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Hybrid project-based didactic strategy in mechanical engineering courses

Estrategia didáctica híbrida basada en proyectos en cursos de ingeniería mecánica

Ricardo Yáñez-Valdez

Abstract

Adopting a didactic strategy that promotes education and autonomous work in the training of an engineering student while it generates academic products for the teacher-student binomial is a real possibility. The application of such a strategy in the hybrid educational model is presented to implement interactive courses in the Mechanical Engineering career at the National Autonomous University of Mexico. The methodological foundation is highlighted as a basis for the pedagogical design of the bimodal courses, and the practical cases developed by the authors in the undergraduate and graduate programs in mechanical engineering under this modality are presented. The research provides the analysis of results obtained from seven subject programs during the last academic periods from the second semester of 2015 to the first semester of 2022. The research based on design specifications, learning objectives, temporal organization, activities, formative and summative evaluation, and a scoring guide proved the efficiency of hybrid format for mechanical engineering courses. Based on these results, it is concluded that project-based learning strengthens professional training for engineering students and that it is feasible to apply a conceptual model that associates the project-based learning methodology, the disciplinary scope of a subject and the application of pedagogical techniques in a hybrid environment

Keywords: Higher education, project-based learning, professional training, teaching-learning process.

Resumen

Adoptar una estrategia didáctica que promueva la educación y el trabajo autónomo dentro del proceso de formación de un estudiante de ingeniería, y que tal interacción genere productos académicos para el binomio profesor-estudiante, es una posibilidad real. Se presenta la aplicación de dicha estrategia en el modelo educativo híbrido para implementar cursos interactivos en la carrera de Ingeniería Mecánica en la Universidad Nacional Autónoma de México. Se destaca el fundamento metodológico como base para el diseño pedagógico de los cursos bimodales, y se presentan los casos prácticos desarrollados por los autores en los programas de pregrado y posgrado en ingeniería mecánica bajo esta modalidad. La investigación brinda el análisis de resultados obtenidos de siete programas de asignaturas durante los últimos periodos académicos desde el segundo semestre del 2015 hasta el primer semestre del 2022. La investigación se basó en especificaciones de diseño, objetivos de aprendizaje, organización temporal, actividades, evaluación formativa y sumativa, y una guía de calificación demostró la eficiencia del formato híbrido para los cursos de ingeniería mecánica. Con base en estos resultados, se concluye que el aprendizaje basado en proyectos fortalece la formación profesional de los estudiantes de ingeniería y que es factible aplicar un modelo conceptual que asocie la metodología de aprendizaje basado en proyectos, el alcance disciplinar de una materia y la aplicación de técnicas pedagógicas en un entorno híbrido.

Palabras clave: Educación superior, aprendizaje basado en proyectos, formación profesional, proceso de enseñanza-aprendizaje.

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Introduction

The classroom has been considered the space in which formal education takes place. In this space, different cultural and socioeconomic contexts, as well as different emotional and psychological climates, coincide. In this space, students acquire knowledge through different didactic strategies applied by their teachers, who teach different subjects, which can be modified when professors consider this necessary (Kleinman, 2005; Okojie & Olinzock, 2006). The contents and objectives are established in the institutional programs or syllabi of each subject, and with them, teachers carry out their didactic strategy. Currently, technology has provided a virtual space in which the didactic process and other activities, such as consulting books or communicating through video calls, can be developed (Miranda, 2020).

The COVID-19 pandemic prompted the national educational system to carry out educational activities by electronic means so as not to interrupt the institutional educational process. Higher education, high school and middle school already had a work developed and implemented on distance and online education with specific characteristics, although a large part of the educational system was carried out in face-to-face interaction.

The educational field is directly concerned with the implications that the virtual aspect has for teaching-learning processes. In practice, interacting or learning virtually does not entail that this is less real; rather, it occurs via a different way of assuming the learning process (Flores & Meléndez, 2021)—a process in which greater autonomy on the part of students predominates because they have the possibility to self-schedule, self-organize, and collaborate and maintain contact with students and teachers from other regions or countries without apparent geographical limits. Of course, this freedom to "be able to do" must be accompanied by will, discipline, and clear objectives.

