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ENHANCING A COMPREHENSIVE VIEW OF THE INFRASTRUCTURE LIFECYCLE THROUGH PROJECT-BASED LEARNING

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Abstract

This paper describes a teaching innovation project that adopts the project-based learning approach to introduce civil engineering students to their future professional roles and tasks throughout the infrastructure lifecycle. The successful development of the whole process and completion of the infrastructure in the best technical and sustainable conditions require a comprehensive view of the infrastructure lifecycle. Courses on "Project Design" and "Project and Business Management" at the B.Sc. in Civil Engineering simulate practical experiences in bidding, design, estimation, preliminary analysis, and construction planning, linking theory to professional practice. This study describes the organization of both courses to implement the simulations. To analyze the experience from the student's point of view, a survey examined the students' perceptions of the achievement of higher-order learning and their comprehensive view of the infrastructure lifecycle. In addition, the learning results were compared to the students' perceptions. Results indicate that students are aware of the learning improvement after performing the proposed activities. In addition, this approach helps the students to develop the professional competencies needed for the curricula. The coordination of the courses to align the learning activities with the lifecycle phases enables students to deepen their understanding of the phases of the infrastructure lifecycle, while they acquire a comprehensive view of the process. In addition, this approach has improved the motivation and engagement of the students. This teaching innovation project is easily adaptable to other engineering curricula.

Keywords: project-based learning; lifecycle; civil engineering; infrastructure

Introduction

Engineers are expected to solve increasingly important challenges that require essential learning to analyze and reflect rationally (Li and Faghri 2016). Societal needs continually modify current demands. For example, demands for a more sustainable world are forcing higher education to adapt (Barth et al. 2007; Gómez-Martín et al. 2021; Shephard 2008). Civil engineers are responsible for building viable infrastructures. They are increasingly required to consider the sustainability aspects of the infrastructure throughout its lifecycle (design, construction, operation, and demolition phases) (Pellicer et al. 2016; Sierra et al. 2016). Lifecycle thinking helps engineers to consider impact displacements from one lifecycle stage to another (Roure et al. 2018). This process implies that although engineers are usually involved only in one phase of the infrastructure lifecycle in their professional work, they must adopt a holistic view to anticipate the impact of the subsequent phases. In addition, the implementation of each phase requires a production-by-projects approach, in which the idea for the development of a unique product or service must be sold to the client and the contract must be signed first (Alshubbak et al. 2015). In this context, the project management community requires students with competencies in procurement and the execution of each phase of the infrastructure lifecycle.

To respond adequately to this challenge, instructors must adjust the teaching-learning process. Traditional learning methods have proven ineffective in motivating students and providing them with experiences that approximate those in their professional future (Goedert et al., 2011; Sik et al., 2016). Active learning methodologies encourage students to develop their learning and generate rules, procedures, and principles through problem-solving. These methodologies are becoming important (López-Querol et al., 2015) and are widely used in engineering education (García-Segura et al. 2020; Prince and Felder 2006). Project-based learning (PBL) is an active methodology that involves students in complex and realistic projects that are similar to ones they will encounter in the profession. Over the last several decades, research has indicated that PBL engages students in design, problem-solving, decision-making, and research activities, allowing them to work autonomously to complete real projects (Jones et al. 1997). They must apply the content to real situations and work in teams over long periods (Coronado et al. 2021). PBL facilitates the integration of theory with professional activity (Silva et al. 2018). The core activities of PBL are linked to the transformation and construction of knowledge. PBL allows students to work with multidisciplinary problems, the kinds that occur in the professional work of civil engineers (Steinemann 2003).

The literature documents several examples of the successful application of PBL in civil engineering education. Zhang et al. (2018) introduced PBL in Building Information Modeling (BIM) studies and found that this learning environment could promote high-order learning, collaborative teamwork, and communication, all of which are necessary for effective project execution throughout the building's lifecycle. The research of Coronado et al. (2021) found that civil engineering students involved in PBL studies considered their learning to be more effective with a better result-to-effort ratio. They also appreciated the development of professional abilities and skills, such as working in groups, communication/debate, and leadership. Similarly, Li and Faghri (2016) argued that this active methodology is effective as a starting point in the learning process for beginning learners such as junior engineering students. Although a large number of civil engineering courses have implemented PBL to improve their learning results, few have introduced this methodology in an integrated manner throughout the curriculum (Coronado et al.

2021; Kolar et al. 2000). However, this is a necessary step to address the challenge of creating sustainable infrastructure by considering its lifecycle.

Widespread evidence indicates that PBL has the potential to adapt well to courses for civil engineers. PBL requires students to develop the abilities necessary to manage and carry out projects related to the design and construction of infrastructures (Coronado et al. 2021), and it is an efficient methodology for teaching sustainable development in engineering education (Dancz et al. 2018). On this basis, a teaching innovation project (TIP) is proposed to simulate practical experiences throughout the infrastructure lifecycle by applying a continuous PBL methodology. This paper presents the framework and results of the TIP recently incorporated in courses on “Project Design” and “Project and Business Management”.

Methods

Civil Engineering curriculum: courses Project Design and Project and Business Management

The B.Sc. in Civil Engineering, accredited by EUR-ACE and ABET, comprises 240 ECTS (European Credit Transfer System) during 4 academic years. One ECTS corresponds to 25–30 hours of student work, including 10 hours of face-to-face learning. During the first two years, basic and scientific courses (Statistics, Physics, Mechanics, Mathematics, Representation Systems, etc.) and pre-technological courses (Structural Analysis, Construction, Transportation, etc.) are taught, while the third and fourth years focus on specific technological training in civil engineering. The third year is composed of eleven courses: Geotechnics, Structural Concrete, Structural Steel, Risk Prevention and Construction Management, Hydraulics and Hydrology, Building, Highways and Airports, Industrialized Construction, Maritime Engineering, Project Design, and Railways. The last year combines three compulsory courses —Project and Business Management, Geotechnical Engineering, and Hydraulic Infrastructures— with the bachelor’s thesis and elective training complements for civil engineers. The bachelor’s thesis is the culminating major engineering design experience (ABET 2019), which uses the engineering knowledge and skills acquired throughout the degree to develop a final engineering design.

Project Design is a second-semester course in the third year of Civil Engineering studies at Universitat Politècnica de València. This course has 4.5 ECTS distributed across four didactic modules: (1) introduction, (2) procurement, (3) technical design, and (4) BIM. The first module provides an introduction to the infrastructure lifecycle. The second module deals with the two main types of contracts with which a civil engineer is usually involved in the exercise of his/her profession during the procurement process—design and execution. The third module focuses on the design of the infrastructures, based on both creativity and the technical feasibility of the solution, as well as the development of a technical design. The fourth module provides a brief overview of BIM from a collaborative methodology perspective for the creation and management of a construction project.

Project and Business Management is a first-semester course in the fourth year of Civil Engineering studies at Universitat Politècnica de València. This course, which also has 4.5 ECTS, is structured around two main modules: (1) project management, and (2) business organization. In the first module, students acquire knowledge and skills in planning, organizing, conducting, and controlling projects, deepening understanding in the planning of the construction phase. The second module introduces business management within a construction company in which civil engineers carry out their activities, including the organizational hierarchies and the accounting procedures as a control tool for the firm and the construction project.

