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Implementation of 3D printing as a didactic tool for problem solving of engineering systems and devices

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This study explored the impact of 3D printing as an educational tool for engineering systems and device instruction with students of Tecnologico de Monterrey, Campus Toluca, implemented during the August–December 2023 semester. This initiative was integrated into two courses: Modeling Motion in Engineering and Application of Conservation Laws in Engineering Systems. The same group of students (three experimental groups, 73 students; two control groups, 57 students) participated throughout the study. Experimental groups incorporated 3D printing into their challenge-based learning experience, requiring prototypes developed with this technology. In contrast, control groups utilized traditional methods for prototyping, excluding 3D printing. The study evaluated how this integration affects the quality of students' proposed solutions and their attitudes toward problem-solving within a challenge-based learning framework. The assessment employed the Attitudes and Approaches to Problem-Solving Survey, with pre-surveys administered at the study's onset and post-surveys conducted at its conclusion. Results were analyzed to track shifts in problem-solving attitudes over time. This research provides insights into the effectiveness of emerging technologies, such as 3D printing, in fostering innovation and enhancing engineering education, providing a basis for broader application in academic settings.

KEYWORDS

3D printing, CBL, problem-solving, prototyping, engineering systems, engineering devices

1 Introduction

Engineering education has undergone a significant transformation in recent decades, driven by technological advancements and evolving industrial demands. Universities are no longer limited to transmitting theoretical knowledge; they aim to train professionals capable of solving complex problems, collaborating effectively, and adapting to rapidly changing environments. Within this context, the integration of emerging technologies in the classroom—such as additive manufacturing (3D printing), augmented reality (AR), and virtual reality (VR)—has gained increasing relevance, not only due to their potential to enhance learning, but also because of their capacity to tangibly and meaningfully bridge theory and practice (Motyl and Filippi, 2021; Trust et al., 2021; Ilanković et al., 2025).

This shift also aligns with the characteristics of newer students, who have grown up in digital environments and strongly prefer visual, interactive, and hands-on learning approaches (Bower et al., 2014; Ilanković et al., 2025). In this context, it becomes increasingly necessary to rethink traditional instructional strategies by adopting more active, technology-driven, and student-centered approaches that foster motivation, conceptual understanding, and the development of key competencies in engineering.

3D printing (3DP), or additive manufacturing, has become a valuable pedagogical tool with strong potential to transform engineering education. Its ability to convert digital designs into physical objects allows students to materialize ideas, validate prototypes, and grasp abstract concepts through tangible interaction, strengthening the connection between theory and practice (Ford and Minshall, 2019; Munir et al., 2025). In educational contexts, 3DP has been applied across various environments, including universities, primary schools, and special education programs, and has shown particular relevance in STEM fields (Science, Technology, Engineering, and Mathematics) (Pearson and Dubé, 2022). In our educational context, 3DP supported student learning by enabling the creation of physical models and allowing students to engage in tangible experimentation and validation of their designs. Specifically, students tested mechanical functionality, evaluated assembly processes, verified dimensional accuracy, and analyzed the feasibility of their prototypes in response to real-world constraints. These hands-on activities required students to modify their designs iteratively, reflect on errors, and collaborate with peers, fostering the development of critical thinking, creativity, and problem-solving skills essential in engineering practice.

Numerous studies have documented that using 3D models improves spatial visualization, accuracy in mechanical systems analysis, student motivation, and overall learning efficiency (Trust et al., 2018; Ilanković et al., 2025). Moreover, its application promotes essential skills such as critical thinking, creativity, collaboration, and user-centered design (Trust et al., 2018; Kefalis et al., 2024). In higher education, 3DP has frequently been integrated into project-based learning (PBL) methodologies, where students develop functional prototypes to address real-world problems (Arvanitidi et al., 2019). Furthermore, the pedagogical benefits of 3DP extend beyond technical understanding. In a 10-week anatomy course, second-year students from Medicine and Biomedical Sciences designed and printed 3D models of human anatomy (e.g., foot bones and the brain's ventricular system), enhancing their engagement and active learning by assembling the parts using magnets—a process that mimics medical procedures and reinforces spatial understanding (Henssen et al., 2025). In architecture education for young children, 3DP has also been shown to significantly boost creativity, confidence, spatial reasoning, and collaboration, bridging the gap between imagination and tangible outcomes (Sultan Qurraie et al., 2025). Additionally, a study involving pre-service teachers demonstrated that integrating 3D printing into a college-level mathematics course enhanced their understanding of geometric and measurement concepts, increased their confidence with technology, and deepened their awareness of real-world applications of STEM content (Ching et al., 2025).

Additionally, 3DP offers sustainability benefits through its efficient use of materials, which is especially relevant in educational approaches focused on eco-friendly design (Gatto et al., 2015; Stavropoulos, 2023). The early implementation of this technology in engineering programs enables students to engage with tools used in professional practice, strengthening their ability to make informed decisions about their academic and career pathways (Keaveney and Dowling, 2018; Motyl and Filippi, 2021).

Active learning methodologies such as PBL or challenge-based learning (CBL) have gained prominence in engineering education, enabling students to develop complex skills through inquiry, investigation, and resolving authentic problems. These approaches are particularly effective when combined with emerging technologies—such as 3DP, artificial intelligence (AI), or AR—since they enhance student engagement in meaningful and practice-based learning contexts (Arici and Yilmaz, 2023; Coelho et al., 2024).

