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ENHANCING CIVIL ENGINEERING EDUCATION THROUGH PROJECT-BASED LEARNING: INSIGHTS FROM A NATIONAL WOODEN BRIDGE DESIGN AND CONSTRUCTION COMPETITION

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Abstract. Engineering education increasingly emphasizes active learning methodologies to enhance students' technical skills, teamwork, and problem-solving abilities. Among these, Project-Based Learning (PBL) has proven to be an effective approach, particularly in structural engineering courses. This paper presents the experiences and educational impact of a national wooden bridge design and construction competition held for students from Spanish civil engineering schools.

The competition challenges participants to conceive, design, and build a wooden bridge, fostering creativity, analytical thinking, and practical application of structural mechanics. Teams must not only optimize their designs for structural efficiency and sustainability but also manage resources and collaborate effectively—key competencies for professional engineers. The initiative aligns with PBL principles by engaging students in a real-world, hands-on project, promoting experiential learning and enhancing their understanding of material behavior, construction techniques, and structural performance assessment.

Through qualitative and quantitative analysis, this study evaluates the competition's impact on student learning, motivation, and skill development. Survey results highlight how such activities complement traditional coursework, bridging the gap between theoretical knowledge and practical application. The findings suggest that integrating similar competitions into civil engineering curricula can significantly improve student engagement and preparedness for professional challenges.

1 INTRODUCTION

The rapid transformation of the civil engineering profession—driven by technological advancements, sustainability imperatives, and increasingly interdisciplinary project environments—demands a shift in how future engineers are educated. Traditional lecture-based instruction, while foundational, often falls short in fostering the motivation, adaptability, and interpersonal skills required in modern engineering practice. To address this gap, educational institutions are increasingly turning to active learning methodologies, with Project-Based Learning (PBL) emerging as a particularly effective strategy [1].

PBL engages students in complex, open-ended problems that mirror real-world engineering challenges. By placing learners at the center of the educational experience, it fosters not only technical knowledge acquisition but also the development of soft skills such as communication, leadership, teamwork, time management, and conflict resolution. These competencies are crucial for success in professional environments, where collaboration and adaptability are as important as analytical proficiency.

Motivating students to take ownership of their learning is a key benefit of project-based approaches. When learners are immersed in meaningful, hands-on tasks—especially those with tangible outcomes—they often experience increased engagement, a stronger sense of purpose, and deeper learning retention. Competitions and design challenges further enhance this motivation by introducing a spirit of collaboration and friendly rivalry, while simulating the pressures and constraints of real engineering projects.

The long-term benefits of implementing PBL in civil engineering education have been well documented. For example, Coronado et al. [2] examined the long-term benefits of implementing the PBL methodology at the School of Civil Engineering at the University of Castilla-La Mancha, highlighting its sustained impact on student engagement, skill development, and professional preparedness.

The paper first presents the outcomes of a local qualifying at Universidad de Castilla-La Mancha (UCLM), and the final one, where students from various institutions participated in hands-on design and construction challenges. These phases served not only as selection events for the final but also as valuable learning experiences in their own right, fostering local engagement and collaboration. Subsequently, the paper analyzes the results and educational outcomes of the national final, where the top-performing teams competed, allowing for a broader assessment of the initiative's pedagogical impact across diverse academic contexts. Other examples of wooden bridge competitions can be found in [3 to 8].

This paper explores the educational impact of a national wooden bridge design and construction competition organized for civil engineering students from Spanish universities. Anchored in PBL principles, the competition tasks students with conceiving, designing, and constructing a functional wooden bridge within limited resources and time constraints. Beyond strengthening their understanding of structural behavior and construction techniques, the initiative aims to motivate students through experiential learning and to cultivate essential soft skills needed for their future careers. To illustrate the results of the experience, the example of one of the semifinals held at the School of Civil Engineering of the University of Castilla-La Mancha and the final event organized at the Universidad Politécnica de Cartagena (UPCT) are presented. In addition, the results of a survey conducted among participants are also detailed to provide further insight into the impact and reception of the initiative.