Teaching innovation project

The TIP was conducted in the Civil Engineering School at Universitat Politècnica de València to integrate two courses—(1) Project Design and (2) Project and Business Management—on a PBL basis to simulate activities in the professional careers of civil engineers throughout the first phases of the infrastructure lifecycle based on the traditional design-bid-build procurement process (Alshubbak et al. 2015). In this type of procurement process, the owner or promoter enters into a contract with a consulting engineering company to design the infrastructure and undertake the technical design. Then, the promoter enters into a separate contract with a construction company to build the infrastructure. Both contracts are the result of a bidding process in which the owner or promoter selects two companies to conduct the design and construction independently.

The TIP integrated these two courses to simulate three stages: (a) bidding for design, (b) design development, and (c) planning for construction. Initially, the owner provided the problem. The students must interpret the objectives and requirements set out in the procurement documents (administrative and technical). In the bidding for the design stage, they prepared a bid to obtain the contract for developing the design. Then, in the design development stage, they designed an infrastructure according to the limitations and conditions previously set by the owner. In addition, the students also wrote some technical documents for the technical design. Finally, in the planning for construction stage, the students acted as contractors by planning the construction within the best conditions of cost, quality, time, and available resources. The two courses simulated these activities in the same chronological order in which they occur in reality, taking the infrastructure lifecycle as a temporal reference (Fig. 1). Note that although the infrastructure lifecycle also includes the feasibility, operation, and demolition phases, these phases were not simulated because they were beyond the scope of the courses; however, feasibility and operation objectives were considered as part of the decision-making during the design stage.

The courses Project Design and Project and Business Management were traditionally organized combining lectures and individual learning activities. These activities included preparing some exercises and question-and-answer sessions, among others. The methodology of the courses was adapted to simulate the practical experiences using PBL. The course Project Design aimed, within the framework of a TIP, to prepare students for the main tasks they will carry out in an engineering consulting company, which were bid preparation and design. In addition, this course provided a basis for the bachelor's thesis. As the National Academy of Engineering (NAE 2005) recommends, the design process should be introduced to students from the earliest stages of the curriculum. Thus, the TIP enabled students to use many aspects of the design process, including problem definition and project planning, among others (ASCE 2019). In addition, the course Project Design was taught after some specific technological courses, such as Structural Concrete and Structural Steel. Thus, during Project Design, students had the opportunity to use the knowledge and skills developed in previous courses to design an infrastructure. The course Project and Business Management gave continuity to the infrastructure lifecycle by simulating the activities that engineers must carry out in a construction company to plan the construction from the technical design.

In this manner, students gained experience in the work necessary to solve a civil engineering problem and the tasks in which they will be immersed as engineers. The objectives of the TIP were: (O-1) achieve higher-order learning to be able to apply the content in simulated real-life situations; (O-2) develop a comprehensive view of the infrastructure lifecycle; and (O-3) improve the motivation and engagement of students.

Organization of the courses

The organization of the courses was adapted to include the TIP through PBL methodology. For this purpose, the theoretical lectures were reduced and focused on preparing students for PBL activities. During the 2018-19 academic year, a small pilot study was conducted in the Project Design course to simulate the design stage. After analyzing the results, two major conclusions were obtained: (1) the new organization should include face-to-face hours of student work to develop PBL activities; and (2) the design stage should be divided into several partial activities, as this process represented a large phase of the infrastructure lifecycle. Therefore, the organization of the courses was modified to reduce the theoretical lectures and include time allotted for student work. These last activities were designed with the dual objectives of acquiring higher-order learning and achieving a comprehensive view of the infrastructure lifecycle.

Three steps are presented to address the complete TIP framework. The first step explains the preparation of the civil engineering project before the beginning of the classes. The second step describes the classes of the course Project Design, differentiating the theoretical lessons from student work sessions. The third step follows the same structure as the previous step to introduce the classes of the course Project and Business Management. Fig. 2 illustrates the organization of the courses and clarifies the activities incorporated because of the TIP. The detail of each class meeting (two face-to-face hours) is explained below.

Step 1: Preparation of civil engineering project

The instructors of the courses first selected a real civil engineering project to be used as the case study for the entire TIP framework, that is, the two courses. The project was modified each year, so each cohort of students developed a different project for the two-course sequence. The project had to be defined to allow creativity and diversity in the design of solutions. The instructors also prepared a statement of the administrative and technical requirements for performing the work that was consistent with a procurement process. These documents specified the work to be carried out by the team of engineers, as well as the background that motivated the need for the project. This step was completed before the beginning of the classes.

Step 2: Project Design course

Class 1: Introduction of the project (Lecture)

On the first day of the course (two face-to-face hours), instructors presented the organization of the course. Instructors also explained the project and provided the statements of the administrative and technical requirements. These statements were the starting point for conducting the infrastructure lifecycle activities. Students were encouraged to analyze the requirements, visit the location, and consider the project as an engagement that they must conduct as engineers of a consulting company. To start working, they were distributed into groups of 4-5 people. They could freely choose the group members and the group manager.

Classes 2-5: Theoretical concepts of introduction and procurement modules (Lectures)

The students were lectured on the concepts of the introduction and procurement modules for four days (two face-to-face hours for the introduction and six face-to-face hours for the procurement modules). The concepts of both modules prepared students for the next activity.

Classes 6-7: Bidding for design activity (Student work)

Students experienced the preparation of a bid required for a consulting firm to obtain the contract for developing the design. Students were encouraged to present the information needed for the tender and estimate the bid price based on the contract's technical requirements and administrative conditions. They must provide a summary of the information required to submit the bid and the bid price justification. Four hours of face-to-face work were needed for guiding this activity.

Classes 8-12: Theoretical concepts of the technical design module (Lectures)

Then, instructors presented the technical design module before the students undertook the design experience. This module focused on the design of the infrastructures and the technical design documents. Firstly, to promote the creativity and analysis of technical solutions, a guest speaker was invited to explain and discuss the designs. Then, the documents of the technical design were explained using real examples.

Classes 13-20: Design development activity (Student work)

This activity simulated the design of a solution and the development of the technical design by the team of engineers in a consulting company once the contract had been awarded. As the pilot study results recommended, several partial activities (PA) were implemented to execute the design activity through stages. In this manner, students performed the work progressively, and instructors guided them during the learning process. In addition, instructors evaluated and gave feedback to the students after each delivery of the partial activity. Finally, students incorporated the modifications suggested by the instructors and presented the final document as a compendium of the partial deliveries. The design process was divided into six partial activities:

- PA-1: Students searched for reference projects and designed a constructive solution individually based on the requirements.
- PA-2: Team members pooled individual alternatives and selected the best alternative based on a multi-criteria decision-making process that considered technical and sustainable criteria.
- PA-3: Team defined the best construction solution obtained after the multi-criteria decision-making process. They must specify the geometry and materials of the solution.
- PA-4: Team designed the format and table of contents of the technical design.
- PA-5: Team prepared at least five drawings to define the geometry and materials of the solution.
- PA-6: Team defined the technical requirements of two material supplies and two construction processes.

All the tasks were performed in groups, except the first one, which was individual. Two face-to-face hours were needed for guiding each partial activity except PA-5, which needed four face-to-face hours.

Classes 21-22: Theoretical concepts of BIM module (Lectures)

The course content concluded with the BIM module, explaining how this new methodology could be implemented for project design and management.

Class 23: Presentations

The last class focused on the presentations. Students prepared a 10-minute presentation to explain the multi-criteria decision-making process and show their design. Instructors and students had five minutes to ask questions and discuss the details of the designs with each group.

Step 3: Project and Business Management course

Class 1: Introduction of the project (Lecture)

The first day focused on presenting the organization of the course and the objectives of the TIP. In this course, students continued the TIP by simulating the planning for construction activity. Students planned the construction from their technical design developed during the course Project Design. Students must remain on the same team throughout both courses to achieve this continuity. However, as there were students who did not study Project Design during the previous year, they were distributed throughout the groups.

