

Design of a learning activity for the development and evaluation of engineering competencies in the topic of modelling of movement

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Abstract

This paper presents the design and application of a learning activity to develop and assess engineering competencies through a challenge-based motion-modeling project. Grounded in contemporary engineering education, the activity integrates experimental data collection, numerical modeling, and iterative design within a competitive catapult challenge. Students build mechanical prototypes, analyze projectile motion using Tracker, and calibrate numerical models through Euler-based and MATLAB simulations. The study compares this new design with a previously designed activity to evaluate teaching effectiveness, student satisfaction, and the development of competencies. Results indicate improved engagement, alignment between learning objectives and assessments, and strengthened students' competencies.

Keywords: Educational innovation; higher education; physics education; competencies-based education; challenge-based learning.

1. Introduction

Engineering education, which aims to prepare students to design, develop, and operate complex systems in team settings (Crawley et al., 2007), has shifted from traditional models focused on transmitting technical knowledge to active, student-centered approaches (Forcael et al., 2023). Contemporary engineering training programs recognize the need to integrate sound technical knowledge with professional and transversal skills to ensure graduates' employability (Boelt et al., 2022; Hernández-Sabaté et al., 2024). These skills include problem-solving, critical thinking, collaboration, multidisciplinary, innovation, and creativity in real-world contexts (Adeoye & Jimoh, 2023; Frache et al., 2017; Thornhill-Miller et al., 2023). In addition, global

and sustainability competencies, digital adaptability, and technological literacy (Reddy et al., 2024; Vázquez-Villegas et al., 2024) are now considered essential in engineering.

There is a documented gap between the competencies employers require and those developed by academic programs (Segalàs et al., 2010). Empirical studies show that competencies are best developed when teaching combines technical content and activities that recreate authentic professional contexts (Boelt et al., 2022; Miranda et al., 2021). Learning-by-doing approaches, including challenge-based learning (CBL), have demonstrated their effectiveness in this context (Hernández-de-Menéndez et al., 2019; van den Beemt et al., 2023), aligning educational outcomes with the demands of the 21st-century labor market and preparing students for real-world (Santana & de Deus Lopes, 2024). However, their effectiveness depends on curriculum design and their fit with specific learning objectives (Cosme et al., 2019; Frache et al., 2019).

In this work, we redesigned an activity to develop and evaluate two competencies in an undergraduate physics course. By introducing a game-like competitive structure, the activity increased student motivation by making progress visible and rewarding through immediate, tangible outcomes. This work builds on previous research showing that engineering design competitions promote meaningful learning and the development of disciplinary and transversal competencies in first-year engineering students (Pardo Regueiro et al., 2023).

This paper contributes by redesigning and implementing a challenge-based learning activity that integrates physical prototyping, experimental data acquisition, and numerical modeling to teach motion modeling in engineering education and evaluate system explanation and decision-making in an authentic engineering context. Also, it contributes by providing empirical evidence and a pedagogical analysis of the benefits and challenges of the redesigned activity, particularly regarding student engagement, cognitive complexity, and the need for appropriate instructional scaffolding in early-stage engineering programs.

2. Methodology

This work was conducted within the course "Modeling of movement in engineering", offered in the first semester of engineering programs. The didactic technique used in this course was CBL, in which students are expected to develop the competencies listed in Table 1.

Table 1. Rubric for the evaluation of competencies in engineering.