2 WOODEN BRIDGE COMPETITION

The competition challenged students to design, construct, and present a small-scale wooden bridge, following a rigorous set of evaluation criteria that reflected real-world structural design challenges. The assessment was based on five core parameters, each focusing on a critical aspect of structural engineering. First, the adequacy of the conceptual design of the bridge was evaluated in relation to the specific characteristics of a given location, considering factors such as the typology, used materials and construction details between structural elements. This encouraged participants to develop designs that were not only structurally sound but also contextually appropriate and feasible for real-world implementation. Second, the presentation of the proposal was a significant component of the evaluation. Teams were required to effectively communicate their design intent, detailing the rationale behind their structural choices, the selection of materials, and construction techniques. In addition, the students had to respond to technical questions posed by a panel of judges, testing their depth of understanding, problem-solving ability, and capacity to defend their design decisions under scrutiny.

The third key criterion was the self-weight of the structure. This promoted efficient design practices by encouraging students to minimize material usage while still achieving high structural performance. The fourth parameter involved criterion was the load-bearing capacity of the structure, assessed through the application of a concentrated vertical load at the mid-span of the bridge, with a maximum test load of 500 kilograms. This test aimed to simulate real-life loading scenarios and determine the bridge's ability to withstand critical stress conditions without failure. Lastly, the measurement of the maximum displacement exhibited by the bridge at the point of structural collapse. This data provided insights into the ductility and failure mechanism of the design, highlighting whether the bridge failed in a brittle or ductile manner—an important consideration in modern structural safety. Collectively, these criteria created a holistic framework for evaluating not only the technical strength of each entry but also the ingenuity, efficiency, and communication skills demonstrated by the competing teams. Through this competition, students gained hands-on experience and a deeper appreciation for the balance between theory and practice in civil engineering design.

The percentage of each of these criteria is as follows: (1) Conceptual Design 30%, (2) Presentation 20%, (3) Bridge self-weight 20%, (3) Load bearing capacity 15%, (4) Vertical displacement 15%. The first two criteria (50% of the total score) correspond to the subjective evaluations carried out by a jury of Bridge Engineering experts, while the last three criteria (the other 50%) correspond to objective criteria.

In the national competition, the criteria were the same as in the local competition just described. The construction materials and tools were the same for all teams. The teams had five hours to build their bridges. The deck of the bridge was 120 cm long and 30 cm wide. The bridge had to be simply supported on two bearings 110 cm apart, and its maximum total allowable depth is 30 cm. In this edition of the competition, the bridges are supposed to span the Rambla de Benipila in Cartagena. For this reason, the maximum distance between the top of the deck and the lowest point of the structure could not exceed 10 cm.

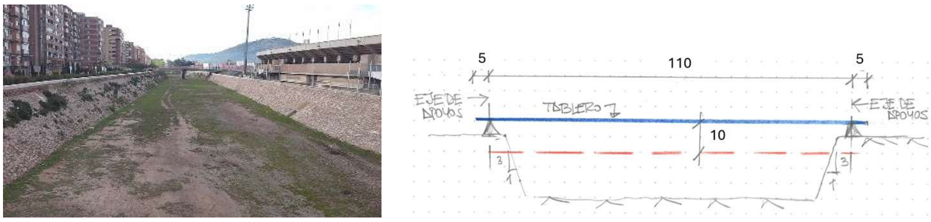

Figure 1: Benipila Watercourse (Cartagena). (Photo: Wikipedia Commons) and geometrical restrictions of the wooden bridge competition (Photo: UPCT)

A total of 12 out of the 14 civil engineering schools in Spain took part in this national competition, which was structured in two stages to foster broad participation and regional representation. The event began with semifinal rounds, each featuring teams composed of four students, who collaborated to design and construct their bridge proposals under the established criteria. The winning team from each semifinal advanced to the national final, which was held in Cartagena, providing a prestigious setting for the concluding stage of the competition. Notably, the final also included the participation of a guest team from the Escuela Politécnica Nacional of Quito (Ecuador), which was specially invited by the organizing institution to promote international collaboration and exchange of ideas. In the following subsections, a brief overview of the results from one of the semifinal rounds, as well as the outcomes of the final competition, is presented.

2.1 Semifinal at Universidad de Castilla-La Mancha

In the semifinal round held at the University of Castilla-La Mancha (UCLM), seven student groups participated, each presenting structurally innovative wooden bridge models. Two representative examples are shown in Figure 2, illustrating the diversity of design approaches and construction techniques employed by the teams. These physical models were subsequently tested at the Laboratory of Structures and Materials, where a custom-designed loading apparatus applied a concentrated load precisely at mid-span (Figure 3). Structural deformations were carefully recorded under incrementally increasing loads to evaluate each bridge's stiffness and load-bearing capacity. The collective load-deformation responses of all seven groups are presented in Figure 4, allowing for direct mechanical behavior comparison. This phase provided students with hands-on experience, bridging theoretical knowledge and practical application, while reinforcing technical skills and teamwork.