Classes 2-7: Theoretical concepts of project management module (Lectures)

The instructor presented the project management module through lectures and individual learning activities to prepare students for the planning for the construction stage.

Classes 8-11: Planning for construction activity (Student work)

During this activity, students acted as the construction site manager to plan the execution and to prepare a detailed work program for the bid. Students took the technical design created in the course Project Design and analyzed all the activities to be carried out for the execution considering the duration, the distribution of the available resources, and the quality as objectives. They must present the following information: (1) key data of the project; (2) work breakdown structure; (3) scheduling; (4) project team; and (5) economic estimation. Eight face-to-face hours were scheduled for guiding this activity.

Class 12: Presentations

Students presented the main results of the planning for construction activity. Instructors and students had the opportunity to ask questions and discuss each alternative presented.

Classes 13-22: Theoretical concepts of business organization module (Lectures)

The last lectures presented the business organization concepts. This final module was not included in the TIP. However, students must prepare a report analyzing the accounting results of a construction company.

Class 23: Presentations

On the last day of the course, students presented the main results of their report and discussed them with the instructor.

Assessment of the student leaning and competencies

Four learning results were defined for each course (Table 1) and assessed by instructors using rubrics (see Appendix I). The authors assigned a code to each learning result for a more convenient interpretation of the results. Regarding Project Design, students of each group provided a peer assessment to award or penalize individual grades from the grade of the team project. Groups divided 100 points among their members according to their involvement in the development of the assignments. In case all members had equally worked, they distributed equitably the points. Otherwise, they provided more points to the more hard-working members. A coefficient *C* was applied to the grade of the team project to obtain individual grades (Equation 1), being X_i the points assigned to a member and $\bar{X}$ the mean value.

$$C_i = 1 - 0.4 * (\bar{X} - X_i)/\bar{X} \quad (1)$$

This method was not followed by the course Project and Business Management; in this case, individual grades were assessed by the instructor according to the student involvement. This last option was possible because most of the activities were developed in the classroom and, therefore, the instructor could directly obtain information about the individual involvement of the students. In addition, these courses must assess several professional competencies. Competence-

Based Learning is defined as a pedagogical approach that focuses on measurable student outcomes (Henri et al. 2017). Competencies can be divided into professional and content-based (Henri et al. 2017). While content-based competencies are linked to specific content that pertains to a subject area, professional competencies develop general skills necessary for success in the professional activity (Henri et al. 2017). Regarding professional competencies, lists of competencies have been defined to promote the student's future professional career (Crawley et al. 2007; De Graaff and Ravesteijn 2001). For example, the American Society of Civil Engineers (ASCE 2019) presented six professional outcomes needed for entry into the practice of civil engineering: communication, teamwork and leadership, lifelong learning, professional attitudes, professional responsibilities, and ethical responsibilities.

Universitat Politècnica de València defined thirteen competencies for professional practice to develop and assess through the undergraduate and graduate degrees: (PC1) understanding and integration of concepts; (PC2) application of concepts and practical thinking; (PC3) analysis and problem-solving; (PC4) innovation, creativity, and entrepreneurship; (PC5) project design; (PC6) teamwork and leadership; (PC7) ethical, environmental, and professional responsibility; (PC8) effective communication; (PC9) critical thinking; (PC10) knowledge of contemporary issues; (PC11) continuous learning; (PC12) planning and time management; and (PC13) use of specific instruments. These competencies are common for all undergraduate and graduate studies, but the level of accomplishment is different in each of them. Anyway, each course must develop and evaluate some competencies. The course Project Design must evaluate PC5, PC6, and PC12, while the course Project and Business Management must assess PC7 and PC11.

The professional competencies assigned to Project Design and Project and Business Management were assessed using rubrics from the student work sessions (see Appendix I), except PC7, which used an alternative activity. In this last case, an ethical dilemma was presented to ignite student discussion. PC5 was assessed using the rubric of the learning results, as PC5 focuses on the design, management, and evaluation of an idea to become a project. PC6 seeks to work and lead teams effectively to achieve common objectives, contributing to their personal and professional development. This competency was assessed using a rubric from the classroom observations and the distribution of the 100 points. PC12 aims to develop the capacity of students to properly plan the available time and schedule the activities necessary to achieve the objectives. For that, students were asked to plan the PBL activities at the beginning of the course. Then, they must control the planning and deliver new plans according to the deviations. This competency was assessed using a rubric. Then, PC11 was also assessed using a rubric from the deliveries of the course Project and Business Management. PC11 promotes the learning process in a strategic, autonomous, and flexible way, in accordance with the objective pursued.

Methods for the TIP assessment

For the assessment of the TIP, the objectives of the TIP were linked to several indicators and evaluation methods. First, investigators defined indicators to determine the impact of the project on each objective. Then, the investigators defined an evaluation method to assess each indicator. Table 2 shows the indicators and evaluation methods selected to evaluate each objective. A mixed-methods approach of student surveys and focus groups was employed to evaluate the students' perceptions of each objective (Clark et al. 2021). Student self-assessments informed about their perceptions of their work and academic abilities (McMillan 2013). In addition, the direct assessments of the learning results and professional competencies were used to evaluate the achievement of higher-order learning using the rubrics explained in the previous sub-section. As several authors pointed out, students' self-assessments tend to be more optimistic than the instructor's assessments (Brown et al. 2015; Sadler and Good 2006), although both assessments tend to be highly similar when self-assessment did not count toward the students' grades (Tejeiro 2012). Thus, this research presents the results of both instructors' and students' assessments and compares them.

Regarding the survey, five parts were defined to respond to each indicator: (I) students' perceptions of their learning results before TIP, (II) students' perceptions of their learning results after TIP, (III) students' perceptions of their development of professional competencies, (IV) students' perceptions of the effectiveness of PBL to promote learning and application of the course content, and (V) students' perceptions of the need to coordinate the courses to deepen their understanding of the infrastructure lifecycle phases. Students completed both a pre-project and post-project survey to evaluate their perceptions related to the learning results (Clark et al. 2021). The pre-project survey contained the students' perceptions of their learning results without experiencing the simulation phases (Part I). The post-project survey included the other parts as they evaluated their perceptions after the active classes. To evaluate their perceptions of the learning results, the survey aligned one statement with each learning result. The statements began with "I consider that I am able to", followed by the learning result. Students selected responses from a five-point Likert-type scale of potential responses—strongly agree, agree, neutral, disagree, and strongly disagree—that best reflected their perception about the item (Rovai 2002). Likewise, the statements in Part III of the survey, which evaluated the students' perceptions of their development of professional competencies through the PBL approach, began with "the PBL activities have helped me to develop", followed by the professional competencies that the curricula should develop. Although the two courses must develop and assess a total of five professional competencies, the survey examines whether the TIP contributes to all the professional competencies. The instructor's assessment of the five professional competencies is also presented and compared with the students' perceptions.

