-time financial dashboards.
The present research emerges from a sustained academic collaboration between Tecnologico de Monterrey (TEC) and Mälardalen University (MDU), who have jointly developed the simulation

architecture, lesson design methodology, and AI integration strategy described in this paper. Building on the central argument that the true value of simulation is not the experience it provides, but the rich behavioural data it generates, and that AI is the mechanism that transforms those data from records of outcome into signals of process. Consequently, this paper describes the architecture of that integration, its shared pedagogical rationale, and its observed effects on competency development across undergraduate engineering cohorts at both institutions.

2 STATE OF THE ART

2.1 Gamification in Engineering Education

Gamification is defined as the application of game-thinking and game mechanics to engage users and solve problems [1][2][3]. Within engineering education, it is important to distinguish between gamification, serious games, and game-based learning. Gamification incorporates game design elements into educational contexts to enhance engagement; serious games are technology-driven designs with primary purposes beyond entertainment; and game-based learning uses existing games as pedagogical vehicles.

The research team's experience, accumulated over more than fifteen years of implementation at TEC, identifies three categories of gamification application: Hard GameBoarders (board games and physical devices), Soft GameBoarders (digital platforms including simulators and puzzle-based tools), and XR GameBoarders (activities based on virtual, augmented, and mixed reality). Survey data collected between 2020 and 2023 across project management cohorts confirmed that 91% of students engage in gaming and 83% favour gamified classroom activities, validating the motivational premise of this instructional approach.

The design of effective gamification activities is guided by three critical variables: Competency Development, Learning, and Engagement. This framework is operationalised as the Wow Experience equation: Wow = (Activity + Creativity + Gamification) ^Emerging Technologies [4]. The equation captures the amplifying role of technology: without instructional creativity and targeted activity design, technology alone does not produce learning.

2.2 Digital Twins and Virtual Laboratories in Engineering Education

Virtual laboratories have emerged as a credible alternative to physical industrial access following the pandemic's disruptions. The Virtual Plant constitutes a high-fidelity Digital Twin of an automotive assembly environment, jointly developed and deployed across both institutions. It enables students to interact with causal industrial logic, where inventory levels affect throughput and quality deviations propagate to customer outcomes, without physical or financial risk.

Previous work by this research group has demonstrated the pedagogical value of integrating immersive reality into project management education. The TEC21 Car Assembly activity, based on a Meccano Buggy model, teaches CPM and PERT network optimisation through a competitive assembly challenge. The MxREP simulator extends this logic into ERP territory, requiring teams to configure production parameters, respond to demand signals, and manage supply chain decisions with direct financial consequences visible on shared dashboards [5][6].

In parallel, Berglund's work [7][8] on the adoption of Extended Reality (XR) in engineering and product design education highlights both its pedagogical potential and the structural constraints that hinder integration, particularly the resource intensity, curriculum misalignment, and added cognitive and technical load associated with standalone XR implementations. The present collaboration addresses these challenges by embedding XR within a curriculum-aligned simulation infrastructure, making it an integrated learning mechanism that supports rather than competes with existing learning outcomes.

2.3 AI in Educational Environments

There is a growing trend of utilising AI as an integrated and more sophisticated AI tool when preparing and designing learning environments [9]. Still, AI has been applied in educational contexts through two primary mechanisms: adaptive content delivery, which adjusts instructional material based on performance signals, and predictive analytics, which identifies students at risk of poor outcomes based on behavioural patterns. The latter has shown promise in STEM contexts, where early indicators of misconception, such as a persistent bias in demand forecasting, would otherwise remain invisible until formal assessment.

The present work extends this logic to operational decision data generated within a simulated industrial environment. Unlike Learning Management System interaction data, simulation behavioural data captures the reasoning process embedded in decision sequences, providing a qualitatively richer signal for both prediction and personalisation [10].

3 METHODOLOGIES

3.1 System Architecture

The MxREP simulator functions as a multi-user ERP environment in which student teams assume managerial roles within a fictional automotive manufacturer. Teams configure production lines, manage inventory and procurement, respond to demand variability, and compete on financial performance metrics displayed through real-time dashboards. The competitive structure, which includes inter-team leaderboards, production rankings, and revenue optimisation objectives, provides motivational scaffolding without displacing academic objectives.

The Virtual Plant extends this environment through XR modules in which students perform embodied assembly tasks, develop CPM and PERT networks, and interact with process simulations, including a robotic Voluntary Milking System (VMS) developed with DeLaval at the CAETEC agricultural research facility [10]. These modules are not a visualisation supplement; they are integrated into the ERP environment's operational decision-making structure, so that assembly efficiency directly affects simulated financial outcomes.

The international collaboration between TEC and MDU was foundational to the system's design, not a later addition. Both institutions contributed to lesson conceptualisation, modular architecture decisions, and cross-institutional pilot testing. This joint ownership produced an environment that is curriculum-adaptable rather than tied to any single institutional model, supporting deployment across the Industrial Engineering, Mechanical Engineering, Mechatronics, Data Science, and Business cohorts of both universities.