After the lockdown in summer term 2022, the return to face-to-face learning relationship gave the possibility of carrying out a hybrid teaching format. "Hybrid education" is an umbrella term that encompasses a variety of approaches including online, distance, remote, and flipped learning; all are aimed at providing student-centered experiences that are deeply personal, meaningful, and engaging (Kolova & Belkina, 2021), without neglecting the presence of the teachers. Hybrid teaching as used in the context of this paper is seen as defined as "synchronous teaching of students in the classroom and online using an online platform" (Ulla & Perales, 2022). This integrative approach

Ricardo Yáñez-Valdez. Profesor titular de la Facultad de Ingeniería de la Universidad Nacional Autónoma de México. Es Doctor en Ingeniería Mecánica y participa en el Centro de Diseño y Manufactura de la Facultad de Ingeniería de la UNAM con el propósito de investigar técnicas y metodologías en diseño mecánico. Tiene el reconocimiento del Sistema Nacional de Investigadores (nivel 1). Entre sus publicaciones recientes se encuentra el libro *Instructivo de prácticas de laboratorio de vibraciones mecánicas Parte 1*, realizado con la colaboración de estudiantes de posgrado en ingeniería mecánica de la UNAM. Es miembro asociado de la Sociedad Mexicana de Ingeniería Mecánica. Correo electrónico: ryv77@unam.mx. ID: https://orcid.org/0000-0002-8518-0906.

involves a combination of scientific education and practical training in technical skills based on an understanding of the problems that need to be solved (Jamison et al., 2014). This is especially important in the training of mechanical engineers.

On the other hand, teaching is no longer just transmitting a series of abstract and theoretical types of knowledge by virtue of the position and experience of the teacher; to teach, an epistemological approach based on three pillars must be consciously chosen (Díaz-Barriga & Hernández, 2010), i.e., knowledge, learning and teaching. Based on these concepts, the learning experiences that motivate the students begin to be planned, from practical, with what attracts them, guiding them to discover and develop their skills in a disciplined way so that they can obtain a broader vision of the interaction between theoretical and practical knowledge, which leads not only to learning but also to innovation. Hybrid teaching format is a process to achieve this purpose (Manciaracina, 2020).

This paper presents the results of a study in a hybrid project-based learning setting in the context of Bachelor (BA) and Master (MA) courses involved team-based engineering design projects in mechanical engineering at the Universidad Nacional Autónoma de México during the second semester of 2015 (2016-1, before the pandemic) until the first semester of 2022 (2022-2, during and after confinement). In the following, a review of existing literature in the field is introduced, before presenting the context and the methodology used. Finally, the results are presented and discussed before concluding.

Study purpose

When the starting point centers on cognition, learning and teaching, whatever the modality in which interaction occurs, the teacher adopts a position. An old-fashioned method in the classroom was to conceive of learning by affirming that students learn through reward and punishment (Sidin, 2021)—offering incentives or reprimands according to their performance, good or bad, in a course. If the position adopted by a teacher lean toward a real and objective approach, educators will generate learning spaces where students must reproduce the information that is provided. On the other hand, if this position responds more to interpretation, educators will ensure that each student evaluates and interprets the information, integrating it into activities that encourage discussion, debate, or criticism. Now, if the professor's conception corresponds to the foundations and methods of scientific knowledge, it will not matter that students simply repeat information or replicate it in the same way as the professor, provided they generate their own questions. Thus, the pedagogical approach of each teacher is different, dependent on their perceptions and beliefs and the environment in which they develop their teaching. The key is found in the level of interaction between teacher and students, entailing the need to overcome the challenge that the use of

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technology implies for one's adapted study modality (López & Valdés, 2020). In any case, the role of the teacher should be understood as that of a facilitator who does not impose a specific learning style but plans meaningful activities for different styles.

Accordingly, the design of project-based hybrid courses can respond to different approaches to knowledge, learning and teaching. In the last decade, there has been a growing interest in educational models of teaching-learning that are adjusted to real needs in the modern world (Romero-Saritama & Simaluiza, 2019; Gómez-Hurtado et al., 2020; Lozano-Ramírez, 2020; Morales-Alarcón et al., 2021; Peña et al., 2021), e.g., the development of new learning spaces (Rodríguez-Paz et al., 2019; Rodríguez-Paz et al., 2022), where solid educational results have been demonstrated in engineering (Gur, 2022). The project-based hybrid learning model has also proven to be a functional strategy in different areas of knowledge (Beneroso & Robinson, 2022; Martín et al., 2021).