Regarding Part IV, four statements were derived from a review of the available literature about the effectiveness of PBL to promote learning and the application of the course content. The review of the literature suggested that PBL helps students to promote high-order learning (Coronado et al. 2021; Rodrigues Da Silva et al. 2012), apply the contents to real situations (Coronado et al. 2021; Zhang et al. 2018), develop the design, problem-solving, and decision-making skills (Gavin 2011; Jones et al. 1997; Lin et al. 2021), and improve the learning process compared to traditional learning methods (Li and Faghri 2016; Lin et al. 2021). Thus, Part IV of the survey included specific statements related to each of these issues. Finally, one statement assessed the potential benefits of coordinating the courses to deepen the students' understanding of infrastructure lifecycle stages (Part V). The last statement evaluated students´ perceptions of the integration of the two courses to simulate the different phases of the infrastructure lifecycle throughout the same project. This statement was used to evaluate one of the objectives of the TIP, which was to develop a comprehensive view of the infrastructure lifecycle. Appendix II provides the complete text of these surveys, which were successfully tested in a pre-test.

The investigators selected the focus group technique for analyzing the students' perceptions of their comprehensive view of the infrastructure lifecycle, as well as their motivation and engagement during the courses. The focus-group technique promotes a collaborative and open discussion among participants (Bhandari and Hallowell 2021). In addition, this method is beneficial for exploring their perceptions on such issues in depth (Bryman 2012). Comparing this technique with group interviews, focus groups usually emphasize a specific topic that can be explored in-depth, whereas group interviews often span very widely (Bryman 2012). In addition, focus groups enable to build up a view out of the interaction that takes place when people respond to each other's views (Bryman 2012). Six students from the course Project and Business Management were selected to provide their views in the focus group. Researchers suggest a group size between six to ten members, being the minimum recommended when participants are likely to have a lot to say on the research topic or to stimulate participants and ensure a smoother session (Bryman 2012; Morgan et al. 1998; Peek and Fothergill 2009). These students were selected randomly considering the following criteria: (1) they must be involved in the entire TIP framework to provide their perceptions of the comprehensive view of the infrastructure lifecycle; (2) they must represent the entire group of students in a range of academic ability; and (3) they must represent the entire group of students in gender.

The focus group took place in May 2021, after the courses ended, and lasted about 90 minutes. Two moderators facilitated the focus group and encouraged students to express their views in complete anonymity. These moderators were not instructors of the courses, but they were familiar with the topic as they belong to the same research area. Structured questions were used for the discussion, as follows:

- Did the TIP help you to experience each stage of the infrastructure lifecycle?
- What difficulties have you found?
- Did the coordination of the courses, using the same project, enable you to have a comprehensive view of the infrastructure lifecycle?

- Have you been motivated by the project-based learning activities of the two courses?

The session was audio-recorded, transcribed, and coded. In addition, one moderator took notes to distinguish who was talking. The codes were used for the content analysis to identify the topics associated with narrative, as the discussion generated by a question can provide valuable insights related to other topics (Bryman 2012). Four codes were used: EXPERIENCE, DIFFICULTIES, COMPREHENSIVE VIEW, and MOTIVATION. Then, a content analysis was used for systematically and objectively identifying characteristics of some given qualitative data (Montalbán-Domingo et al. 2018; Neuendorf 2017). Deductive content analysis was performed as codes were predetermined before the process of analysis and the narratives were assigned to these predetermined categories (Bryman 2012; Goel et al. 2019). The moderators examined the transcriptions and assigned the codes to each narrative. Then, the researchers calculated the inter-rater reliability using Cohen's kappa (Cohen 1960), as this agreement coefficient has been widely used to report the agreement between two raters who classify items into categories (Neuendorf 2017). Results were accepted as the values were greater than 0.8 for every category (Montalbán-Domingo et al. 2018; Neuendorf 2017).

Results and discussion

The 2019-20 academic year was initiated following the complete TIP framework. The students in the course Project Design continued the experience in the course Project and Business Management during the 2020-21 academic year. This paper presents the results of the 2020-21 academic year, including both students in the course Project Design—they began the TIP framework in that year developing a new construction project—and students in the course Project and Business Management who completed the TIP framework—they took the course Project Design in 2019-20 and the course Business and Project Management in 2020-21. The project for students who began the TIP framework in the 2019-20 year consisted of a bypass road that diverted traffic away from a town center; as this road crossed a river, the case also required students to prepare a preliminary design for a viaduct. The project for students beginning in the 2020-21 academic year was a pedestrian bridge to enhance a bicycle and pedestrian route that connects the town with the beach.

The following sub-sections analyze the learning results, as well as the results of the survey and focus group. Surveys were answered by 56 out of the 65 students (86% of the students) in the course Project Design and 57 out of the 63 students (90% of the students) in the course Project and Business Management. Note that students were informed during the introduction of the project that they were immersed in a TIP and they were free to participate in the research. Each of the following sub-section responds to each TIP objective through the analysis of the indicators.

Achieve higher-order learning to be able to apply the content in simulated real-life situations

Students' perceptions of their learning results were analyzed before their participation in the student work sessions (coded as "before") and after their participation (coded as "after"). Results showed significant differences between both surveys for all the learning results (Fig. 3 and 4). These outcomes indicated that students believed that PBL significantly enhanced their learning results in both courses. In addition, looking at the distribution of the answers, results of the post-project survey had less variability than results of the pre-project survey, concluding that students' perceptions were more consistent after their participation. Most of the students considered that, after the active classes, they achieved all the learning results.

The learning results of the two courses were assessed by instructors through rubrics. Fig. 5 shows that between 69% and 75% of the students in the course Project Design acquired a proficient level on the four learning results. Regarding Project and Business Management, the exemplary results were higher as this percentage was about 43% to 56% (Fig. 6). The peer assessment led to a coefficient C (Equation 1) between 0.7 and 1.2. This means that individual grades were, in some cases, penalized because of a lack of involvement.

Comparing the learning results with the students' perceptions, some relationships between both outcomes were found. Firstly, bidding and budget learning results obtained the lowest grades and were also the worst rated in the post-project survey. This outcome indicates that, as discussed previously, students' self-assessments are frequently more optimistic than the instructor's assessments. However, both assessments tend to be similar if self-assessment did not count toward the students' grades (Tejeiro 2012). Secondly, those learning results that received the lowest scores in the pre-project survey, were the ones that obtained less exemplary and proficient results. This means that the previous knowledge has a considerable influence on the final results. Therefore, if previous courses assist in preparing students for acquiring some learning results, students are more likely to obtain high grades in those learning results. By contrast, it is difficult to obtain exemplary results when the concepts are introduced for the first time. This underlines the necessity to coordinate the courses and introduce PBL methodology in an integrated manner throughout the curriculum.

Students' perceptions of their development of professional competencies were evaluated during the course Project Design (PC_PD) and the course Project and Business Management (PC_PBM) to assess whether the PBL activities were adequate for them to acquire these competencies. Results included in Appendix III (Fig. S1) indicate that the median values were equal to 4.0 for all the competencies across both courses, which suggest that students believed that the PBL activities helped them to develop all of the professional competencies. In addition, students within Project and Business Management were more convinced of the impact of the PBL approach on the development of these competencies. Results of the instructor's assessment of the five professional competencies are presented in Fig. 7. Most of the students obtained exemplary and proficient results for these five competencies, particularly in the course Project and Business Management. Results also indicated that PBL activities progressively improved the competencies. In addition, although these courses must develop and assess only five professional competencies, the activities designed for the TIP also contributed to the development of the other professional competencies.

