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Implementing a Challenge-Based Automotive Engineering Concentration for Experiential Learning in Mechanical Engineering Education

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Abstract*– Engineering programs in highly integrated domains such as Automotive and Mechanical Engineering require educational approaches that effectively bridge theoretical knowledge, technical competencies, and professional skills within authentic learning environments. This paper presents and analyzes the implementation of an Automotive Engineering Concentration designed under a challenge-based learning framework, in which students engaged in the design, manufacturing, and system integration of a functional electric vehicle aligned with international competition standards. The concentration was structured into two sequential curricular units and implemented during the August–December 2023 academic term, involving nineteen undergraduate engineering students from multiple campuses. Participants worked in multidisciplinary teams responsible for critical vehicle subsystems, fostering system-level thinking and interdisciplinary collaboration. A descriptive–analytical research approach was adopted, combining the analysis of curricular design, student academic performance, and technical evidence derived from the developed prototype. Results indicate consistently high academic performance, positive learning progression, and effective integration of knowledge across engineering domains. The successful participation of the developed vehicle in national competitions, where it achieved first place in 2 races and third place in the overall Electratón México competition, provides external validation of the technical and educational outcomes of the proposed model. Despite limitations related to sample size and the absence of a control group, the findings offer relevant evidence supporting the integration of authentic engineering challenges within curricular concentrations as a viable strategy to enhance engineering education and better align academic training with industry demands.

***Keywords*-- engineering education, higher education, challenge-based learning, automotive engineering education; mechanical engineering; experiential learning; competency-based education; automotive engineering concentration.**

I. Introduction

Engineering education in the twenty-first century stands at a critical turning point. The increasing complexity of technological systems, the convergence of multiple engineering disciplines, and growing industry demands for graduates capable of integrating rapidly into real professional environments have exposed the limitations of traditional educational models, particularly in fields such as Mechanical and Automotive Engineering. In these domains, the fragmentation of knowledge into isolated courses and the predominance of decontextualized academic exercises hinder the development of systemic understanding and transferable professional competencies.

In response to these challenges, contemporary engineering education has progressively evolved toward student-centered approaches in which learning is constructed through engagement with real and meaningful problems. Within this context, challenge-based learning has emerged as a robust pedagogical framework that redefines the professional world as an extension of the classroom, promoting active participation of organizations and industry partners as formative collaborators. This approach is further strengthened by the presence of inspiring faculty committed to educational innovation and continuous improvement of teaching practices, as well as by curricular flexibility that enables learning to adapt in terms of time, space, and modality through the strategic use of technology.

Prior research in Mechatronics Engineering education has shown that intentionally designed experiential learning environments significantly enhance the development of transversal competencies, student autonomy, and the ability to address complex problems in authentic contexts [1], [2]. Likewise, challenge-based learning has proven effective in articulating theoretical knowledge with authentic practical experiences, fostering memorable learning processes that strengthen both professional competencies and students' sense of disciplinary identity [3].

In the specific context of Automotive Engineering, these educational demands are further intensified by the inherently interdisciplinary nature of vehicle systems, which integrate mechanical design, electrical and electronic systems, manufacturing processes, regulatory compliance, and safety standards. Effective instruction in these areas requires learning experiences that expose students to the real complexity of designing and building functional systems, moving beyond approaches limited to simulations or small-scale projects. [4-6].

Within this framework, student participation in real-world projects involving the design and manufacturing of electric vehicles represents a high-impact pedagogical strategy aligned with the principles of challenge-based learning, curricular flexibility, and the creation of meaningful university learning experiences. Developing a complete vehicle demands not only the integrated application of technical knowledge, but also interdisciplinary coordination, resource management, regulatory compliance, and experimental validation, core elements of professional practice in Mechanical and Automotive Engineering [7-9].