Recent studies have demonstrated that combining CBL with technologies like 3DP allows students to acquire procedural knowledge while solving real-world challenges through scientific and design-based reasoning (Mo and Tang, 2017; Lara-Prieto et al., 2023). Moreover, studies conducted in developing countries such as Vietnam have revealed that integrating 3DP into engineering education fosters creativity, problem-solving skills, and technical proficiency among students, even in resource-constrained environments. Despite obstacles such as high material costs and misaligned curricula, students and faculty highlighted the value of 3DP in advancing education and sustainable development goals (Tuan et al., 2024). A systematic review covering 85 studies across 14 disciplines in surgical education reported high satisfaction rates with 3D-printed models, emphasizing their accuracy, customizability, and value in simulation-based learning for complex procedures (Taritsa et al., 2024).

Within the TEC21 educational model—which organizes learning around interdisciplinary challenges in collaborative environments—it has been observed that many first-semester students face difficulties in proposing technically sound solutions. In particular, there is a tendency to rely on traditional manufacturing strategies, resulting in prototypes often being unoriginal and overly similar to those provided by instructors. While the delivery of low-quality prototypes is one of the most visible manifestations of this issue, it reflects a broader challenge: the lack of essential problem-solving skills, analytical thinking, creativity, and synthesis among early-stage engineering students (Membrillo-Hernández et al., 2021). This situation highlights the need to design educational strategies that foster technical knowledge and promote critical thinking, autonomy, and the ability to generate innovative solutions in real-world contexts.

Even when working under frameworks like PBL or CBL, first-year students frequently lack knowledge of manufacturing processes, affecting their deliverables' quality. As identified by Lin et al. (2018), 3D modeling and other computer-aided design (CAD) tools alone may be insufficient for students to assess the feasibility of their ideas, thereby reinforcing the need for tools that enable tangible experimentation with designs.

To evaluate the impact of this intervention on students' attitudes and approaches to problem-solving, the "Attitudes and Approaches to Problem Solving" (AAPS) instrument was employed (Mason and Singh, 2010). This tool has been widely validated in physics and engineering education contexts (Mason and Singh, 2016). It provides a reliable means of identifying levels of expertise in how students approach complex problems. AAPS has proven effective in detecting significant differences in attitudes between novice and expert learners, including aspects such as metacognition, planning, graphical representations, and self-reflection.

Its application in this study allows for assessing whether the adopted pedagogical approach facilitates a shift toward more expert-like behaviors, such as reflective analysis, strategic diversity, and autonomous decision-making. As such, AAPS serves as a learning assessment tool and a guide for instructional improvement.

Despite growing interest in integrating emerging technologies in engineering education, important gaps remain in the literature.

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Specifically, few empirical studies explore how 3DP impacts the quality of first-year student projects in Latin American contexts. Likewise, there is a lack of research documenting the combined use of CBL and 3DP and their influence on the development of problem-solving skills as assessed by instruments like AAPS.

This study aims to close this gap by analyzing an educational experience focused on integrating 3DP into an interdisciplinary challenge in the first semester of engineering programs. The main objective is to evaluate how this integration affects the quality of students' proposed solutions and their attitudes toward problem-solving within a CBL framework. From the above, some aims emerge, such as analyzing the differences in attitudes and problem-solving approaches between students who used 3DP and those who used traditional prototyping methods. To assess whether hands-on experience with 3DP fosters expert problem-solving attitudes, such as flexibility, autonomy, persistence, and alternative approaches.

Pursuing the aims enunciated above, the following research questions (RQ) arise:

> *RQ1.* Are there overall or individual differences in the attitudes and problem-solving approaches for students who use 3D printing instead of the traditional prototyping methods?
>
> *RQ2.* Are there differences in individual problem-solving attitudes for students who use 3D printing instead of the traditional methods?
>
> *RQ3.* What are the most improved individual attitudes toward 3D printing?

2 Methodology

The current study was conducted at the professional level at Tecnologico de Monterrey, Campus Toluca, during the August–December 2023 semester (Figure 1). The course *Modelling Motion in Engineering (F1006B)* lasts 5 weeks, and the course *Application of Conservation Laws in Engineering Systems (F1007B)* also lasts 5 weeks. Both courses had a total of five groups, subdivided into two control groups with 57 students and three experimental groups with 73 students. The same students and instructors participated in both courses, applying identical evaluation criteria, activities, and assignments.

The experimental groups were assigned the task of utilizing 3D printers—specifically the Ender 3 Max, Ender-3 V3 SE, and CR-10 Smart Pro models, all manufactured by Creality—to develop prototype solutions in response to challenges framed within a CBL context. In contrast, 3D models could either be sourced from existing digital libraries or created independently using computer-aided design (CAD) software such as SolidWorks or AutoCAD.

Conversely, the control groups were permitted to employ any construction techniques for their prototypes, with the exception of 3D printing. Table 1 outlines the materials employed in the fabrication of the final prototypes. Notably, the control groups utilized a broader range of materials, primarily due to their emphasis on manual design and assembly processes.