Part IV of the survey focused on the students' perceptions of the effectiveness of PBL to: (E1) promote higher-order learning; (E2) apply the course contents to real situations; and (E3) develop the design, problem-solving, and decision-making skills to design an infrastructure and prepare a bid in Project Design, or to prepare a detailed construction plan in Project and Business Management; and (E4) improve the learning process compared to traditional techniques. The results included in Appendix III (Fig. S2) indicate that students considered PBL effective in promoting learning and the application of the course content. The median values indicate that students: agreed that PBL helped them to acquire knowledge on both subjects; strongly agreed that PBL helped them to apply course content to real-life situations; agreed that PBL helped them to achieve the main goals of the courses; and strongly agreed and agreed that PBL helped them to improve the learning process compared to traditional techniques in the Project Design and Project and Business Management courses, respectively. After analyzing the results of the indicators associated with the first objective, it can be concluded that outcomes suggest that the TIP approach improves the acquisition of a higher level of competency and promotes the practical application of civil engineering tasks in real infrastructure projects.

Develop a comprehensive view of the infrastructure lifecycle (bidding, design, and construction)

One question assessed students' opinion of the value of coordinating the two courses to simulate the infrastructure lifecycle phases for the same project (see Fig. S2). The most frequent answer among those students in the course Project Design was that they agreed on the need to coordinate the courses to deepen their understanding of the infrastructure lifecycle phases (C_PD), while the most frequent answer among those in the course Project and Business Management was that they strongly agreed on the need to coordinate the courses (C_PBM). Therefore, students in the first course considered the continuity of the methodology important; however, students in the second course considered it essential. This outcome suggests that students who finished the TIP better appreciated the value of this approach.

Students who participated in the focus group highlighted their satisfaction with the TIP framework. They learned the basic concepts of design and construction for different types of infrastructures in their civil engineering studies. They appreciated that this approach helped them "*to see the real application for the professional future*", as Student 1 stated. They recognized the difficulties in understanding the infrastructure lifecycle, as Student 2 mentioned: "*At the beginning, I was very confused with the process*". Student 6 added, "*the most difficult part was knowing what we had to do in each part of the process since we had difficulties to differentiate* *the tasks and the documents that encompassed the technical design. However, once we investigated and consulted other technical designs, we understood what had to be done and, personally, the work helped me to consolidate more the knowledge of the course and to better understand the different parts of the infrastructure lifecycle. Regarding Project and Business Management, I personally had fewer difficulties since I knew the project previously".*

They took the opportunity to express their perceptions about the need to coordinate the courses to deepen their understanding of the infrastructure lifecycle phases. Student 3 stated: "*It was helpful to use the same technical design in both courses to deepen in each stage*". In the same way, Student 6 pointed out: "*I consider that the fact of using the same technical design allowed us to devote more time to the real application of the construction planning in Project and Business Management*". All the students stated that the TIP had achieved the goal of promoting a comprehensive view. Student 3 said: "*I could gain this comprehensive view once I had been immersed in the two courses*". This perspective, shared by the other students, confirms the outcome of the previous indicator, in which students from the second course showed a greater appreciation for the coordination of the courses.

They concluded that after going through all the tasks, they believed that they had a comprehensive view of the infrastructure lifecycle and will be able to improve their work on one phase by considering the others. For example, Student 3 observed: "*this approach will allow us to think about how the infrastructure would be built when we are designing it*". Student 6 agreed: "*I will be able to improve the planning of the construction with a better understanding of the project*". Student 4 added: "*although these tasks are carried out by different professionals, this approach will help us to see the global goal, which is to create a sustainable infrastructure*".

Improve the motivation and engagement of students

Instructors observed during the courses that students were motivated and engaged when they were occupied in the student work sessions. To confirm this perception, the moderators asked students who participated in the focus group about these aspects, and the results indicated that all of the students were very motivated. For example, Student 1 stated: "*there are tasks throughout the engineering studies that you do to finish them; however, this is not the case* [with PBL]*; you do* *it with eagerness*". Student 2 added: "*I was very motivated because it was very different from the works of other courses; this is a challenge; you start to see real projects*". When asked about the causes that motivated them in each course, small differences emerged among the students. Student 4 responded: "*I enjoyed more doing the PBL activities of Project Design, as in my opinion it better imitated reality*". However, Student 2 had a different opinion: "*I enjoyed Project and Business Management more because I had more time to do it, as the activities of Project Design coincided with the ones of other courses*". Student 6 concluded: "*In general I was more motivated by the projects of Project Design since I could see how we were advancing throughout the design. In addition, the fact that there were several deliveries allowed us to bring the work more up to date and make it more consciously. I also liked the Project and Business Management project; however, I had to do it more quickly, so I consider that I had less time to assimilate it and therefore I had less motivation*". These opinions show that the level of motivation depended on different aspects of the courses, such as the time they had to enjoy the experience and the extent to which it imitated reality. However, despite their situations, all of the students confirmed that the TIP approach fulfilled the objective of motivating the students.

Lessons learned

The TIP has entailed numerous advantages for the students' learning, such as enhancing the collaborative work, obtaining new design skills, understanding the importance of acquiring a comprehensive perspective of the infrastructure lifecycle, and motivating them; however, this experience has also given a glimpse of a series of difficulties that need to be addressed to guarantee the success of the PBL implementation. This section summarizes the learning gained from the simulations, which can be used to improve future stages of the TIP or help other civil engineering educators to implement similar innovations:

- The first day of the course should focus on the introduction of the project, so students can face the project from the first day.
- It is important to contextualize the phase of the infrastructure lifecycle before starting each simulation to avoid difficulties.

- To improve the results of the design stage, it is recommended to include an initial task for investigating other technical designs to have some references for the development of the design.
- Large activities should be divided into several deliveries to evaluate and give feedback to the students. In this case, students can incorporate progressively the modifications suggested by the instructors.
- The project should be selected considering the content of previous courses. In addition, it is important to define a project that promotes creativity and diversity in the design of solutions.
- Activities should be designed considering that they must imitate reality. In addition, they should be scheduled considering the time needed for their development and the activities of other courses. Otherwise, students lose motivation.
- Giving feedback and informing about the student's progress is important to engage students.
- The coordination of the courses is necessary to acquire a comprehensive view of the infrastructure lifecycle, as students need to be immersed in the two courses to achieve this objective.
- It is important to introduce PBL methodology in an integrated manner throughout the curriculum, as students who are not familiar with the PBL need to develop several activities to perform better and achieve higher-order learning.
- The continuity of the methodology through the same project is recommended, as students are more motivated when they work on projects with which they are already familiar.

Limitations

This approach has proven to be an effective pedagogical tool to teach effectively the diverse engagements that civil engineers must conduct throughout the infrastructure lifecycle. However, the courses did not include simulations of the phases of feasibility, operation, and demolition, which were beyond their scope. Future research should focus on developing and testing new experiences by incorporating additional courses in civil engineering into this framework. This approach is valid for simulating many activities in the professional future of a civil engineer. Therefore, it could incorporate additional courses to enhance the lifecycle view of civil engineering students, promoting a better vision of sustainability throughout the degree program.

Regarding the methods, this study used surveys and the focus group technique to examine the students' perceptions. These methods have several limitations. Firstly, students' self-assessments may not be realistic, as they may overestimate their performance (Brown et al. 2015; Sadler and Good 2006). In addition, surveys have the disadvantage that a low response rate and self-selection bias may influence the representativeness of the sample (Testa et al. 2016). To avoid this limitation, there is a need to integrate the results with different methodologies (Testa et al. 2016), such as instructor's assessments (Tejeiro 2012). The focus group technique has the advantage of promoting a collaborative and open discussion among participants (Bhandari and Hallowell 2021). However, as a small number of participants is recommended to stimulate participants and ensure a smoother session (Bryman 2012; Morgan et al. 1998; Peek and Fothergill 2009), the results may not represent the opinions of the complete group. Another limitation of this technique is the lack of independence in the responses of group members, as a dominant member or the moderator may influence the responses of other members (Sim and Waterfield 2019). Some of these limitations can be addressed following the recommendations of the researchers to conduct focus groups (Bryman 2012; Sim and Waterfield 2019).