Figure 2: Examples of the designs in the UCLM semifinal: (a) Group "Puente al Éxito", and (b) Group "Infrapaths".

These physical models were subsequently tested at the Laboratory of Structures and Materials, where a custom-designed loading apparatus was used to ensure the application of concentrated load precisely at mid-span. An example of one such loading test is shown in Figure 3. Throughout the experiment, structural deformations were carefully recorded for incrementally increasing loads to assess each bridge's stiffness and load-bearing capacity.

Figure 3: Loading test at the semifinal.

The load–deformation responses of all seven groups are collectively presented in Figure 4, allowing for direct comparison of their mechanical behavior.

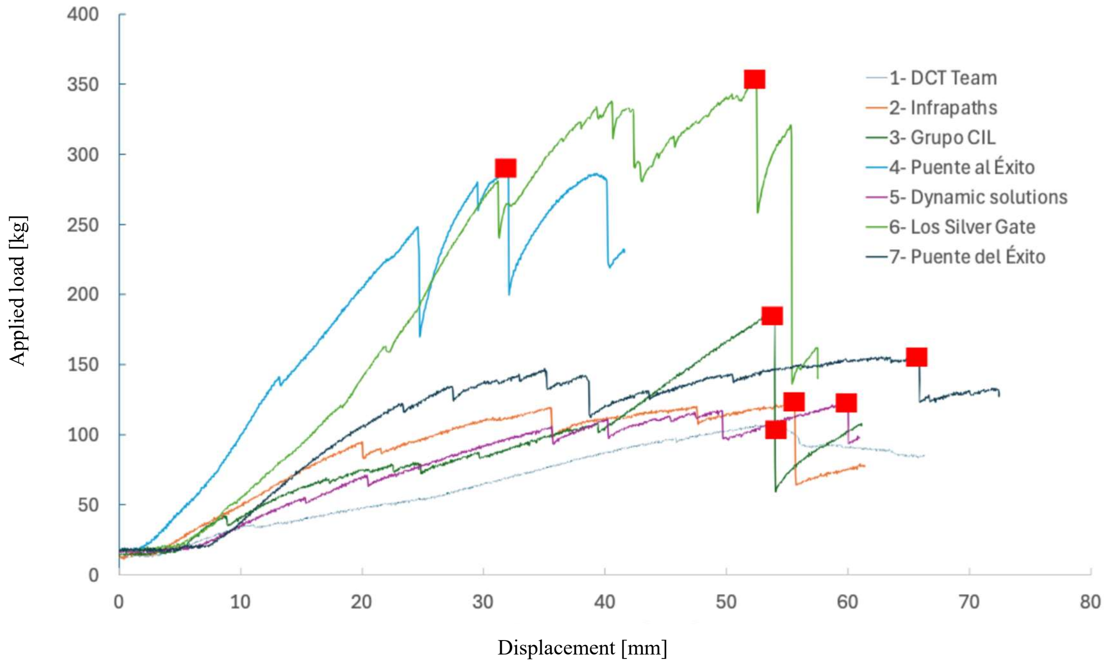

Figure 4: Load-deformation diagram of the seven groups participating in the UCLM semifinal. The vertical axis shows the applied load (kg) and the horizontal axis shows the vertical displacement at mid-span (mm). The curves represent the structural response of each model under increasing loads, allowing comparison of their stiffness and load-bearing capacity.

2.2 Final round at Universidad Politécnica de Cartagena

The final round took place at the Universidad Politécnica de Cartagena (UPCT), involving 12 winning teams from local phases across Spain and a guest team from the Escuela Politécnica Nacional of Quito, Ecuador. Each team consisted of four students and replicated local phase conditions to optimize preparation (Figure 5). The loading device used in the final, designed specifically by the second author, introduced loads by inserting gym plates into vertical rods, amplifying the nominal weights according to their positions. Applied forces were measured with a digital dynamometer, and vertical displacements at mid-span were recorded with a laser meter; both devices connected via Bluetooth to a computer for real-time data processing (Figure 6). Besides structural performance under load, teams presented and defended their designs before a jury of bridge engineering experts, promoting the integration of technical knowledge with communication and leadership skills. This comprehensive competition format fostered motivation, critical thinking, and collaboration—key elements of Project-Based Learning.