The first course centered on the design and construction of a trebuchet-style catapult. While the experimental groups employed 3D modeling and printing techniques, the control groups relied on traditional methods, including hand sketching, manual cutting, and physical assembly using the materials listed in Table 1. In the second course, the focus shifted to the development of a water-powered rocket prototype. Key components such as the rocket nose cone, fuselage, and ailerons—critical to aerodynamic performance—were fabricated using both 3D printing and conventional construction methods, depending on the group.

One of the evaluation instruments used was the AAPS. A pre-AAPS survey was administered at the beginning of the 7th week, and a post-AAPS survey was conducted at the beginning of the 17th week to measure changes in students' attitudes and approaches to problem-solving over time. The Cronbach's alpha for this instrument

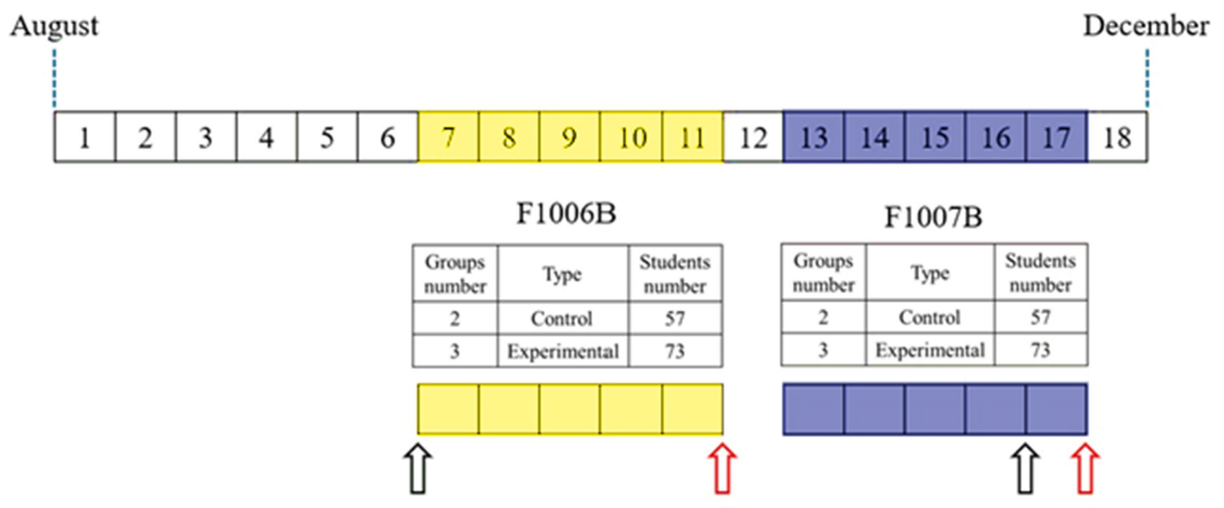

FIGURE 1
Flowchart of the project implementation. The August–December semester is split into the 18 weeks labeled above. Arrows indicate the application of the pre and post-surveys, respectively.

TABLE 1 Materials commonly used, with the exception of the 3D printer, for control and experimental groups.

Control group	Experimental group
1. Wood 2. Screws 3. Nuts 4. Wires 5. Cardboard 6. Styrofoam 7. Clay 8. Glue 9. Wrench keys 10. Hammers 11. Rulers 12. Pencil 13. Paper	14.Filament of Polylactic Acid (PLA)

was determined to be 0.82, which is considered reasonable for test-design standards (Mason and Singh, 2010). This survey explores students' attitudes, perceptions, and approaches to problem-solving in various contexts.

The AAPS instrument was translated into Spanish and validated through the forward- and backward-methods (Maneesriwongul and Dixon, 2004; Takriti et al., 2024). In brief, a single English professional with a C1 certification carried out the initial translation from English to Spanish. The translated version was then reviewed and refined in collaboration with a professor experienced in education research. Finally, the revised questionnaire was evaluated by the group of professors who teach the course in which the study was conducted, in order to identify and resolve any discrepancies. The full questionnaire was administered as an electronic form, maintaining the same wording and order of questions.

For clarity, an item of the AAPS instrument (Mason and Singh, 2010) can be exemplified as follows: To what extent do you agree with each of the following statements when you solve physics problems?

15 If I'm not sure about the right way to start a problem. I'm stuck unless I go see the teacher/TA or someone else for help.
16 (A) Strongly Agree. (B) Agree Somewhat. (C) Neutral or Do not Know. (D) Disagree Somewhat. (E) Strongly Disagree.

As indicated in the AAPS instrument, scores were calculated by assigning +1 (A, B) for each favorable response, −1 (D, E) for each unfavorable response, and 0 for neutral responses (C) (Mason and Singh, 2010). The average scores were calculated for each student in the pre-test and post-test. Then, these averages were used to determine the class average at each point. Changes in scores were analyzed to evaluate the course's impact on students' attitudes and approaches to problem-solving.

A second evaluation was made consisting of an oral presentation of the Trebuchet-type catapult and water-powered rocket, respectively, made by the students in teams of 4 to 5 team members. Finally, students presented an introduction, objectives, employed methodology, relevant results and discussion, conclusion, and future work. All the instructors employed the same evaluation criteria, and the assigned scores were part of their final grade for each course (F1006B and F1007B).

3 Results and discussion

3.1 General results

The results of the prototyping activities are shown below. Figure 2 shows a comparison between the experimental and the control group's final prototypes of the trebuchet style catapult and the water-powered rocket. The contrast between using 3D print clearly demonstrates professionalism while the traditional methods illustrate improvements that can be made to look more professional which is in accordance with previous results indicating that 3D printed models have a better quality comparing who those constructed by hand (Greenhalgh, 2016). On both cases, the functionality was achieved showing development through problem solving.