Conclusions

This paper presents a TIP at Universitat Politècnica de València with the goal of simulating different phases of the infrastructure lifecycle through a PBL environment. Two courses simulate three specific stages of this lifecycle: (a) preparation of a bid to gain the contract for the engineering consulting company, (b) design of an infrastructure and elaboration of the technical design, and (c) construction planning from the perspective of a construction site manager before construction begins. Instructors coordinated the two courses—Project Design and Project and Business Management—to prepare students for the primary civil engineering tasks they will encounter in real infrastructure projects. The organization of the courses to adapt to PBL methodology is presented in this paper.

Results of surveys and a focus group examined the student's experience. These outcomes together with the instructor's assessments using rubrics were employed to evaluate the TIP objectives. Regarding the first objective—achieve higher-order learning to be able to apply the content in simulated real-life situations—surveys administered before and after PBL indicated that students believed that they improved their learning results after being immersed in the activities in both courses. The instructor's assessments confirmed that most of the students acquired exemplary and proficient levels on all the learning results. Results showed that as the students develop more activities through PBL, they perform better and improve progressively their competencies. In addition, although these courses must develop and assess only five professional competencies, the PBL activities helped them to develop all the professional competencies. The positive opinion about the effectiveness of PBL confirmed that this approach is essential to expose students to roles and tasks related to the profession of civil engineering.

Regarding the objective of developing a comprehensive view of the infrastructure lifecycle, students recognized that they had difficulties understanding the infrastructure lifecycle during the first steps of the TIP framework. However, after participating in these activities, they believed that they had achieved a more comprehensive view, which will enable them to design and construct sustainable infrastructures. In addition, they asserted that using the same project in both courses helped them to deepen their understanding of each stage. Concerning the third objective, the focus group results corroborated the engagement and motivation of the students. All these results have helped instructors to define some lessons learned. For example, it is important to contextualize the phases of the infrastructure lifecycle, design activities close to reality, inform student about their progress, allow enough time to develop the activities, and coordinate the courses through the same project to improve the motivation and engagement of students.

Data Availability Statement

All data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supplemental Materials

Appendices I, II, and III are available online in the ASCE Library (ascelibrary.org).

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Table 1. Learning results of the courses

Courses	Learning results	Code
Project Design	Design an infrastructure (or part of it) creatively	DESIGN
	Propose and select an alternative based on the objectives and limitations of the project	DECISION
	Structure and develop the documents of a technical design	TECHNICAL
	Make a bid for a tendering process	BIDDING
Project and Business Management	Design a work breakdown structure	WORK
	Plan the scheduling	SCHEDULING
	Plan the project team	TEAM
	Estimate the budget	BUDGET

Table 2. Indicators and evaluative methods for assessing the achievement of the objectives

Objectives	Indicators to assess the impact of the project	Evaluation method
O-1: Achieve higher-order learning to be able to apply the content in simulated real-life situations	Students' perceptions of their learning results before and after PBL	Survey (Parts I and II)
	Learning results	Rubric
	Students' perceptions of their development of professional competencies	Survey (Part III)
	Professional competencies	Rubric
	Students' perceptions of the effectiveness of PBL to promote learning and application of the course content	Survey (Part IV)
O-2: Develop a comprehensive view of the infrastructure lifecycle (bidding, design, and construction)	Students' perceptions of the need to coordinate the courses to deepen their understanding of the infrastructure lifecycle	Survey (Part V)
	Students' perceptions of their comprehensive view of the infrastructure lifecycle	Focus group
O-3: Improve the motivation and engagement of students	Students' perceptions of their motivation and engagement during the courses	Focus group