This paper describes and analyzes the implementation of an Automotive Engineering Concentration developed under the Tec21 educational model at Tecnológico de Monterrey, whose central focus was the conception, design, fabrication, and testing of an electric vehicle aimed at meeting the technical requirements of the Electratón México competition. The concentration was structured into two sequential curricular units and promoted multidisciplinary collaboration through specialized teams responsible for key vehicle subsystems, incorporating educational principles previously validated in experiential and industry-oriented Mechanical and Mechatronics Engineering programs [1-3], [10-12].

Based on the analysis of curricular design, implementation methodology, and academic outcomes achieved by participating in students, this study provides empirical evidence of the educational value of integrating real automotive engineering projects within professional-level curricular concentrations. The findings reinforce the relevance of challenge-centered educational models, inspiring faculty engagement, curricular flexibility, and meaningful learning experiences as key drivers for more effective engineering education and stronger alignment with current industry demands.

II. Program Design and Educational Framework

The Automotive Engineering Concentration was intentionally designed as a curricular response to contemporary challenges in engineering education, particularly integrated fields such as Mechanical and Automotive Engineering. Its conception is grounded in the recognition that effective engineering education requires learning experiences that move beyond fragmented, course-based instruction and instead promotes the functional integration of knowledge, skills, and professional attitudes within authentic practice-oriented contexts.

From an educational innovation perspective, the program design is structured around four interconnected pillars: challenge-based learning, inspiring faculty, curricular flexibility, and meaningful learning experiences. These elements are not implemented independently; rather, they operate as an integrated system that guides curricular structure, instructional strategies, and learning assessment mechanisms [13-16].

Challenge-based learning constitutes the pedagogical core of concentration [17-19]. The central challenge, the conception, design, and fabrication of a functional electric vehicle aligned with the technical requirements of the Electratón México competition, was framed as a complex, open-ended, and authentic engineering problem that closely mirrors professional practice in the automotive industry. This approach enables real-world contexts to function as an extension of the classroom, fostering informed decision-making, uncertainty management, and contextualized application of technical knowledge, all of which are essential competencies in Mechanical and Automotive Engineering education.

The curricular structure of the concentration was organized into two sequential learning units: Automotive Engineering I (M3005C), delivered over six weeks, and Automotive Engineering II (M3006C), developed across eleven weeks. The first unit focused on consolidating essential theoretical and regulatory foundations, including automotive design principles, mechanical and electrical systems, and the analysis of technical regulations associated with the competition. The second unit emphasized project planning, detailed design, manufacturing, and vehicle validation, enabling structured progression from conceptual development to implementation and testing of a real engineering system.

A distinctive feature of the program was the organization of student work into specialized multidisciplinary teams, reflecting the operational structure of professional engineering projects. Students were distributed across six teams responsible for key vehicle subsystems: chassis; front suspension and steering; rear suspension and braking systems; powertrain; electrical system; and bodywork and safety. This configuration promoted technical interdependence, effective communication, and a systemic understanding of the vehicle as an integrated whole—competencies that are fundamental to Automotive Engineering formation.

Program implementation was supported by an inspiring faculty composed of instructors with strong disciplinary backgrounds and a clear commitment to educational innovation. Faculty members assumed the role of learning facilitators rather than content transmitters, focusing on technical mentoring, continuous formative feedback, pedagogical mediation, and competency-oriented decision-making, in alignment with contemporary approaches to engineering education.

In addition, the concentration incorporated curricular flexibility through the strategic use of technological resources, access to specialized workshops, and time management structures that enabled students to autonomously organize the design, manufacturing, and testing phases. This flexibility not only accommodated diverse learning rhythms and styles, but also reproduced dynamics characteristics of real engineering projects, where planning and time management are critical components of professional performance.

Finally, the program design prioritized the creation of meaningful learning experiences, understood as those that integrate technical learning with students' personal and professional development. Participation in the construction of a real vehicle fostered high levels of engagement, sense of belonging, and collective responsibility, factors identified in the literature as key enablers of deep and sustainable competency development in Mechatronics Engineering and related fields [1-3].

Overall, the educational framework of concentration integrates validated pedagogical principles with a coherent curricular implementation aligned with current automotive industry demands, offering a replicable training model for engineering programs seeking to strengthen the connection between theory, practice, and professional performance.