To answer RQ1, an analysis of the overall results is reported. As evidenced by the results obtained after evaluating the instrument, shown in Table 2, the differences between the experimental and control groups are insignificant. Despite similar pre- and post-survey average scores in both groups, the control group showed a more significant improvement than the experimental group, with a difference of 0.09641. This finding suggests that other factors contributed to improving problem-solving attitudes and approaches in the control group. Introductory-level students typically have an average score of 0.33 (Mason and Singh, 2010). Thus, that value was improved by our first-semester students from the School of Engineering and Sciences at the Toluca Campus. In particular, the experimental group exhibited higher scores in the pre-survey of about 0.40419, whereas the control group in the post-survey had 0.46005 (See Table 2). Although the experimental and control groups showed improvements in their average scores between the pre- and post-surveys, there was no significant difference between them. This result contrasts the literature, pointing that 3D printing of a CO_2-car engineering design showed noticeable difference in creativity, learning process and race outcome in comparison with those handmade cars (Chien and Chu, 2018). This suggests that the course did not have a differential impact on attitudes and approaches to problem-solving between the two groups. RQ1 will be revisited regarding groups and individuals in the latest subsection.

Furthermore, when analyzing the post-survey scores between the control (mean = 0.460 and standard deviation = 0.199) and experimental (mean = 0.42 and standard deviation = 0.207) groups using an independent two-sample t-test, no statistically significant difference was found (T-value = 0.83, p-value = 0.414). The 95% confidence interval for the difference in means ranges from −0.059 to 0.14, indicating that the perceptions of both groups were statistically similar after the intervention. This result supports the idea that the intervention did not significantly enhance or worsen students' problem-solving attitudes based on group assignments.

Prior to conducting the t-test, normality of the distributions was assessed using the Anderson–Darling test. Although the control group showed a slight deviation from normality ($p = 0.012$), the sample sizes for the control group ($n = 22$) and the experimental group ($n = 71$) support the robustness of the t-test to such deviations. To complement the statistical significance, the effect size (Cohen's d) was calculated as 0.2, which is considered a small effect size. This suggests that, beyond the lack of statistical significance, the intervention had only a minimal practical impact on students' problem-solving attitudes based on group assignments.

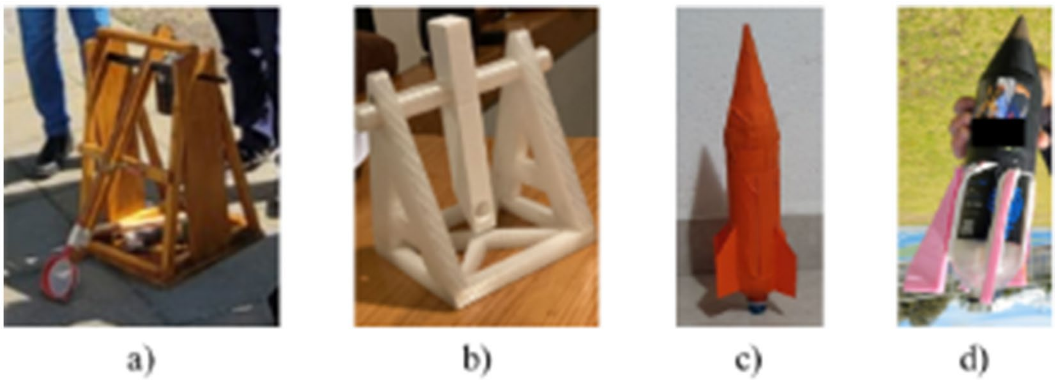

FIGURE 2
Comparison between traditional construction methods compared to the usage of 3D printing. Panel **(a)** and **(b)** Trebuchet style catapult. Panel **(c)** and **(d)** water-powered rocket.

TABLE 2 Results of the AAPS survey.

Group	Average score Pre-survey	Average score Post-survey	Difference
Experimental	0.40419 ± 0.1928	0.41965 ± 0.2068	0.01545
Control	0.36363 ± 0.1923	0.46005 ± 0.1991	0.09641

Additionally, to validate whether the observed differences between the pre- and post-survey scores were statistically significant, a paired t-test was performed using Minitab. The results showed no statistically significant difference between the pre-survey scores (mean = 0.427 and standard deviation = 0.2047) and the post-survey scores (mean = 0.3939 and standard deviation = 0.1924), with T-value = −1.77 and p-value = 0.081. This reinforces the previous observation that, despite slight changes in the mean scores, the intervention did not lead to a statistically significant change in students' problem-solving attitudes over time.

On the other hand, to analyze the diversity of items in the AAPS survey in the context of the RQ2, Figure 3 shows the average scores per question for the pre-survey. It can be observed that the experimental groups achieved higher scores in the case of several items (1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 24, 25, 26, 27, 29, 30, and 31, 33). As expected, this aligns with the information presented in Table 2.