Fig. 1. Teaching innovation project (TIP) framework

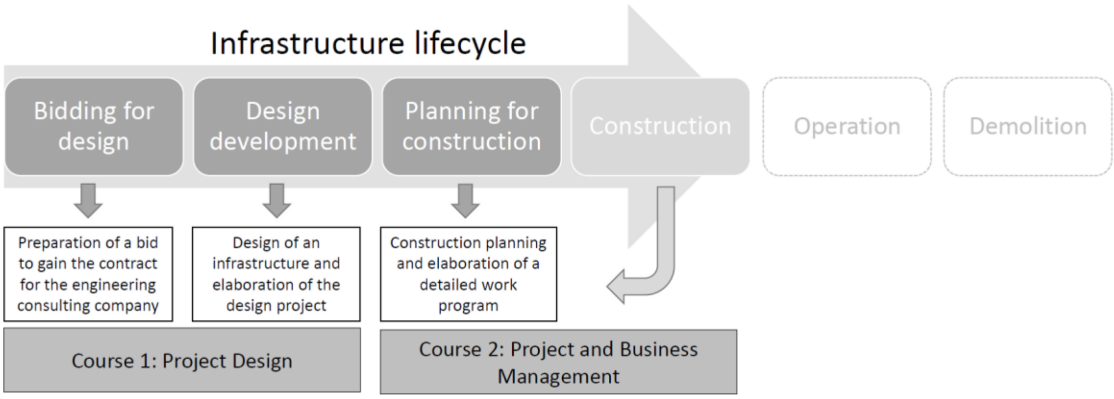


Fig. 2. Organization of the courses

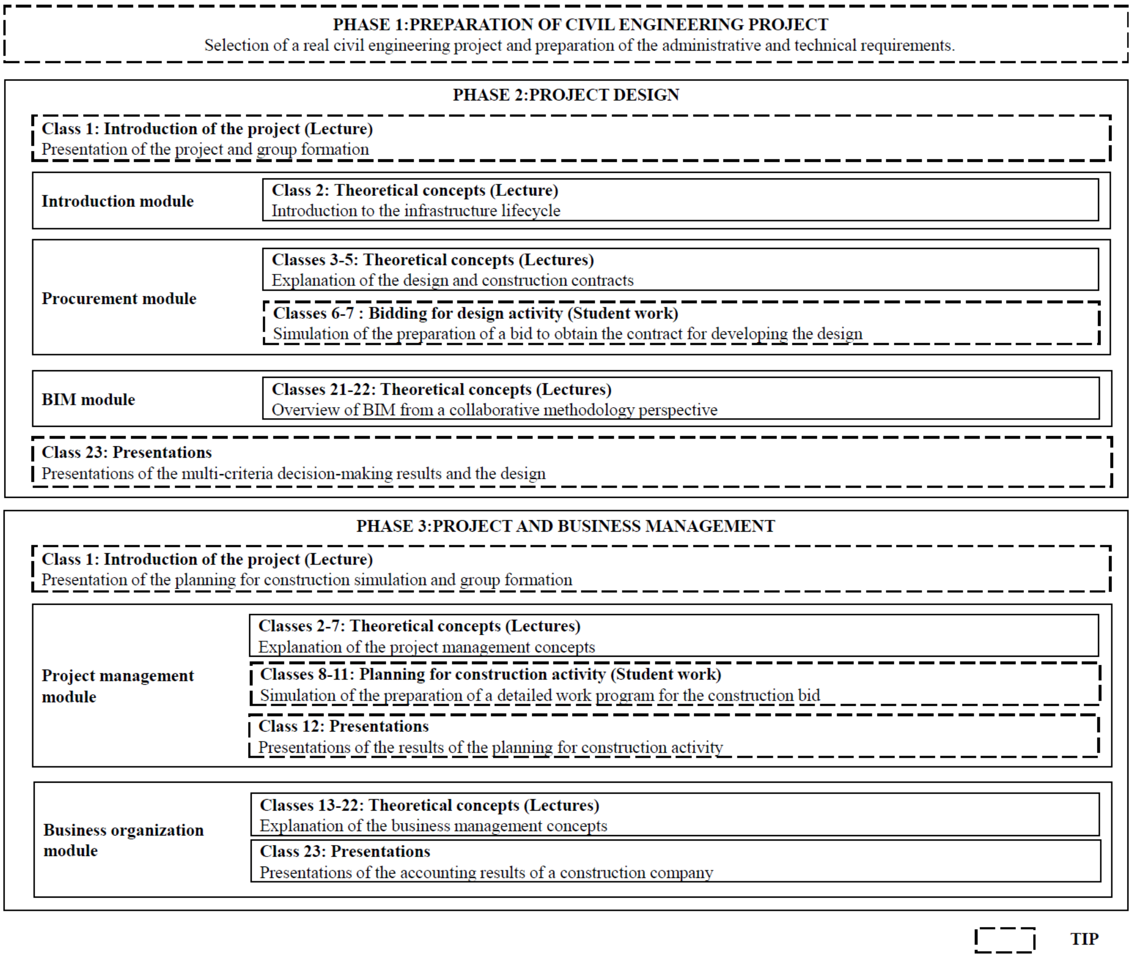


Fig. 3. Perceptions of the learning results in the Project Design course

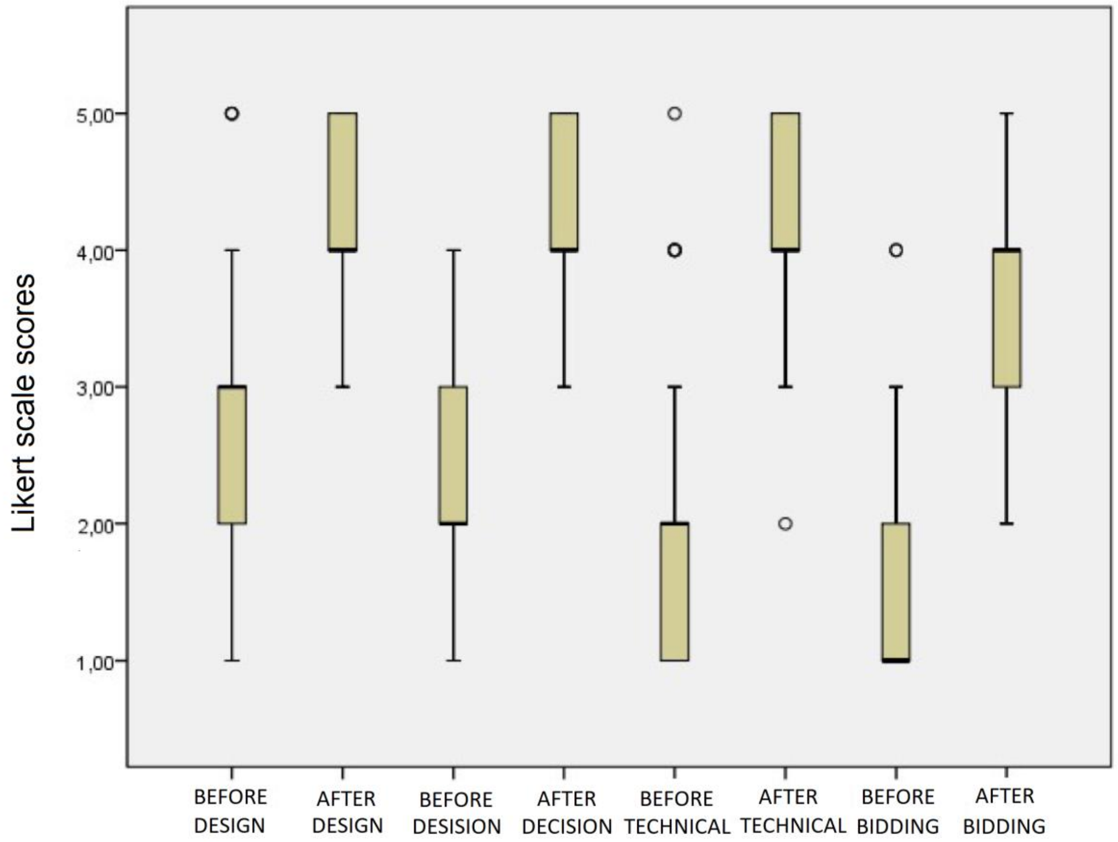


Fig. 4. Perceptions of the learning results in the Project and Business Management course

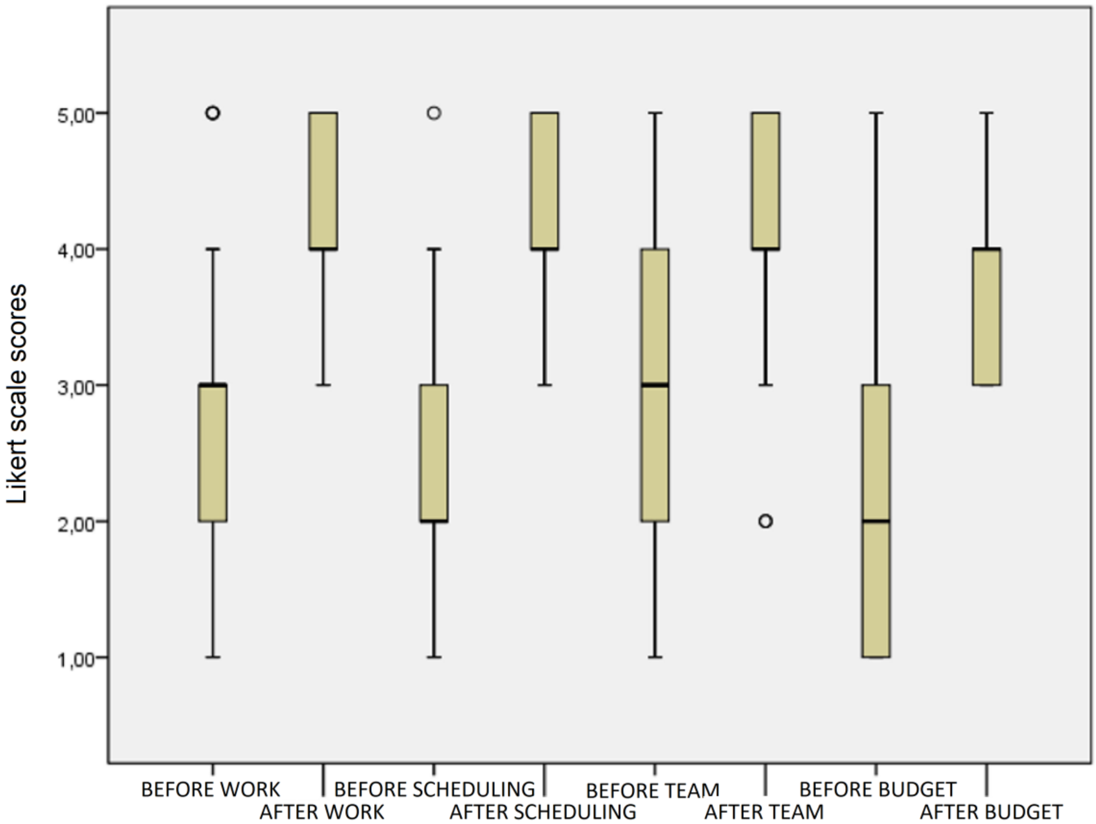


Fig. 5. Instructor's assessment of the learning results in the Project Design course