3.2 Data Capture

Every student interaction generates structured log data. In the ERP modules, this includes inventory configuration decisions, demand-forecasting inputs, and supply-chain parameter adjustments. In the XR assembly modules, it captures the sequence of steps, the task latency, and the deviation from optimal assembly paths.

In the agricultural simulation, variables include cow health indicators, milking cycle data, and breeding decisions. All data streams are stored in relational databases that serve as the foundation for AI processing [10]. Teachers configure the simulator to align with the lessons' specific objectives.

A quality control lesson emphasises statistical process control and the traction subsystem of a Meccano F1 device, which is a project evaluation lesson that targets the creation of an economic dashboard resulting from investment decisions. This configurable structure means that each lesson generates a distinct data profile tailored to the competencies under development.

3.3 AI Processing Pipeline

AI integration follows a three-stage pipeline. In the first stage, real-time data from XR and ERP interactions is extracted and normalised. In the second stage, machine learning models compare individual student performance trajectories against expert-defined operational benchmarks and against aggregated historical performance from prior cohorts. This comparison reveals behavioural signals that precede poor outcomes, such as persistent assembly sequence errors or systematic overestimation of demand. In the third stage, the system generates personalised feedback for students and flags emerging patterns for instructor review.

A prototype conversational tutor, currently under evaluation, responds to student queries about parameter configuration using context derived from accumulated session data. This component is designed to provide on-demand scaffolding without requiring instructor intervention for routine clarifications, freeing the instructor's attention for complex pedagogical decisions.

3.4 Educational Design Constraints

All lessons are designed under three explicit constraints: conceptual mastery of disciplinary content, development of transversal competencies including systemic thinking and decision-making under uncertainty, and maintenance of sustained engagement. These constraints correspond directly to the three variables of the Wow Experience framework. The instructor's role within this model shifts from primary content deliverer to interpreter of AI-generated insight, determining which flagged patterns warrant direct intervention and which represent productive struggle.

3.5 Application of the MxREP and virtual plant

Over the past 5 years, we have implemented the virtual plant an average of 9 times per year in different learning units (UF) within TEC. Every UF has two groups, each group has an average of 31 students. Improvements have been implemented in the last 3 years, such as changes in the distribution centres for the logistics module and the additional products that can be assembled (e.g., drones), which have increased the ability to influence a greater number of students. 1

Since last semester (August - December 2025), it has been possible to share the simulator as it is hosted on Roblox. For the present contribution, the results of the last teaching units of the Industrial and Systems Engineering program are analysed, involving two groups of 26 (Group #1) and 29 (Group #2) students taking the UF IN3001B Design of a Smart Organisation. Both groups had to solve a problem-based scenario focused on designing a drone manufacturing plant, requiring them to learn to calculate line capacity and to design the plant layout, including the total number of machines and employees. The IN3001B is the capstone unit in the Industrial and Systems program, and the challenge for these students is to design a smart manufacturing system for drone assembly.

A pre-test was developed, consisting of 20 questions randomly selected from a pool of 50. Subsequently, the students completed the entire exercise, which included hands-on practice with physical drones, followed by use of the simulator and access to the virtual and augmented reality lessons. The lesson ended with a post-test also consisting of 20 questions randomly assigned from a pool of 50 questions to minimise the risk of copying or identical exams.

4 RESULTS AND DISCUSSION

4.1 From Outcome Monitoring to Behavioural Prediction

The most practically significant outcome of AI integration was the shift from post-hoc performance review to real-time behavioural monitoring. In prior simulator implementations, instructors could evaluate teams only through final financial outcomes. The AI layer made it possible to identify, for instance, that a team's end-of-session inventory failure was preceded by a systematic pattern of demand overestimation visible in the first third of the session, well before any financial consequence had materialised. Instructors reported that this early signal allowed them to redirect student attention before misconceptions became entrenched.

This shift has direct implications for instructional practice. Rather than diagnosing learning problems after the fact, instructors can intervene at the moment of misconception. The system thus functions as a distributed diagnostic tool: the AI processes data that exceeds any individual instructor's capacity for attention and surfaces the subset of signals that require human pedagogical response.

4.2 Competency Assessment

The AI-enhanced system enabled evaluation of both disciplinary and transversal competencies. Disciplinary competencies assessed included demand-forecasting accuracy, application of statistical process control, CPM/PERT network optimisation, and supply-chain configuration. Transversal competencies, including decision-making under uncertainty, team coordination, and systemic risk analysis, were evaluated through behavioural pathway analysis.

The system could distinguish between teams that achieved good outcomes through structured reasoning and those that arrived at similar scores through trial-and-error iteration, a distinction invisible to outcome-only assessment. This granularity is particularly relevant in competency-based educational models such as TEC21, which require evidence of the reasoning process rather than outcome performance alone.

Qualitative observations across cohorts indicated improved student confidence in interpreting industrial data dashboards and greater willingness to iterate on complex problems when feedback was specific and timely rather than deferred to end-of-session review. Formal assessment data comparing cohorts with and without AI-enhanced feedback is currently being collected and will be reported in subsequent work.