The reasons for designing and applying a hybrid model in lieu of other teaching models were identified by Graham & Dziuban (2007): to improve teaching and learning pedagogies and increase accessibility, flexibility, and cost effectiveness. These three reasons could explain why instructors, trainers or students may choose blended learning over other types of teaching and learning.

Creating new learning methods centered on BA and MA students is of the utmost importance. In this sense, it was aimed to describe the experience of an application of the hybrid learning model during projects in curricular courses for the mechanical engineering career—to reveal how this strategy provides learning to students and significant results for the teacher, which are translated into tangible teaching resources.

Project-based hybrid learning

Conception of hybrid learning

A pedagogical model must always accompany students because the traditional (called face-to-face learning relationship) and virtual models are very different from each other. In Albiladi & Alshareef (2019), the mixed learning environment is illustrated in relation to face-to-face and online learning. In Rodríguez & Ramírez (2007), a mental map is illustrated in the development of a model that allows the design of bimodal courses, and roles are established as one of the didactic strategies to be used during face-to-face interaction developed in class. Competences and pedagogical models are related to the teacher, students, and technology to achieve meaningful learning and a coherent course with the hybrid model. Studies show that there are no significant differences between a physical or remote presence in terms of conceptual understanding and that successful learning and teaching activities are interrelated with established, epistemic, and social design decisions (Raes, 2022). A hybrid course model consists, therefore, of an adequate mix of these learning models, since there is no single model that allows the use of didactic strategies in accordance with the requirements of a course.

Challenges and stages of project-based learning

Throughout a course, the teacher proposes a series of activities with the intention of developing the skills of students. These are actions with a beginning and an end, with the purpose of assimilating, applying, and evaluating the information transmitted during the course. Students play an active role, not just a receptive one, to process this information. In this sense, it is essential that students discover work as a reality and as an essential value for their training, a value that in their own experience they translate into learning by observing, building, manipulating, repeating, and even correcting.

Project assignments are essential in university engineering courses since they allow the implementation of knowledge while confronting students with real situations in their discipline. Project work allows the achievement of educational purposes through a set of actions, interactions and resources aimed at the resolution of a specific problem or situation and the development of a tangible (such as a prototype) or intangible (such as productions) production. With this way of working, it is proposed that students learn from their own experience to apply the theoretical principles necessary to carry out their profession—not only to acquire knowledge about engineering but also to learn to be an engineer. Students will become engineers to the extent that they practice by being exposed to a series of projects that confront them with the real world, together with the complexity, uncertainty and frustration of the factors that influence such exercises (Ting-Ting & Yu-Tzu, 2020).

Project-based learning encompasses a sequence of activities arranged in stages. Table 1 shows a summary of these stages.

Table 1
Stages of Project-based Learning

Stage 1: Diagnosis to identify the problem
It is recommended to provide a global description of the project based on interviews, surveys, field visits, etc.
Stage 2: Planning and organization
This should involve the object of study, the justification for the project, the objectives, the activities to be carried out, the resources, the tools, the schedule of activities, the procedure to follow, and the results.
Stage 3: Execution
Planning, research, expert consultation, construction (design, manufacturing), experimental tests, presentation.
Stage 4: Evaluation
Students' achievements and difficulties in each project activity, learning outcomes, aptitudes, and abilities are evaluated. The progress of the project is evaluated, not only the results of the project.

Source: Made with data from Peña et al., 2021.

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Research methodology

It has been hypothesized that project-based hybrid learning will be the most efficient for acquiring knowledge and autonomous learning skills for future professionals of mechanical engineering while that such interaction generates academic products for the teacher-student binomial.

Participants

The sample (*n*) comprises undergraduate and graduate courses involving team-based engineering design projects in mechanical engineering in the Faculty of Engineering (FE) at the Universidad Nacional Autónoma de México (UNAM). At present, 12 of the programs of FE have the endorsement of the Council for the Accreditation of Engineering Education (Cacei), and the Graduate Programs in Engineering are part of the National Quality Graduate Program (PNPC) of the National Council of Humanities, Science and Technology (Conahcyt).