In Figure 4, the average scores per question for the post-survey can be observed where the control groups' scores are higher, as confirmed by the data in Table 3. In this case, the experimental group obtained higher scores only in a reduced set of items (8, 9, 23, 24, 28, 30, 31, 33). Although the control group had a higher proportion of students who improved their results between the pre- and post-surveys compared to the experimental group, it is still important to note that a considerable percentage of students in both groups showed improvements in their attitudes and approaches to problem-solving. Also, these results suggest that the control group improved significantly in understanding and applying physical principles, adopting conceptual approaches, and reflecting on their problem-solving processes. However, according to the corresponding items, both groups improved on questions related to approximation, error awareness, and exploring different approaches, reflecting general progress in problem-solving skills.

3.1.1 Insights from improved AAPS items in the experimental groups

To further understand the observed benefits of 3D printing on students' problem-solving attitudes, a deeper analysis was conducted focusing on the AAPS items in which the experimental groups showed improvement. The following items showed meaningful gains: 1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 19, 21, 22, 23, 24, 25, 28, 29, 30, 31, 32, and 33. Rather than listing each item individually, the questions were grouped into thematic categories based on the skills or attitudes they assess. The following Table 3. Summarizes the grouped AAPS items, their focus, and the associated educational benefit observed when using 3D printing in physics-based learning environments.

This thematic grouping highlights how 3D printing supports the development of multiple interrelated skills, including conceptual reasoning, strategic thinking, collaboration, and persistence. By engaging students in hands-on prototyping activities, 3DP fosters meaningful learning experiences that go beyond quantitative score improvements. The observed cognitive gains suggest a shift toward expert-like attitudes and behaviors in physics problem-solving, reinforcing the value of integrating emerging technologies into engineering education.

3.2 Analysis of relevant items

To highlight the improvement achieved through 3DP and to answer RQ3, the following analysis relies on the selected items previously identified. In item 8, "There is usually only one correct way to solve a given problem in physics," the experimental group students disagreed more (0.31) than those in the control group. Thus, it is possible to assume that the students, through 3DP, noticed that the problems in physics can be turned into other ones by the advanced manufacturing technique proposed. Consequently, they assumed that there were several ways to solve a given problem in physics. Similarly, there is a minimal improvement of about 0.02 in the manner in which the students of the experimental group face the linear conservation problems. The above is due to the answers obtained for item 9, "I use

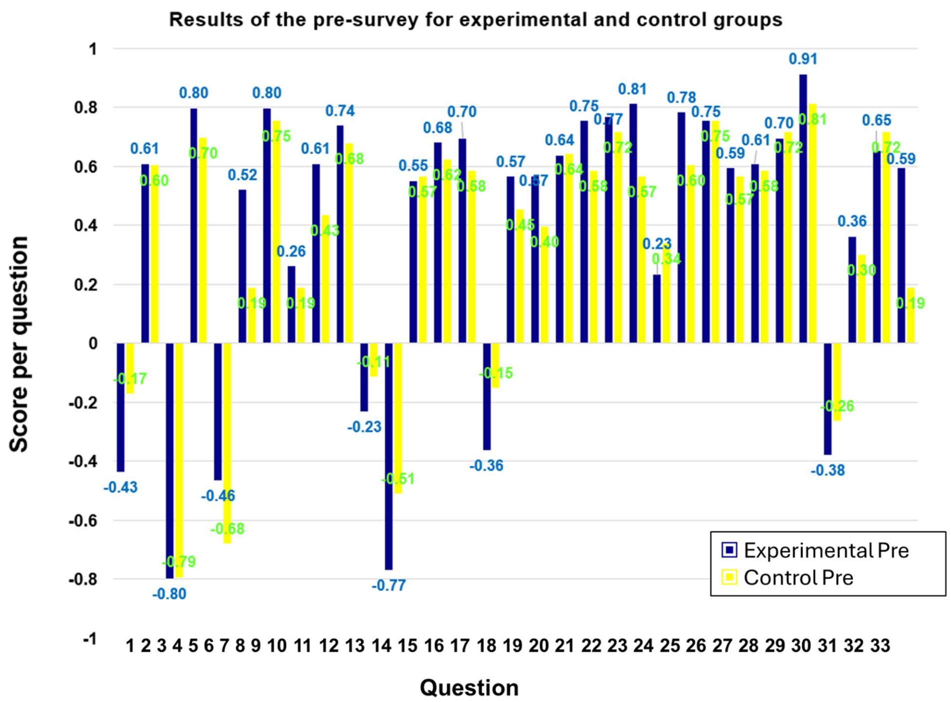

FIGURE 3
Pre-survey results for experimental and control groups.