Competence	Outstanding (91-100)	Solid (81-90)	Basic (71-80)	Incipient (≤ 70)
SIIT0101 Explains the operation of engineering systems and devices	Elaborates arguments in a precise way to explain the functioning of a system, incorporating in an articulated way the essential principles or laws of engineering and sciences, punctually supporting the description of the dependencies that manifest the variables involved.	Develop arguments in a clear way to explain the operation of a system, fully incorporating the relevant principles or laws of engineering and sciences, correctly supporting the description of the dependencies manifested by the variables involved.	Elaborates arguments in an imprecise way to explain the functioning of a system, adequately incorporating basic principles or laws of engineering and science, appropriately supporting the description of the dependencies manifested by the variables involved.	Elaborates arguments in a confusing way to explain the functioning of a system, inadequately incorporating irrelevant principles or laws of engineering and science, and inappropriately supporting the description of the dependencies manifested by the variables involved.
SIIT0302 Decision Making	Comprehensively generates proposals for solutions to complex problems, consistent with a previous essential analysis, in which it systematically incorporates relevant principles of engineering and sciences	Correctly generates proposals for solutions to complex problems, consistent with a prior essential analysis, and appropriately incorporates relevant principles of engineering and science.	Generates, in a limited way, proposals for solutions to complex problems, imprecisely applying a prior essential analysis, incorporating, in a disjointed way, pertinent principles of engineering and science.	Improperly generates proposals for solutions to complex problems, inadequately applying a previous analysis, in which it does not incorporate relevant principles of engineering and science, or does not incorporate them.

The original activity proposed in this course was a challenge in which students analyzed and physically prototyped an automobile steering system based on a rack-and-pinion mechanism. Teams studied the mechanism's components and their reversibility, then focused on converting steering-wheel angular displacement into rack translation and, through linkages, into wheel steering angles relative to a global chassis reference frame (Figure 1).

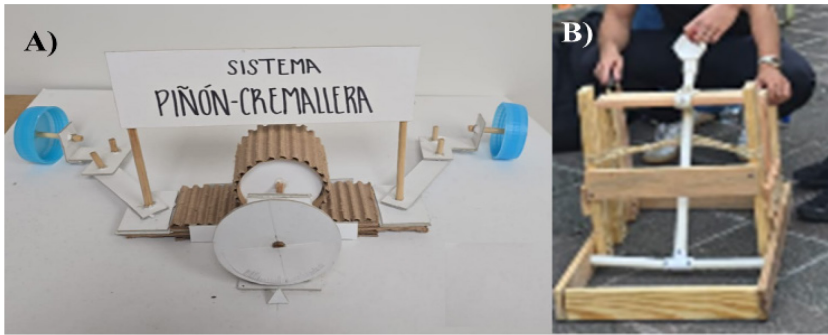


Figure 1. Prototypes of a rack and pinion mechanism (A) and a catapult (B).

This activity was difficult to build, covered a narrower range of course content, and was more challenging to model mathematically. Additionally, the development and assessment of the SIIT0101 competence related to explaining system operation proved particularly difficult for students. Because of this, we proposed a competition in which teams design and build a medieval-inspired catapult (torsion- or trebuchet-like) and develop a computational interface to estimate and visualize the projectile trajectory, accounting for aerodynamic drag. Students investigate the mechanisms and design parameters, construct a device within specified dimensional constraints, and conduct controlled launches using standardized projectiles. Then, experimental motion data is captured using video analysis software (Tracker) to extract two-dimensional kinematic variables (position, velocity), which are then used to calibrate and validate predictive models. Performance was evaluated based on accuracy by minimizing the cumulative error in hitting three predefined targets: (i) a ground target at 3 m, (ii) a ground target at 5 m, and (iii) an elevated target located 5 m away and 1 meter above the ground. The competition structure progresses from intragroup qualifiers to an intergroup final round, with performance evaluated on precision and range across multiple targets at varying distances and elevations. Teams iteratively refine the mechanical system and the mathematical model, first implementing Euler's method in spreadsheet form under laminar drag assumptions and later implementing a MATLAB simulation under laminar drag assumptions, tuning drag coefficients using experimental evidence. Requiring repeated comparison between simulated and observed trajectories, supported by graphical and time-based outputs, the challenge frames modeling not as an abstract exercise, but as a decision-driving tool for design, optimization, and competitive strategy.

To understand the impact of the new challenge, an author-developed questionnaire was administered to assess students' satisfaction and perceptions. The survey asks students to rate:

1. Their general experience.
2. How effective the activity was for understanding projectile motion,
3. ...air resistance or friction,

4. ...Newton's Laws, and
5. ...overall physics content.
6. Whether they applied knowledge from mathematics, and
7. ...numerical methods.
8. How effective was the activity in understanding how to model projectile motion?
9. The usefulness of the tracker, and
10. ...MATLAB software.
11. How well did the catapult activity allow them to compare real phenomena with theory?
12. ...learning teamwork (12).