Figure 1 summarizes the integrated educational framework of the Automotive Engineering Concentration, highlighting the central role of an authentic engineering challenge and its articulation with the four pedagogical pillars that support competency development in Automotive Engineering.

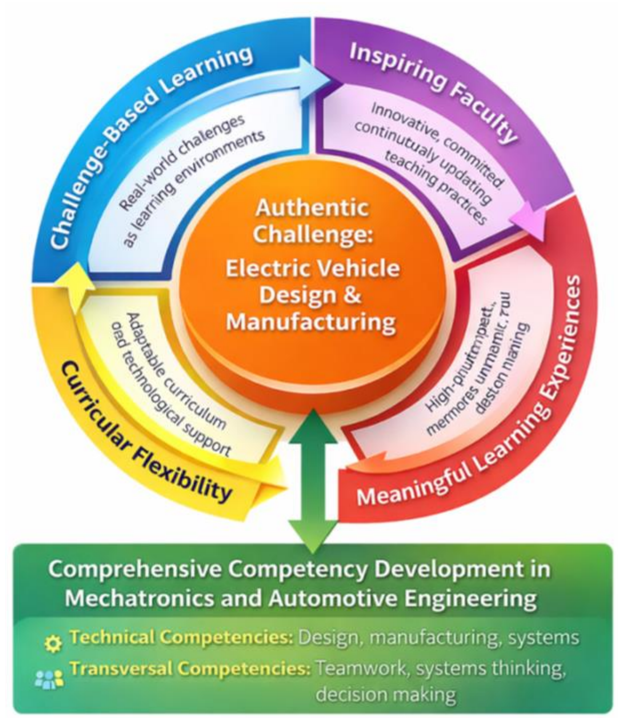

Fig. 1. Integrated educational framework of the Automotive Engineering Concentration based on a challenge-based electric vehicle design and manufacturing approach (authors' own elaboration).

III. Methodology

This study adopts a descriptive-analytical educational research design aimed at examining the implementation and outcomes of an industry-aligned, challenge-based learning experience within a professional engineering concentration. The methodological approach was designed to systematically document the curricular structure, instructional strategies, and academic outcomes associated with the Automotive Engineering Concentration, while preserving the authenticity of the educational setting in which the intervention was conducted.

A. Context and Participants.

The Automotive Engineering Concentration was implemented during the August–December 2023 academic term at Tecnológico de Monterrey and involved 19 undergraduate engineering students from multiple campuses. Participants were selected based on academic performance and demonstrated interest in automotive and mechanical engineering, ensuring a cohort with sufficient technical preparation to engage in a complex, multidisciplinary engineering challenge.

The cohort reflected the interdisciplinary nature of the program, with students enrolled in programs closely related to Mechatronics, Mechanical, and Robotics Engineering. This diversity enabled the study to examine learning processes representative of contemporary engineering education environments that emphasize system integration and cross-disciplinary collaboration.

B. Instructional Design and Learning Activities

The methodological structure of the concentration was organized around a single authentic engineering challenge: the conceptualization, design, manufacturing, and validation of a functional electric vehicle aligned with the technical regulations of the Electratón México competition. This challenge functioned as the central organizing axis for all instructional activities, assessments, and learning milestones.

Learning activities were distributed across two sequential curricular units. The first unit emphasized conceptual foundations, regulatory frameworks, and system-level understanding, while the second unit focused on applied engineering processes, including detailed design, subsystem integration, manufacturing, and experimental validation. Instructional strategies included guided design reviews, iterative prototyping cycles, technical mentoring sessions, and collaborative problem-solving activities, all conducted in workshops and laboratory environments.

Students were organized into six specialized multidisciplinary teams, each responsible for a critical vehicle subsystem. This organizational structure was intentionally designed to replicate professional engineering workflows and to promote inter-team coordination, systems thinking, and accountability for subsystem integration within a complex engineering project.