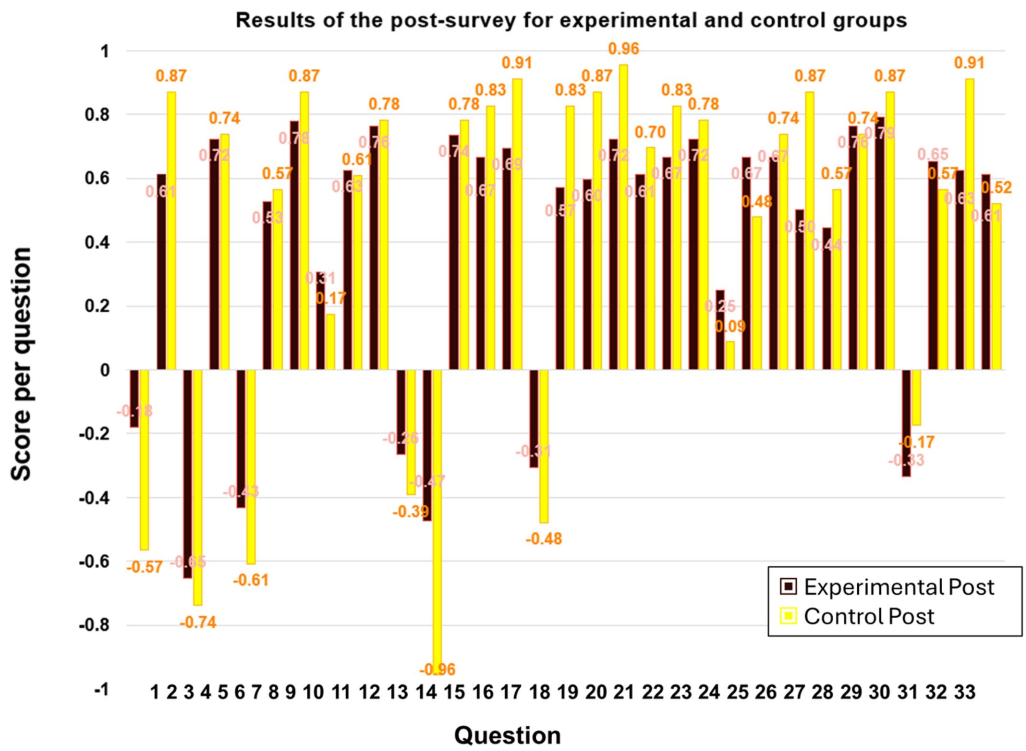

FIGURE 4
Post-survey results for experimental and control groups.

a similar approach to solving all problems involving conservation of linear momentum even if the physical situations given in the problems are very different." It can be noticed that the flexibility gained by the 3DP is also applicable in contexts beyond the

TABLE 3 Summary of the skill and attitudes, analyzed through the AAPS items listed, as well as their benefits expected.

Skill/Attitude category	AAPS items	Benefit of 3D printing in physics learning
Conceptual understanding and principle-based reasoning	2, 4, 7, 10, 12, 14, 21	Encourages students to focus on the underlying physics principles before applying formulas, fostering deep understanding and reducing superficial or purely algorithmic approaches.
Real-world modeling and physical reasoning	2, 5, 6, 22, 29	Promotes the use of approximations and assumptions necessary for translating physical phenomena into functional prototypes, while also strengthening error analysis and model refinement.
Strategic thinking and metacognition	1, 6, 13, 22, 23, 25, 29	Supports the development of self-monitoring and self-correction skills, enabling students to reflect on their problem-solving processes and persist through iterative testing and failure.
Visual representation and symbolic reasoning	15, 17, 18, 19, 31	Reinforces the importance of drawing diagrams and solving problems symbolically before computation, which aligns naturally with the CAD design and 3D printing workflow.
Flexibility and multiple-solution thinking	8, 9, 13, 28, 33	Encourages students to explore diverse approaches to problem solving and recognize that the same principle can be applied in varied ways, supported by the freedom in prototype design.
Collaboration and peer learning	24, 25	Facilitates cooperative problem solving, as 3D projects are often team-based and require discussion, revision, and joint decision-making.
Persistence and enjoyment of challenge	23, 26, 27	Builds resilience by engaging students in trial-and-error design cycles, making them more comfortable with difficulty and more confident in facing complex problems.

prototyping phase of the projects since the physics problems involving conservation are harder to learn due to their more abstract nature. However, it is also important to mention that the control group improved from 0.43 to 0.61 using traditional prototyping techniques. All the above agree with the difference reported in the case of item 28, "I try different approaches if one approach does not work." In this case, the experimental group overcomes the control one by 0.02. Once again, the flexibility of thinking can be extended to the famous Samuel Beckett's quote, "Try again, fail again, fail better." Even in the educational framework, the improvement achieved using small steps can be encouraged to the students using flexible manufacturing techniques such as 3DP. Another question related to the performance to face the problems through alternative approaches is the 33, "Suppose you are given two problems. One problem is about a block sliding down an inclined plane. There is friction between the block and the incline. The other problem is about a person swinging on a rope. There is air resistance between the person and air molecules. You are told that both problems can be solved using the concept of conservation of total, not just mechanical, energy. Which one of the following statements do you MOST agree with? Choose only one answer." As in the previous ones, the experimental group obtained greater values than the control one, of about 0.61 and 0.52, respectively.

Another important achievement found in the current proposal is persistence and resilience to face problem-solving situations. In the case of question 23, "If I cannot solve a physics problem in 10 min, I give up on that problem," a remarkable disagreement of 0.25 was obtained in the experimental group. In contrast, only 0.09 was accounted for the control one. The above tells us about the persistence needed to solve some problems. In addition, question 24, "When I have difficulty solving a physics homework problem, I like to think through the problem with a peer," reported an important improvement of 0.67 in the case of the post-test applied to the experimental group. In comparison, only 0.48 was obtained in the control group. Thus, socializing problems with the instructor, essential in creating the 3DP prototypes, can improve communication with peers and coworkers. It is pertinent to remember that the solution to a given problem can be proposed by analyzing it with another person.