They also rate how effective this catapult activity was at developing the SIIT0101 and SIIT0302 competencies. This survey was completed by 31 of 61 students in Fall 2025. We finally present the results, the final competency evaluation, and the final grades for students participating in the new challenge. The data was analyzed in a quantitative, descriptive, and qualitative manner, under an inquisitive approach (Lincoln & Guba, 2025) and compared with the paradigm knowledge-understanding described by Ritchhart (2015, p 47-50).

3. Results

Our first result is that the difference between the means of students' assessments of teaching for both challenges was not statistically significant ($p\text{-value} = 0.762$). In Figure 2, we present condensed results from the students' questionnaire responses after the catapult challenge.

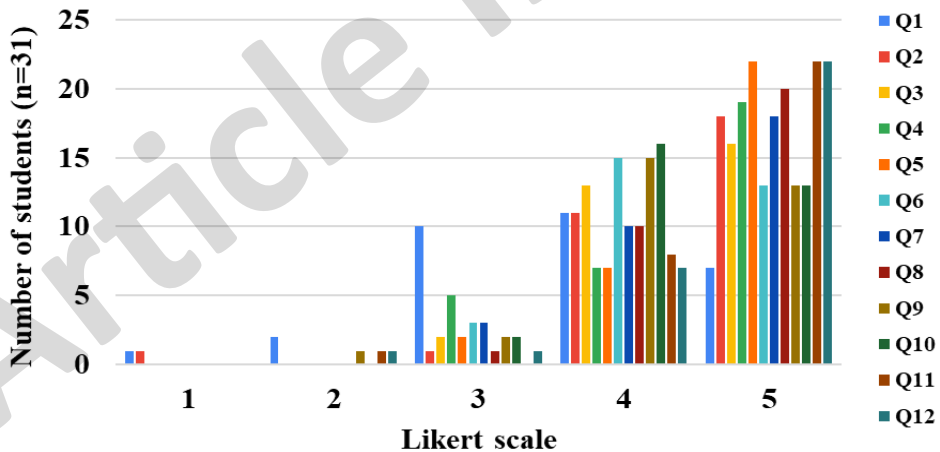


Figure 2. Averages of the Likert scale for the survey administered to students after the catapult challenge. Each image number corresponds to the numbers appearing in Section 2.

As observed, students rated their general experience with 3–4, while the dominant pattern is a concentration of responses at the high levels (4 and 5) of the Likert scale for the remaining questions.

Regarding students' perceptions of competencies development, Figure 3 shows that students feel they have developed the class skills.

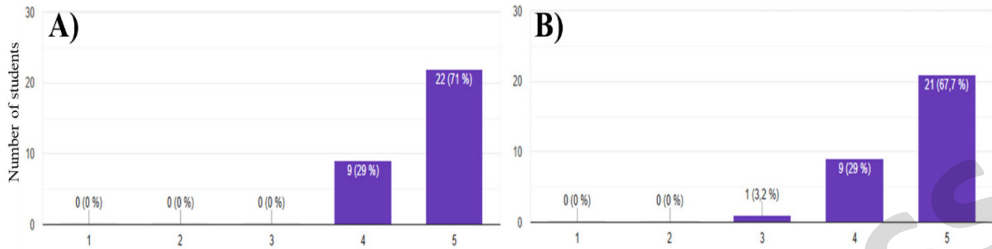


Figure 3. Answer to the questions: How effective was this catapult activity in developing the competency SIIT0101? (A), and how effective was this catapult activity in developing the SIIT0302 competency? (B).