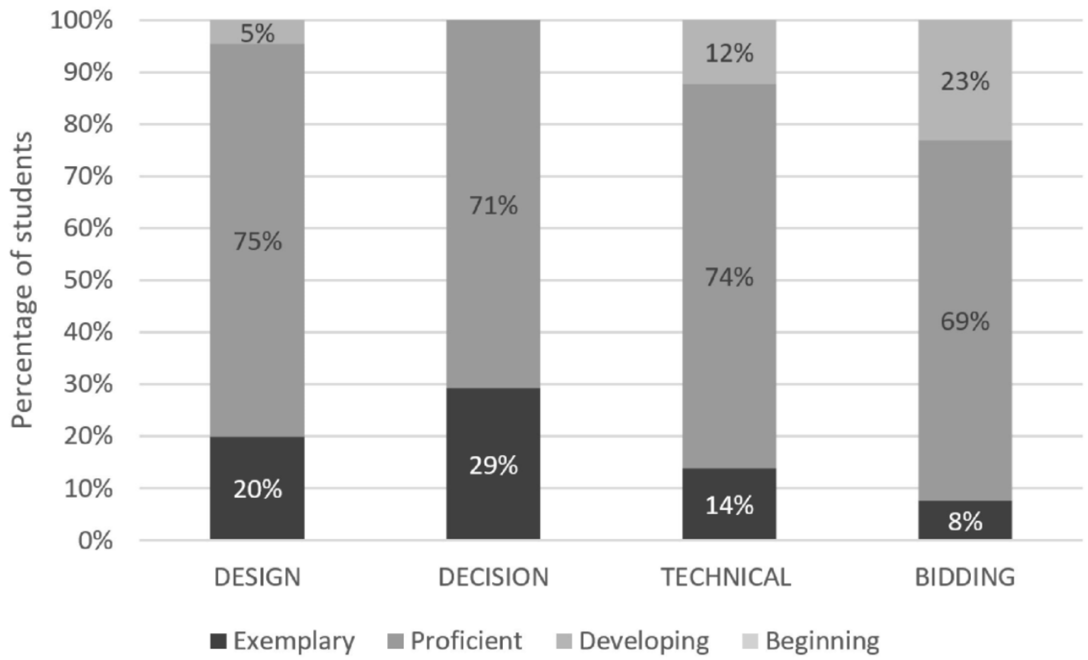


Fig. 6. Instructor's assessment of the learning results in the Project and Business Management course

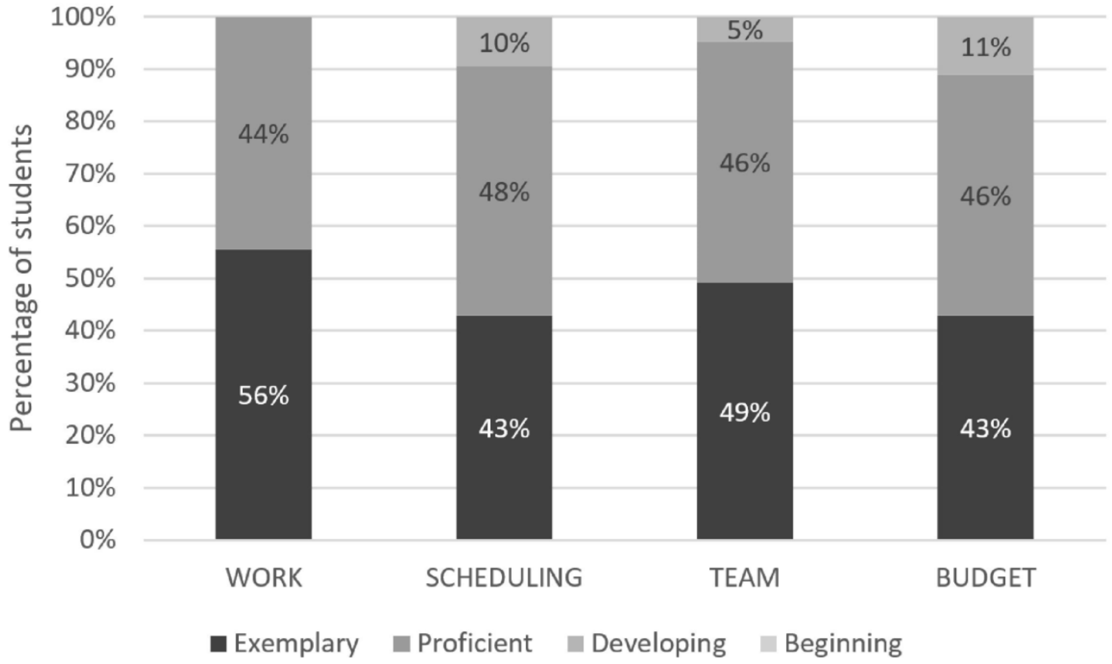
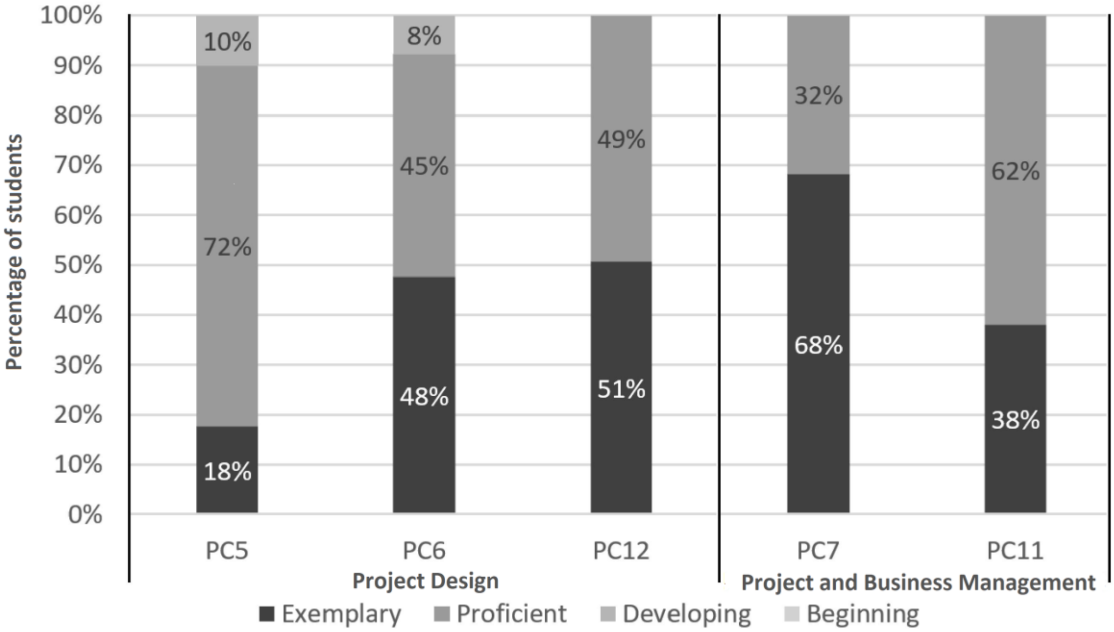


Fig. 7. Instructor's assessment of the five professional competencies



Note: PC5 = project design; PC6 = teamwork and leadership; PC7 = ethical, environmental, and professional responsibility; PC11 = continuous learning; PC12 = planning and time management