There were 375 participants in the BA courses and 30 participants in MA courses. Bachelor students are in their sixth (20%), seventh (50%) and eighth (30%) semesters, aged between 20 and 24 years; 22% were women and 78% were men. MA students are in their first semester, aged between 22 and 25 years; all of them were men. Five BA subject programs and three MA subject programs were considered without any selection criteria, each with a different number of participants according to enrollment. At least one group per semester worked within a hybrid learning format. The course duration comprised 48 hours of classroom work combined with autonomous activity. Classes were held in a university classroom two days a week, while virtual courses were conducted through Skype services (online lessons). During the pandemic, the Zoom platform was used instead of Skype. The focal students also organized virtual conversations to discuss their projects and share design concepts.

The research was carried out during the academic period from the second semester of 2015 to the first semester of 2022, approximately 16 weeks per semester in length from the first day of classes through the last day of exams (Table 2 to Table 5). In the period from the first semester of 2020 to the first semester of 2022, the University taught classes in all its programs and courses virtually due to the global health contingency. Being that way, in semesters 2021-2 (Jan.-June 2021) and 2022-1 (Aug.-Dec. 2021) no projects were commissioned.

Process

The projects carried out by students were unit projects and final projects (Table 2 to Table 5). Unit projects are short projects where two or three weeks of hard work are needed, and it is necessary to apply an analysis tool to carry them out. The complex-

Table 2

Hybrid project-based didactic setting in Bachelor (BA) courses before the pandemic

Group	Course	Semester	*n*	Project type and objective	Description
BA	Mechanisms	2016-1 (Aug.-Dec. 2015)	18	Final project: Design of a mechanism to turn a laptop on a desk	Design a mechanism that allows turning a laptop, inside a desk, from a storage position to a position for observation and use
BA	Machinery Dynamics	2016-2 (Jan.-June 2016)	32	Final project: Design and analysis of mechanism to guide an automatic weapon	Synthesize and analyze the dynamics of a mechanism that continuously guides a toy automatic weapon using an actuator
BA	Machine elements in mechanical design	2017-1 (Aug.-Dec. 2016)	42	Final project: Design and build a device that, subjected to rotation, can soar and fly	Design an aerial screw ¿is it possible to drive it mechanically?
BA	Mechanical Vibrations	2017-2 (Jan.-June 2017)	30	Final project: Vibratory model of a system with multiple degrees of freedom	Choose a vibratory system with more than one degree of freedom and model its displacement response
BA	Machine elements in mechanical design	2018-1 (Aug.-Dec. 2017)	40	Final project: Mechanical design of a speed multiplier based on an epicyclic train	Apply the theory of machine element design and design and build a gear train that delivers a higher output angular velocity than the input velocity
BA	Mechanisms	2018-2 (Jan.-June 2018)	25	Final project: Synthesis of a cam follower system	Apply a follower cam system to orient a mobile base
BA	Machine elements in mechanical design		42	Final project: Design of a single-seater hovercraft	Design a scale hovercraft to transport a crew member
BA	Selected Topics in Mechanical Engineering	2019-1 (Aug.-Dec. 2018)	3	Unit Project: Apply geometric tolerances in the design of a flat mechanism	Design a flat mechanism and apply geometric tolerances of shape, orientation, and location
BA	Mechanisms	2019-2 (Jan.-June 2019)	29	Unit Project: Design of a closing mechanism for fastening profiles structural using flat cams	Design a closing mechanism based on a flat cam for non-clamping permanent structural profiles
BA	Machine elements in mechanical design	2020-1 (Aug.-Dec. 2019)	24	Unit Project: Design of torsion springs	Design a projectile launcher mechanism and apply a torsion spring to store energy

Source: Own construction.

ity of such a project corresponds to the content in a unit of the course syllabus. On the other hand, final projects, are long projects; they require six or eight weeks of dedicated work where it is necessary to apply two or more analysis tools to complete them. The complexity of such a project corresponds to most of the course content. The decision to include one or more-unit projects, a single final project, or a combination of these is made by the teacher.

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Table 3

Hybrid project-based didactic setting in Master (MA) courses before the pandemic

Group	Course	Semester	*n*	Project type and objective	Description
MA	Mechanical Vibrations	2018-2 (Jan.-June 2018)	6	Unit Project: Control of vibrations in embedded beam subjected to harmonic excitations by imbalance	Design an experiment and mitigate the vibrations by means of a vibration absorber
MA	Classical Mechanics	2019-1 (Aug.-Dec. 2018)	8	Unit Project: Analysis and application of variational calculus	Study the problem of the brachistochrone curve in an experimental way
MA	Classical Mechanics	2019-2 (Jan.-June 2019)	5	Unit Project: Nonlinear mechanics and chaos	Study the dynamic characteristics of a double pendulum, related to the concepts that define a chaotic system, such as sensitivity, unpredictability and nonlinearity
MA	Mechanical Vibrations	2020-1 (Aug.-Dec. 2019)	5	Unit Projects: Vibratory systems; modeling and experiments	Design experiments of different vibratory systems, according to the topics included in a current course, to validate the theoretical models
MA	Machine elements in mechanical design		4	Unit Project: Resonance and its effects	Experimentally check the effects of resonance on an unbalanced body

Source: Own construction.