In addition, the application of 3DP also positively influenced the students' perceptions regarding solutions derived through numerical and computational methods. For instance, item 30, "It is much more difficult to solve a physics problem with symbols than solving an identical problem with a numerical answer," obtained a greater disagreement in the case of the experimental group, of about −0.3. Similarly, the answers of the experimental group to question 31, "While solving a physics problem with a numerical answer, I prefer to solve the problem symbolically first and only plug in the numbers at the very end," overcame the control one by 0.65 and 0.57, respectively. These results suggest that exposure to 3DP technology and CAD tools significantly enhanced the students' perceptions regarding computationally assisted approaches for solving complex problems.

From all the above, these improvements indicate positive changes in autonomy, flexibility, understanding of concept applicability, and persistence in problem-solving by introducing 3DP-based learning.

Although the quantitative results indicate that the control group exhibited a greater overall improvement in problem-solving attitudes, a more detailed analysis revealed that the experimental group showed notable progress in specific dimensions such as autonomy, cognitive flexibility, persistence in the face of challenges, and collaborative problem-solving. These qualitative gains, while meaningful, may not have been fully captured by the global AAPS scores, highlighting the need for complementary assessment approaches that better reflect the formative impact of tools like 3D printing.

3.3 Analysis of the groups and individuals

Since the experiment was carried out in several groups with the same treatment, a complementary study was reported regarding the groups and individuals under study, revisiting RQ1. As seen in Table 4, the average scores are very similar, but there is greater improvement in the control groups, with 68% showing improved results compared to 49% in the experimental ones. Table 5 shows the results for each group, exhibiting the difference between the average pre-survey score and the average post-survey score.

According to the results in Table 5, the control groups achieved better outcomes, as the difference between the average pre-survey and post-survey scores is higher and positive. The negative value observed in experimental group 2 indicates a decline in the post-survey results. The results in Table 5 show that the differences between pre- and post-survey averages were higher in the control groups compared to the experimental groups. This suggests that the approach used in the control group may have had a more significant impact on students' attitudes and approaches to problem-solving.

To complement the analysis of group averages and percentages, Figure 5 provides a visual representation of students' individual performance in both the experimental and control groups on the pre- and post-surveys. This analysis is relevant because it allows us to observe the variability within each group and identify patterns of improvement or decline that may not be evident when analyzing only group means. As shown in Figure 5A, many students in the experimental group improved their AAPS survey results. In contrast, Figure 5B shows that most students in the control group achieved better results in the post-survey.

To determine if there is a correlation between problem-solving attitudes and academic performance, another analysis of the results involves examining the average number of students who improved and worsened in each group (see the results in Table 4). Although this analysis was not part of the initial research design, final grades were examined in an exploratory manner to analyze whether students' problem-solving attitudes were reflected in their academic performance. As seen in Table 6, the grades obtained are not

TABLE 4 The percentage of students that improved or worsened their results according to the pre- and post-AAPS survey.

Group	Pre and post-comparison	Final score	Percentage
Experimental	Worsened	0.29935	51%
Experimental	Improved	0.53598	49%
Control	Worsened	0.32900	32%
Control	Improved	0.52121	68%

TABLE 5 Comparisons of the scores obtained by all the groups.

Experimental 1	Experimental 2	Experimental 3
0.04473	−0.01910	0.00922

Control 1	Control 2
0.10245	0.18398

TABLE 6 Final grades of the experimental and control groups.

Block	Experimental 1	Experimental 2	Experimental 3	Control 1	Control 2
F1006B	80.8	90.0	83.1	82.7	82.0
F1007B	80.4	90.5	87.3	84.6	78.0

The maximum grade is set to 100.