Figure 5: Participants teams and their designs (Photo: UPCT)

Schools were encouraged to make the local phase in each school as similar as possible to the final phase, as this would provide good training for students. In particular, the local round in Castilla-La Mancha was very similar to the final round, so no further details will be given, except that the device used to load the bridges was different. In this device, which was specially designed by the second author, the loads were introduced by inserting gym plates into a set of vertical rods. Depending on the position of the rod, the nominal weight of the gym plate is amplified by a different factor, resulting in the load acting on the bridge. The applied force was determined with a digital dynamometer and the vertical displacement in the center of the span was measured with a laser meter. Both devices were connected via Bluetooth to a computer that processed the data. Figure 6 shows some details and the loading of the bridge built by the team of the Universidad Politécnica de Valencia.

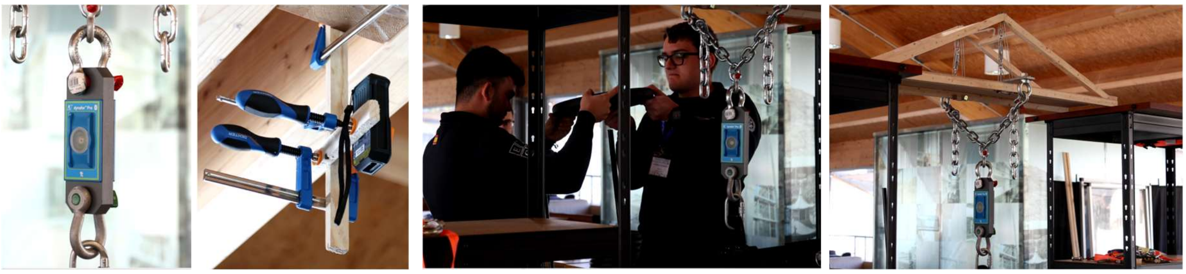

Figure 6: Digital dynamometer, laser meter, gym plates being inserted in vertical rods, test of the Universidad Politécnica de Valencia at the final round (Photos: UPCT)

This edition was dedicated to the memory of Javier Manterola (1936-2024), Professor of Bridges at the Universidad Politécnica de Madrid and one of Spain's most outstanding bridge designers. A special prize bearing his name was awarded to the best conceptual design. A small exhibition of his work was held at the competition venue and Prof Martínez Cutillas, one of his closest collaborators, gave a lecture on his work. The competition was sponsored by the Colegio de Caminos (Spanish Society of Civil Engineers).

The winners were the Polytechnic University of Cartagena (winner), the Polytechnic University of Valencia (second) and Seville (third), which also received the special Javier Manterola prize (Figure 7 and [9]).

Figure 7: Winner teams and their designs. From left to right: Univ. Politécnica de Valencia (2nd), Univ. Politécnica de Cartagena (Winner) and Univ. de Sevilla (3rd). Photo: UPCT.

3 SURVEY

In order to assess the educational impact and students' perceptions of the Wooden Bridge Design and Construction Competition, a structured survey was administered to participants following the final event. The survey comprised 15 Likert-scale questions (1 = strongly disagree to 5 = strongly agree), organized across several pedagogical dimensions: motivation, learning outcomes, teamwork and communication, applicability to professional practice, and overall satisfaction. A total of 31 responses were collected, representing over 65% of the participants in the final round.

The results show a highly positive reception of the initiative. Participants strongly agreed that the competition enhanced their motivation to learn (mean = 4.74), encouraged engagement with structural engineering content (mean = 4.68), and increased their interest in bridge design (mean = 4.63). These outcomes align with the foundational principles of Project-Based Learning (PBL), especially in fostering intrinsic motivation through hands-on, goal-oriented activities.
From a learning perspective, respondents reported a notable improvement in their understanding of structural behavior (mean = 4.74), material use (mean = 4.66), and construction processes (mean = 4.63). Notably, the experience was perceived as a meaningful complement to theoretical coursework, bridging the gap between classroom learning and real-world application (mean = 4.74). This perception supports the idea that authentic design-build challenges can significantly enhance conceptual retention and practical reasoning.

Teamwork and communication—key transversal skills in engineering education—were also rated highly. Students indicated that the experience significantly improved their teamwork (mean = 4.79), communication (mean = 4.55), and leadership abilities (mean = 4.45). These results suggest that collaborative, time-bound tasks with tangible deliverables cultivate soft skills essential for professional readiness.