Table 4

Hybrid project-based didactic setting in Bachelor (BA) courses during the pandemic

Group	Course	Semester	*n*	Project type and objective	Description
BA	Machine elements in mechanical design	2020-2 (Jan.-June 2020)	34	Final project: Mechanical design of a speed multiplier based on an epicyclic train	Design a projectile launcher mechanism and apply a torsion spring to store energy
BA	Machine elements in mechanical design	2020-2 (Jan.-June 2020)	34	Final project: Mechanical design of a speed multiplier based on an epicyclic train	Apply the theory of machine element design and design and build a gear train that delivers a higher output angular velocity than the input velocity
BA	Machinery Dynamics	2020-2 (Jan.-June 2020)	22	Unit Project: Simulation of spatial kinematics	Derive the equations of motion for different problems of analysis on the rigid body in space and simulate them

Source: Own construction.

Each project is carried out according to some topic of the course content. For example, in the subject of gear design, for the subject of machine element design, students applied the knowledge to solve a problem posed as a final project whose objective was to design a speed multiplier based on an epicyclic train. Another ex-

Table 5
Hybrid project-based didactic setting in Master (MA) courses during the pandemic

Group	Course	Semester	*n*	Project type and objective	Description
MA	Classical Mechanics	2021-1 (Aug.-Dec. 2020)	2	Unit Project: Quadratic resistance of air	Derive the equations of motion for a projectile that is projected in a resistant medium and is subjected to a uniform gravitational field

Source: Own construction.

ample, in the resonance theme, from the mechanical vibrations course; students applied their knowledge to solve a problem posed as a unit project, demonstrating the torsional resonance phenomenon.

Each group of students, separated into teams of 4 or 5 members, solve the same problem, with agreed upon restrictions and specifications. Besides, all group of students were offered the same course material and support independently of their participation in the study. Students must come up with a creative solution to such a problem, check its solution and demonstrate how it works. The teacher remains involved throughout the project in the role of advisor. Therefore, it takes only a few minutes to resolve the doubts raised at the beginning of a class or respond via email if necessary. Feedback is essential in the achievement of a project.

Instruments

The effectiveness of the proposed method and its related features were evaluated qualitatively. At the end of the course, semi-structured interviews were conducted with each team. A special 16-item questionnaire in Educafi forms was conducted to reflect on what students had learned working under each project and what challenges they encountered. Educafi is a learning management service supported by Moodle through which the teachers create virtual learning environments. It was developed and managed by academic computing services (Unica) at UNAM. The questions were answered and printed by the participants before the final examination. Additional questions that were not previously prepared by the teacher as interviewer could be asked.

Whit these semi-structured interviews, students were to articulate three domains: (a) planning, (b) design criteria, (c) challenges, and (d) applied solutions. Additionally, students are directed to share the professional development, skills, or experiences that they had previously acquired with their peers. On the established delivery date, each team presents a statement of their problem, the objectives that have been derived, their results and the implementation of their solution. Eventually, it is possible to identify that one solution is better than another. The best result is chosen and developed to prepare it according to the academic product that it merits. Survey lasted 15 minutes. Notes were taken to conduct content analysis.

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Procedure

First, the learning objectives must be defined: the knowledge, skills, and attitudes that students should manifest because of their participation in the different learning activities. These activities are needed to acquire and master the content and skills to be developed. For example, at the end of a given course, students will demonstrate competence when defining, explaining, distinguishing, identifying, writing, etc. For such a learning objective to have an impact on teacher productivity, the project-based learning methodology in the hybrid learning modality should be adopted. According to the stages of this modality (see Table 1), in the development of an engineering project, there are three important moments:

1. The identification and description of the problem, their requirements, and specifications.
2. The approach to and selection of concepts to implement the best solution.
3. Testing the functionality of the solution in addition to communicating it.