In their open-ended responses, students suggested ways to improve their performance in the challenge, focusing on planning, testing, and design. Some emphasized the need for better preparation and more launch trials, saying they would “carry out more tests,” “practice before the competition.” Others mentioned improving equipment, such as creating “a better launch base,” “a better rocket,” or “a better catapult design,” and using other materials. Suggestions include improving communication and providing closer follow-up on the team's progress to ensure balanced and equitable teamwork. As students understand the challenge, they can explain what failed in their learning.

As observed in Figure 4, most students showed solid development of competencies (as evaluated by the teacher), especially in SIIT0101, which was consistent with their perceptions.

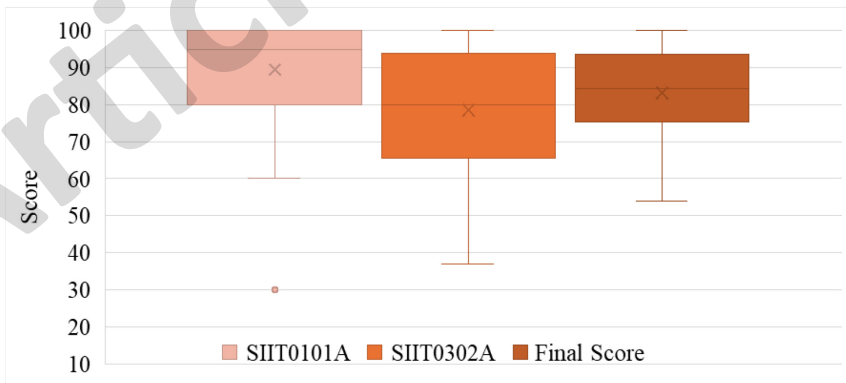


Figure 4. Average score of competencies and the course (n=61)

4. Discussion

The distinction between the knowledge and understanding paradigms emphasizes the design of learning models that promote deep understanding and critical thinking in engineering education. In our case, the first challenge was more complex to understand, and students only made informed decisions based on their knowledge to complete the activity. There was no evidence of learning. The catapult challenge motivated students to think about improving their performance in the competition.

In the current digital context, and particularly with the growing presence of artificial intelligence in engineering practice and education, fostering deep disciplinary understanding, model validation, and evidence-based decision-making has become increasingly critical. The transition from the rack-and-pinion steering challenge to the catapult-based challenge represents a pedagogical improvement that enhances curricular alignment, supports the development of scientific thinking, and provides a scalable framework for competency-based learning in early engineering education.

A more rigorous analysis would examine whether the use of Tracker and numerical modeling in MATLAB may impose cognitive load on first-semester students, potentially favoring procedural knowledge over the deep understanding associated with learning, as described by Ritchhart (2015). From this perspective, it would be relevant to consider how pedagogical scaffolding could be adjusted to better support students' progressive conceptual integration and the development of modeling competence.

In conclusion, the results indicate high levels of engagement and a positive perception of the development of the SIIT0101 and SIIT0302 sub-competencies. It would be appropriate to refine future educational intervention proposals to ensure that technological tools serve as catalysts for deep conceptual understanding and enrich the overall experience for engineering students.

References

- Adeoye, M. A., & Jimoh, H. A. (2023). Problem-Solving Skills Among 21st-Century Learners Toward Creativity and Innovation Ideas. *Thinking Skills and Creativity Journal*, 6(1), 52-58. <https://doi.org/10.23887/tscj.v6i1.62708>
- Boelt, A. M., Kolmos, A., & Holgaard, J. E. (2022). Literature review of students' perceptions of generic competence development in problem-based learning in engineering education. *European Journal of Engineering Education*, 47(6), 1399-1420. <https://doi.org/10.1080/03043797.2022.2074819>
- Cosme, N., Hauschild, M. Z., Molin, C., Rosenbaum, R. K., & Laurent, A. (2019). Learning-by-doing: Experience from 20 years of teaching LCA to future engineers. *The International Journal of Life Cycle Assessment*, 24(3), 553-565. <https://doi.org/10.1007/s11367-018-1457-5>