4.3 Scalability and Cross-Institutional Transfer

The cloud-based architecture of the Virtual Plant allowed consistent deployment across both institutions without requiring duplication of local laboratory infrastructure. Students at MDU and TEC engage with the same simulation environment and data pipeline, enabling genuine cross-institutional comparison of competency development. The parallel deployment has also stress-tested the system's modularity: differences in curricular structure, academic calendar, and disciplinary emphasis between the two universities required the architecture to flex without losing analytical coherence, and on that count, it has performed well.

The agricultural VMS simulation is a notable example of this adaptability. Data from real DeLaval robotic milking operations at CAETEC was integrated into the simulation environment, allowing AI algorithms to process cow health and milk quality variables that students must interpret to make breeding and milking cycle decisions [10]. This cross-domain extension confirms the generalisability of the AI integration architecture beyond its original manufacturing context.

4.4 Application of the MxREP and Virtual Plant Approach

The statistical results are shown by applying a pre-test on the knowledge of line capacity analysis to the students from group #1. As seen in Figure 1A, most of the data are left-skewed with a low average; 8 of 25 students scored 45 out of 100.

After conducting the Simulation Session, the vast majority of students achieved a maximum score of 100 (Figure 1B). A paired t-test was done to analyse the significance of the application. The results show that the hypothesis that traditional learning and learning based on immersive technologies with an ERP component are the same in students is rejected, with a t-value of -9.78, a p-value of 7.58E-10, and 95% of confidence level. This indicates sufficient evidence that traditional learning and immersive learning based on the MxREP simulator, combined with XR technologies in a stressful environment, are not the same.

Furthermore, according to the confidence level, it can be concluded that immersive learning based on the MxREP simulator, combined with XR technologies in a stressful environment, generates better knowledge among students.

A B

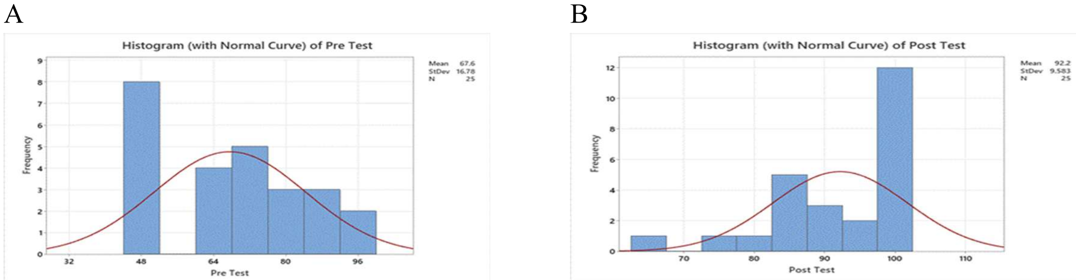

Figure 1. Distribution comparison between Pre (A) and Post Test (B)

5 CONCLUSIONS

Integrating AI directly into a gamified Digital Twin environment can significantly enhance the pedagogical information available to engineering educators. The core innovation lies in the system's capacity to transcend traditional outcome-based assessment. By meticulously converting students' granular simulation interaction logs into sophisticated behavioural prediction models, the framework redefines assessment. It shifts the focus from merely evaluating what products or results students generated to a deeper analysis of how they reasoned, made choices, and navigated complex systemic constraints. The development and validation of the Virtual Plant ecosystem, which hosts the AI-enhanced gamification, is a testament to sustained and equal collaboration between TEC and MDU. This partnership was foundational, ensuring the resulting architecture possessed exceptional scalability and institutional neutrality; this way, it can serve the distinct pedagogical needs, programme structures, and educational traditions of both institutions with parity.

While the preliminary results are highly promising, a crucial and acknowledged limitation of the current study is the systematic absence of a fully controlled, large-scale quantitative assessment. Addressing this gap constitutes the central focus of current and ongoing research efforts. Future development priorities are structured around three core pillars: (1) achieving more granular, individual-level behavioural modelling to identify and address student-specific misconceptions in real-time; (2) establishing formalised, quantitative cross-institutional competency benchmarks that allow for direct, objective comparison of student performance across TEC and MDU; and (3) extending the validated predictive architecture to encompass additional critical simulation domains, including complex sustainable energy systems design, smart logistics and supply chain optimisation.

Ultimately, the findings reinforce two essential and immutable pedagogical principles. First, gamification itself does not generate knowledge in isolation; true, durable learning arises from the careful, meticulous design of activities that strategically harness core game mechanics (e.g., scoring, badges, rapid feedback loops) to directly support explicit, predetermined learning objectives. Second, AI is not a substitute for the irreplaceable expertise of the instructor. Rather, AI functions as a powerful force multiplier, exponentially increasing the instructor's diagnostic capacity by providing deep, real-time insights into student reasoning processes that are otherwise invisible. The integration of these two principles represents the enduring and significant contribution of the collaboration between Tecnológico de Monterrey and Mälardalen University.

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