At all times, students are required to mobilize their previous knowledge and learn from others, working in situations close to everyday school life in such a way that they learn by doing. Their experience becomes a way to exercise active learning. Thus, following this process should lead to the production of relevant knowledge, allowing it to be naturally integrated into the practice of students as a dynamic, constantly evolving process (Prince, 2004).

By identifying a need, the reality of the problem to be solved is pointed out objectively. All the characteristics of the problem, the facts and background, are described. At the same time, the restrictions imposed or identified, as necessary, must be translated into clear specifications. In the implementation of the solution, the best solution studied is applied, and its feasibility is tested and iterated if necessary. The best solution is not always the cheapest, and its feasibility should be evaluated based on the available resources.

Disseminating results implies the elaboration of tangible teaching tools. Like reading, writing involves an intellectual effort and a broad process; thus, the production of written texts will be significantly related to the didactic activities that derive from the project itself. It is important that each document, derived from one or more projects, has sufficient quality in its writing (coherence and cohesion, organization, pagination, and formal aspects of the text), supporting its potential to be published in a forum according to the level of commitment and seriousness. Any evidence on the development of the project as well as its solution is stored for future consultation by students and those interested in similar projects or as a reference for students just entering their career. These activities should be carried out systematically to achieve better results.

Temporary organization of content presentation

The next step is to define the temporal organization of the presentation of content, activities, evaluations, and other actions carried out throughout the courses. This is programmed according to the learning objectives to ensure there is coherence between the topics, activities, and learning assessments. The quantity and complexity of the material to be developed, the activities that will need to be included, and the forms of evaluation must be established. At this point, the needs of the distance students, their access possibilities, and the types of support and tutoring that will be required by the teacher on, for example, an educational platform should be considered in the organization of a project-based hybrid course.

- *Information*. This refers to information related to the topics of the educational program. It must be adaptable to different virtual education platforms that adhere to the Sharable Courseware Object Reference Model (SCORM) standard and should be considered a complement to the material presented in a class, which students are encouraged to consult independently.
- *Evaluation*. Evaluation of the fulfillment of the objectives involves verifying what students have truly achieved, or are achieving, in terms of the competencies established in the objectives of each topic or unit. Such evaluation is not only summative but also formative (Romero et al., 2018); it is a means to certify the knowledge and skills of students and a source of feedback for the teacher.
- *Virtual platform: Materials and contents*. The virtual platform allows to organize a variety of tools on which the development of a virtual course is based and, as students, to access these resources. The teacher must clearly establish the rules and procedures from the beginning, emphasizing consistency, since students will be able to navigate the course with greater fluency and confidence when they can access its contents and activities in expected spaces.

  Just as the content of the subject to be discussed is of the utmost importance when designing a project-based hybrid course, so are the support materials related to the subject. They must be available to students to ensure they can find what is necessary to orient themselves and understand or expand the topics covered. The following elements must appear on the virtual platform:

  - *Course program*. The information that the program should include is as follows:
    - Name, group, hours, and prerequisites.
    - Teacher data. A contact email where students can submit their individual queries about the course. Hours and place of attention for students.
    - General objective of the course.
    - Thematic content with objectives.

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- Schedule of activities.
- Methodology and learning strategy.
- Evaluation, items, and percentages.
- Teaching resources.
- Bibliography and references.

- *Materials*. It is possible to include any type of file if they are organized logically. The course syllabus can be used as the basis for sorting folders, readings, text, videos, tables, diagrams, presentations, notes, etc. by topic or subtopic so that access to the information is adequately facilitated.
- *Instructions*. Instructions must be fully explained in writing. The description area can include instructions for carrying out tasks, exercises, practices, projects, or research work.
- *Bibliography*. It is important to include a mandatory or complementary bibliography, as a list or as files, with hyperlinks, etc. for any type of classification.

Results

The strategy for promoting the teaching of meaningful learning rests on three main attitudinal characteristics: a) the teaching and learning proposal is organized around relevant problems in which b) students see themselves as protagonists of the problems raised and where c) a pedagogical environment is constituted in which students carry out a cognitive activity, developing complex skills using their criteria for decision-making. At the end of each course, semi-structured interviews were conducted with each student. A survey form was worked out to reflect on what they had learned working under the projects.