- Crawley, E. F., Malmqvist, J., Östlund, S., & Brodeur, D. R. (Eds.). (2007). Overview. En *Rethinking Engineering Education: The CDIO Approach* (pp. 6-44). Springer US. https://doi.org/10.1007/978-0-387-38290-6_2
- Forcael, E., Garcés, G., & Lantada, A. D. (2023). Convergence of Educational Paradigms into Engineering Education 5.0. 2023 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC), 1-8. <https://doi.org/10.1109/WEEF-GEDC59520.2023.10344026>
- Frache, G., Nistazakis, H. E., & Tombras, G. S. (2017). Reengineering engineering education: Developing a constructively aligned learning-by-doing pedagogical model for 21st century education. 2017 IEEE Global Engineering Education Conference (EDUCON), 1119-1124. <https://doi.org/10.1109/EDUCON.2017.7942989>
- Frache, G., Tombras, G. S., Nistazakis, H. E., & Thompson, N. (2019). Pedagogical Approaches to 21st Century Learning: A Model to Prepare Learners for 21st Century Competencies and Skills in Engineering. 2019 IEEE Global Engineering Education Conference (EDUCON), 711-717. <https://doi.org/10.1109/EDUCON.2019.8725214>
- Fromm, E. (2003). The Changing Engineering Educational Paradigm. *Journal of Engineering Education*, 92(2), 113-121. <https://doi.org/10.1002/j.2168-9830.2003.tb00749.x>
- Hernández-de-Menéndez, M., Vallejo Guevara, A., Tudón Martínez, J. C., Hernández Alcántara, D., & Morales-Menendez, R. (2019). Active learning in engineering education. A review of fundamentals, best practices and experiences. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 13(3), 909-922. <https://doi.org/10.1007/s12008-019-00557-8>
- Hernández-Sabaté, A., Albarracín, L., Ramos, O., Gil, D., Sánchez, C., & Martí, E. (2024). From traditional teaching to flipped classroom: Impact on learning in engineering degrees. *Journal of Technology and Science Education*, 14(3), 798. <https://doi.org/10.3926/jotse.2623>
- Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J.-M., Ramírez-Montoya, M.-S., Navarro-Tuch, S. A., Bustamante-Bello, M.-R., Rosas-Fernández, J.-B., & Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers & Electrical Engineering*, 93, 107278. <https://doi.org/10.1016/j.compeleceng.2021.107278>
- Pardo Regueiro, J. M., De Los Ángeles Constantino-González, M., López, O. O., Ángel López Mariño, M., Heredia, A. S., & Rubio Názer, F. (2023). Competences development and significative learning through engineering design competition. 2023 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC), 1-6. <https://doi.org/10.1109/WEEF-GEDC59520.2023.10343685>
- Ritchhart, R. (2015). *Creating cultures of thinking: The 8 forces we must master to truly transform our schools*. Jossey-Bass, a Wiley brand.
- Santana, A. L. M., & de Deus Lopes, R. (2024). Using Real-World Problems and Project-Based Learning for Future Skill Development: An Approach to Connect Higher Education Students and Society Through User-Centered Design. En U.-D. Ehlers & L. Eigbrecht (Eds.), *Creating the University of the Future: A Global View on Future Skills and Future Higher Education* (pp. 393-417). Springer Fachmedien. https://doi.org/10.1007/978-3-658-42948-5_20

- Segalàs, J., Ferrer-Balas, D., & Mulder, K. F. (2010). What do engineering students learn in sustainability courses? The effect of the pedagogical approach. *Journal of Cleaner Production*, 18(3), 275-284. <https://doi.org/10.1016/j.jclepro.2009.09.012>
- Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J.-M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence*, 11(3), 54. <https://doi.org/10.3390/jintelligence11030054>
- van den Beemt, A., Vázquez-Villegas, P., Gómez Puente, S., O’Riordan, F., Gormley, C., Chiang, F.-K., Leng, C., Caratozzolo, P., Zavala, G., & Membrillo-Hernández, J. (2023). Taking the Challenge: An Exploratory Study of the Challenge-Based Learning Context in Higher Education Institutions across Three Different Continents. *Education Sciences*, 13(3), Article 3. <https://doi.org/10.3390/educsci13030234>