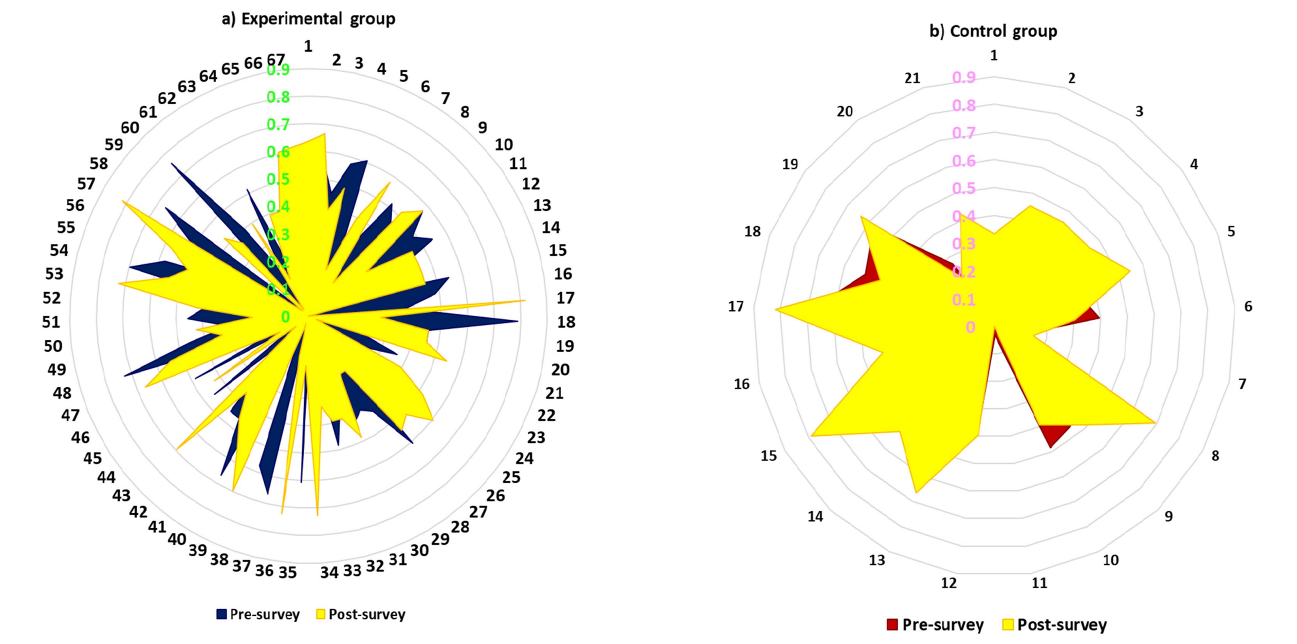

FIGURE 5
Individual performance of the students in the experimental group **(a)**, and the control one **(b)**, on the pre- and post-surveys.

correlated with the scores obtained by the AAPS survey. The results of the AAPS survey do not appear to be related to students' final grades in each course (F1006B and F1007B). It suggested that attitudes and problem-solving approaches may not predict academic grades in this specific context.

4 Limitations

1 **Access to technology:** Limited printer availability caused bottlenecks during high-demand periods.
2 **Technical training:** Training in design software and 3DP was more demanding than anticipated.
3 **Time constraints:** The iterative nature of prototype development competed with other curricular activities.
4 **Resources and maintenance:** Printer maintenance and technical issues occasionally delayed progress.

During the implementation of the 3D printing of the catapult structures and rocket parts, only 4 Creality (CR-10 Smart Pro 3D) printers were used, so the 3D printers were operating continuously during around 3 weeks attending the prototypes of around 73 students. It must be considered that the students organized work teams of a maximum of 5 members so the quantity of prototypes to be printed was around 15. It should be noticed that every prototype of the catapult was conformed for at least 5 pieces, meaning that the printing time for the whole prototype was done in more than 1 day, since every single piece was printed individually, provoking a bottleneck in the use of the available printers. It is highly recommended to consider at least 2 more printers for this purpose.

On the other hand, the professors had to teach students 3D designing for modelling basic structures in SolidWorks. It took more time than previewed causing even to give additional lessons out of the programmed classes. Having a previous workshop on 3D design modelling would be helpful before the implementation of the course that includes 3D printing.

Additionally, the students did not have only the activity of the 3D prototypes printing, but also regular academic activities, causing stress on them due to the accumulation of several tasks to be completed by students.

Finally, during the operation of the printers an issue was identified, which consisted of the PLA filament globe stuck in the deposition nozzle of the printer, causing a delay in the printing agenda of prototypes. A camera was installed on one side of the printers to observe from an application in a mobile, the progress of the printing process of parts in real time, and it immediately stopped the operation of the printer once it was identified the issue described in this paragraph.

Additionally, it is important to mention that this study was conducted following the educational research guidelines established by Tecnologico de Monterrey. Information consent was obtained from all participants, and personal data was handled in accordance with institutional confidentiality policies. The consent form used was part of a protocol previously approved by the Educational Innovation Project Committee (NOVUS), an Institute for the Future of Education initiative that promotes evidence-based educational innovation within the institution.

5 Conclusion

This study explored the integration of 3DP within the CBL environment in engineering courses at Tecnologico de Monterrey, Campus Toluca. The educational intervention focused on first-semester students enrolled in the Modeling Motion in Engineering and Application of Conservation Laws in Engineering Systems courses.

Based on the AAPS survey results, both experimental and control groups showed improvements in their problem-solving attitudes between the pre- and post-surveys; however, the average differences between groups were not statistically significant. These findings suggest that, within the short duration of this intervention, incorporating 3DP did not lead to a measurable advantage over traditional prototyping methods in terms of overall AAPS scores. In order to address this limitation, the intervention can be implemented in other physics courses from the second semester, still first year students, making a longer duration of the intervention. Additionally, other evaluation instrument to measure the used of 3DP exclusively can be added as a complimentary to the AAPS instrument.

Nevertheless, qualitative observations and item-level analyses revealed meaningful gains in specific areas for students in experimental groups. These included greater flexibility in approaching problems, improved symbolic reasoning, increased persistence in solving complex tasks, and enhanced collaboration skills fostered by the prototyping process. Such improvements, although not fully reflected in aggregated scores, are valuable outcomes that align with the competencies sought in early-stage engineering education.

The experience also highlighted relevant challenges, such as limited access to equipment, the need for additional training in 3D design, and time constraints caused by concurrent academic activities. Addressing these limitations—through better resource planning, more preparatory design workshops, and extended implementation time (second semester physics courses) —could amplify the educational benefits of integrating 3DP into similar courses. Another element to address the limitations mentioned above is to include the use of laser cutting equipment for prototyping. This will show students engagement with 3DP against other prototyping methods.

In conclusion, while the statistical results did not show significant differences between groups, the integration of 3DP enriched students' learning experiences, fostered key problem-solving behaviors, and provided insights for refining future implementations. Longer-term studies and broader applications are recommended to capture the full potential of 3DP as a didactic tool in engineering education.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

ÁM-P: Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. IJ-A: Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. AM: Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. SM: Conceptualization, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1541586/full#supplementary-material

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