The students admitted that the hybrid project-based course helped them to learn their professional skills. The majority (91.2%) liked the hybrid way for communication, which was a specific way of the organization for the educational process. Few participants (35,8%) of the project-based course admitted that they had learned how to interact with other students effectively. Some participants also noted that they had learned many things about adaptability and how to involve themselves in an education process.

79,6% noted that they learned how to use new methods of organizing their studies while studying supported material. Some of them (25.4%) appreciated learning with practical and challenging projects. As the graduate participants had proper technical and technological skills, the course assisted them to acquire new communication skills, which could help them mastering their engineering skills. 79.9% agreed that project-based learning course completion increased their level of proficiency. Table 6 to Table 9 show the results achieved by the teacher/students pairing.

Table 6
Academic products generated before the pandemic with BA students

Semester	Final participants	Academic product
2017-2	1	Divulgation article: Coupled oscillators (Normal modes approach) (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/12123)
2018-1	3	Divulgation article: Diseño mecánico de un multiplicador de velocidad basado en un tren epicicloidal (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/12948)
2018-2	2	Divulgation article: Diseño de mecanismo con doble leva plana (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/15253)
	4	Divulgation article: Diseño mecánico de un aerodeslizador monoplaza (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/14395)
	3	Divulgation article: Control de vibraciones en viga empotrada sometida a excitaciones armónicas (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/14418)
2019-1	1	Divulgation article: Aplicación de las tolerancias geométricas en un mecanismo de cruz de malta (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/15347)
2019-2	3	Patent request (status: Accepted) Title: Quick closing and opening mechanism for fastening structural profiles (https://aim.autm.net/public/project/45071/)
2020-1	4	Divulgation article: Aplicación de un resorte de torsión para el diseño de un mecanismo lanzador de proyectiles (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/17059)

Source: Own construction.

Table 7
Academic products generated before the pandemic with MA students

Semester	Final participants	Academic product
2019-1	1	Divulgation article: El problema de la curva braquistócrona (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/16004)
2019-2	1	Divulgation article: El péndulo doble como ejemplo de sistema caótico (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/16363)
2020-1	1	Divulgation article: Resonancia torsional: Probando el fenómeno (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/16759)

Source: Own construction.

All teams were given the same indication of a problem posed by the teacher with similar restrictions and specifications. The students came up with a creative solution to their problem, tested their solution and then demonstrated how it works.

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Table 8

Academic products generated during the pandemic with BA students

Semester	Final participants	Academic product
2020-2	5	Divulgation article: Avances en el diseño mecánico de un multiplicador de velocidad basado en un tren epicicloidal de dos etapas (http://132.248.52.100:8080/xmlui/handle/132.248.52.100/17191)
2022-2	1	Digital teaching material Title: Kinematic simulations FI-UNAM (https://www.youtube.com/watch?v=P0yzYoJUPro&t=123s)

Source: Own construction.

Table 9

Academic products generated during the pandemic with MA students

Semester	Final participants	Academic product
2021-1	2	Journal article: Horizontal projectile motion comparing free fall and drag resistance. (https://doi.org/10.31349/RevMexFisE.17.156)
2021-2	5	Book: Instructivo de prácticas de laboratorio de vibraciones mecánicas parte 1 (by-product from the unit projects of 2019-2 "vibratory systems") (http://www.ptolomeo.unam.mx:8080/xmlui/handle/RepoFi/17572)

Source: Own construction.

Regarding evaluation in the teaching-learning process

The indicator on the summative evaluation that was carried out prior to the completion of each project revealed the degree of retention in the fundamental knowledge that students obtained via an exam with concept questions and problems posed in a specific way. On the other hand, when evaluating the projects, either unit project or final project, a formative evaluation was favored. This should be promoted by the teacher himself because it serves as a basis for students to learn to appropriate the concepts and criteria that motivate self-regulation and self-learning (Mora-Torres et al., 2011). Mutual evaluation is always recommended because it encourages self-evaluation and co-evaluation by the members of each team (Espejo et al., 2021).

The rubric, as a scoring guide, describes the degree to which a student is executing a process. It allows tracking the progressive levels of competence and expertise through a range of possible performance metrics and how students move from one level to another. The evaluation of the results of the projects described in Tables 2 to 5 was thus carried out using the rubric shown in Table 10. Self-evaluation and co-evaluation of the participants was carried out, motivating an interesting discussion of their results. All team members were encouraged and given the opportunity to participate.