Regarding alignment with professional practice, the participants agreed that the competition simulated real-life engineering challenges (mean = 4.74), and that it helped them better understand the role of engineers in society (mean = 4.58). Moreover, they appreciated the opportunity to apply academic content in a competitive and creative setting (mean = 4.71).

The overall satisfaction with the initiative was remarkably high, with a global satisfaction score of 4.84 out of 5.

Open-ended responses further emphasized the value of experiential learning and expressed interest in participating in future editions. Several students highlighted the opportunity to learn under pressure, the excitement of public testing, and the inspiration derived from observing peer designs and failures. Many students emphasized the practical application of theoretical knowledge as a significant benefit. For instance, one participant noted, "Applying the knowledge acquired in class is very enriching as it allows us to clearly observe the reason for each component." This sentiment was echoed by others who appreciated the hands-on experience and its role in reinforcing classroom learning.

Several respondents highlighted the challenges they faced, such as time management and material optimization. One student mentioned, "Time management was a very important factor to consider as everything had to be very well organized to finish the assembly of the structure on time." This reflects the real-world pressures and constraints that engineers often encounter, thereby enhancing the educational value of the competition.

Team dynamics and conflict resolution were also recurrent themes. Participants generally reported positive teamwork experiences, with comments like, "We distributed tasks for measurements, design improvement, cutting pieces, and assembly," indicating effective collaboration and task distribution. However, some noted the importance of clear communication and leadership in overcoming conflicts and ensuring smooth project execution. The feedback also included suggestions for future improvements, such as enhancing transparency in scoring and providing more detailed feedback. One participant suggested, "I would improve the fairness by ensuring all teams have the same materials, as some teams had a type of glue that others did not." This highlights the importance of fairness and consistency in competitive settings.

These findings confirm the effectiveness of the competition not only as a pedagogical tool but also as a motivational and formative experience. The event supported the acquisition of both technical and transversal competencies, thus reinforcing the value of integrating PBL initiatives and design challenges into civil engineering curricula.

The competition model demonstrated in this study offers significant potential for scalability and adaptability to diverse international educational contexts. Given variations in available resources, cultural approaches to engineering education, and institutional frameworks, the fundamental principles of this hands-on, project-based competition can be tailored to suit different environments while preserving its pedagogical strengths. Moreover, the methodology is readily extendable beyond wooden bridge design to other civil engineering subfields such as steel structures, geotechnical engineering, or hydraulics, allowing integration into various specialized curricula. Replicating similar initiatives can foster not only discipline-specific technical skills but also crucial transversal competencies including teamwork, communication, leadership, and problem-solving—skills essential for the holistic preparation of engineering graduates worldwide. Therefore, scaling this model could contribute to modernizing civil engineering education globally by bridging theory and practice through experiential, competitive learning formats.

4 CONCLUSIONS

- The Wooden Bridge Competition successfully engaged civil engineering students from across Spain, with participation from 12 out of 14 civil engineering schools, fostering nationwide academic involvement.
- The competition's structure, which included local semifinals and a national final, promoted teamwork, innovation, and applied learning in a realistic, hands-on environment.
- Evaluation criteria, including conceptual design, structural performance under load, deformation behavior, presentation quality, and structural weight, provided a comprehensive assessment framework aligned with real-world engineering challenges.
- Participation of the Escuela Politécnica Nacional (Ecuador) in the final round added an international dimension, encouraging cross-cultural academic exchange and collaboration.
- The event proved effective in reinforcing key civil engineering concepts such as load distribution, material efficiency, structural analysis, and communication skills.
- Results from the competition demonstrated a high level of creativity, technical knowledge, and problem-solving ability among students, highlighting the educational value of project-based learning.
- The overall satisfaction with the initiative was remarkably high, with a global satisfaction score of 4.84 out of 5. Open-ended responses emphasized the value of experiential learning and expressed interest in future editions. Students highlighted the opportunity to learn under pressure, the excitement of public testing, and the inspiration derived from observing peer designs and failures. They appreciated the practical application of theoretical knowledge, the challenges of time management and material optimization, and the importance of teamwork and conflict resolution. Suggestions for improvement included enhancing transparency in scoring and providing more detailed feedback.
- Overall, the competition served as a successful model for experiential engineering education and could be further expanded in future editions to include more international participants and broader challenges.

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