C. Role of Faculty and Learning Mediation

Faculty participation was framed within a facilitative and mentoring-oriented instructional role, consistent with contemporary models of challenge-based and experiential learning. Instructors provided continuous formative feedback, technical guidance, and pedagogical mediation throughout the project lifecycle, supporting student decision-making while preserving learner autonomy.

This instructional approach ensured alignment between pedagogical intent and competency development, while maintaining the authenticity of the engineering challenge and avoiding excessive instructor intervention that could undermine the experiential nature of the learning process.

D. Assessment Strategy and Data Sources

Within the Tec21 educational framework, this concentration is structured as an intensive, full-time semester-long commitment (18 credits), involving approximately 35 contact hours per week. To ensure rigorous engineering standards, students were required to submit a comprehensive suite of deliverables, including CAD engineering drawings, finite element analysis (FEA) of the chassis under impact scenarios, machine design calculations for component sizing, and a detailed cost analysis. Academic performance was determined through a competency-based rubric: 60% of the grade was derived from technical milestones (subsystem reviews and reports) and 40% from the final system integration and vehicle performance. Regarding team dynamics, faculty addressed potential issues like uneven participation or 'slacking' through weekly peer-evaluation logs and proactive mentoring sessions. Furthermore, implementation challenges primarily involved tight lead times for specialized component procurement and the high-pressure timeline of finishing a functional prototype within seventeen weeks, necessitating a streamlined manufacturing approach that strictly followed the Electratón México technical regulations

E. Data Analysis Approach

Data analysis followed a descriptive analytical approach, focusing on the interpretation of academic performance indicators and their relationship to instructional design features and the learning environment. Quantitative data were examined to identify achievement patterns across the cohort, while qualitative evidence was used to contextualize observed outcomes and support interpretations related to competency development, interdisciplinary integration, and student engagement.

Rather than pursuing causal inference, the methodological intent was to generate practice-based evidence that informs the design and implementation of challenge-based concentrations in engineering education. This approach is consistent with established research practices in educational innovation, where the primary objective is to document effective instructional models and extract transferable design principles.

IV. RESULTS AND DISCUSSION

The results derived from the implementation of the Automotive Engineering Concentration are analyzed from an integrated perspective that combines academic performance, technical project outcomes, and development of transversal competencies, in coherence with the challenge-based educational framework described in previous sections.

A. Academic Performance and Learning Progression.

The analysis of final grades corresponding to the two curricular units (Automotive Engineering I and II) reveals overall high academic performance and positive learning progression throughout the concentration. In particular, a significant proportion of students demonstrated improved performance during the second unit, coinciding with the transition from predominantly conceptual activities to phases focused on design, manufacturing, and integration of real engineering systems.

This progression suggests that direct exposure to an authentic engineering challenge contributed to a deeper consolidation of learning, especially among students who initially exhibited moderate performance levels. These findings are consistent with experiential learning models in engineering education, where contextualized application of knowledge enhances both conceptual understanding and operational competence.

B. Evidence of Technical Outcomes

From a technical standpoint, the primary outcome of the formative process was the fabrication of a functional electric vehicle, conceived and developed by students in response to the central challenge of concentration. The resulting prototype integrates structural, mechanical, and electrical subsystems in a coherent manner, meeting the technical and regulatory requirements for participation in the Electratón México competition.

Figure 2 presents the electric vehicle developed during the concentration, including a general view of the prototype and details of key subsystems. This visual evidence supports the level of technical complexity achieved and confirms that students were able to materialize a functional system through informed design, manufacturing, and integration decisions made throughout the project.

Fig. 2. Electric vehicle prototype developed as the central engineering challenge of the Automotive Engineering Concentration.

Beyond meeting design, safety, and integration criteria, the developed vehicle successfully participated in national competitions, achieving first place in two races and third place overall in the Electratón México competition. This outcome provides strong empirical evidence of the technical performance attained by the students and reinforces the effectiveness of the implemented educational model in facilitating the transfer of theoretical knowledge into competitive, real-world engineering solutions.

C. Disciplinary Integration and Collaborative Work.

The organization of the project into specialized multidisciplinary teams enabled students to confront the challenges inherent to Automotive Engineering in a realistic manner. The need to coordinate decisions across subsystems, resolve integration conflicts, and adapt designs under real constraints fostered the development of a system-level perspective of the vehicle as an interdependent whole.

Figure 3 illustrates the experiential learning environment during the design, manufacturing, and integration phases, highlighting active student participation in workshops and laboratory settings. These scenarios reflect dynamics characteristic of professional engineering projects, where collaborative work, technical communication, and shared decision-making are essential components of effective performance.

Visual evidence complements the academic results and supports the interpretation that learning extended beyond the acquisition of technical knowledge, encompassing complex social and cognitive processes associated with professional engineering practice.

Fig. 3. Students working in multidisciplinary teams during the design, manufacturing, and integration phases of the project.

D. Development of Transversal Competencies

Beyond quantifiable outcomes, the implementation of the challenge revealed a significant development of transversal competencies, particularly in teamwork, time management, technical communication, and systems thinking. Assigning responsibility for critical vehicle subsystems required students to assume defined roles, negotiate technical decisions, and respond to the consequences of those decisions during final system integration.

These observations are consistent with prior research in Mechanical and Mechatronics Engineering education based on challenge-oriented and real-context learning environments, where engagement with authentic problems has shown strengthening students' readiness for professional practice.

E. Discussion from an Educational Innovation Perspective.

From an educational innovation standpoint, the results support the effectiveness of integrating real engineering challenges within curricular concentrations as a strategy for strengthening the teaching of highly complex engineering disciplines. Unlike approaches centered on simulations or limited-scope projects, the construction of a functional physical system enabled students to directly experience the interaction between theory, practice, and real-world constraints.

The combination of academic evidence, tangible technical outcomes, and observations of the learning process suggests that the implemented model offers a replicable framework for Automotive Engineering programs seeking closer alignment with current industry demands. Nevertheless, the scope of the study is limited to a single cohort, highlighting opportunities for future research involving larger samples and comparative designs.

V. Conclusions

This study demonstrates that the integration of real-world engineering challenges within curricular concentrations constitutes a relevant and effective educational strategy for teaching extraordinarily complex engineering disciplines, such as Automotive, Mechanical and Mechatronics Engineering. The design and implementation of the Automotive Engineering Concentration enabled a coherent articulation of theoretical knowledge, practical activities, and competency-based assessment within an authentic learning environment, fostering educational experiences aligned with current industry demands.

Nevertheless, it is important to acknowledge significant methodological limitations. First, the study is based on a single student cohort with a limited sample size, which constrains the generalizability of the findings. Second, the research design does not include a control group, preventing causal inferences regarding the impact of the proposed educational model in comparison with traditional instructional approaches. In addition, academic performance indicators relied primarily on internal assessment measures, suggesting the need for more diversified and longitudinal evaluation metrics in future studies.

Despite these limitations, the evidence presented reveals consistent patterns of disciplinary integration, development of technical competencies, and strengthening of transversal skills. These outcomes are further supported by external validation of technical performance, as reflected in the successful participation of the developed vehicle in international competitions. This achievement adds credibility to the proposed educational model by demonstrating its effectiveness in real and competitive engineering contexts.

As future work, the Automotive Engineering Concentration will be implemented again during the August – December 2026 academic term, creating the opportunity to replicate the study under comparable conditions. This new implementation will enable comparative analyses across cohorts, the introduction of curricular refinements, and the strengthening of data collection through more diversified assessment instruments and quasi-experimental approaches. Additionally, longitudinal tracking of participating students is planned to examine the longer-term impact of the model on subsequent academic performance and professional integration.

Overall, this work establishes the foundation for a continuous research line in engineering education innovation, aimed at systematically evaluating the impact of challenge-based curricular concentrations as an effective mechanism to bridge the gap between academic training and professional engineering practice.

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