Table 10
Rubric for evaluating unit and final projects

	Performance level	10-9 Practitioner	8-7 Apprentice	6 Rookie
Execution criteria	Dominance and authenticity	Linked to real life	Little credibility and poorly linked to reality	Implausible approach
	Understanding the topic	Moderately enough	Uninteresting	Lack of clarity
	Following up on the topic and opening discussion	Stay on topic all the time, encourage serious discussion	Stay on the subject most of the time, some traces of discussion	Hard to stay on topic, biased
	Complexity of the proposal	Demonstrate superior cognitive abilities	Knowledge and skills are perceived to be scarce	Knowledge is low
	Vocabulary	Vocabulary appropriate for the audience, they even define words that might be new to them	Appropriate vocabulary for the audience. They include words that may be new but do not define them	Vocabulary not very appropriate for the audience
	Curricular link	High curricular incorporation	Average curricular link	Link with the content is scarce

Source: Own construction.

Discussion of the results

Because the project-based hybrid learning model strategy comprises an instructional method based on inquiry and collaboration, which facilitates students' learning through their participation, commitment and enthusiasm, it contributes to their construction of experiences, knowledge and the development of their competences because students must identify a need, describe the problem, determine what they know and what they do not know, find information and provide creative solutions, encouraging their imagination and discipline.

Whether for strategic planning or in a health emergency, a teacher must make the most of the virtual learning environment in any of its modalities. Experience and knowledge are essential to the successful application of the instructional design model (Dorfsman & Horenczyk, 2021). A diagnosis to understand the didactic strategies implemented by experts and develop training processes that strengthen teaching practice is therefore recommended.

In order to guarantee the effective execution of a project, the following is recommended: Before a course, each project must be defined according to the content of the subject with sufficient clarity. A final project must be more ambitious than a unit project. Execution times must be set very carefully. The teacher's experience and his or her knowledge of the state of the art in his or her field of expertise is essential to propose projects with excellent potential. During the development of their project, the students most committed to their training should be identified. The most

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important results depend on both parties. Finally, the best proposal must be selected by comparing the results of each work team, preferably publicly and partially. This motivates students to continue in consistent work. Credit for students should not be overlooked for any reason.

During the project review stage, students should be motivated to propose creative solutions and they should know that it is not enough to simply repeat a solution for convenience or because it is easier. The teacher always acts as a facilitator, motivator, and moderator to ensure that students are taught that what is complicated is interesting and is, then, a challenge to overcome; thus, they will more strongly associate with and dedicate themselves to work.

Conclusions

Education and work are essential aspects in the development of an engineering student because they are part of their own life (Picard et al., 2022). Work is a unique resource, capable of contributing elements of innovation through the application of creativity and imagination. Today, it is not enough to educate young people by transmitting a series of abstract and theoretical information; it is necessary to educate them with practical experience.

It is essential that students discover work to be a substantial value for their training, a value that in their own experience translates into learning when observing, doing, building, manipulating, repeating, and correcting. Project-based learning is essential in university engineering courses since it allows the implementation of knowledge while confronting students with real situations in their discipline. This activity represents, for students, a way of applying what has been learned in class while assimilating their acquired learning; for the teacher, it represents the possibility of generating an academic product through teaching whose potential is based on the problem raised or the scope itself; it could be a theoretical problem or an experimental one.

The development of innovative methods in the teaching of engineering through the methodology of project-based learning is justified when students achieve the curricular integration of contents, which normally appear in no apparent order, i.e., the ability to specify practical results in a real-world approach. When applying the rubric described in Table 10 to evaluate the construction of learning, students are understood to have acquired the level of practitioner by contrasting the indicators on the left and the performance levels at the top.

Regarding the attributes for graduation from the Faculty of Engineering (FE) at the Universidad Nacional Autónoma de México (UNAM) (see Table 11), which lists competencies and indicators, project-based learning contributes to developing attitudinal learning among mechanical engineering students.

Table 11
Attributes for graduation and their indicators for a mechanical engineering career

	Description	Indicator
Attribute 1	AE1 Identify, formulate and solve mechanical engineering problems applying the principles of physics, mathematics and engineering sciences, as well as computational and experimental tools	AE1-I1 Identify and analyze mechanical engineering problems
		AE2-I2 Plans and solves mechanical engineering problems using basic science and engineering science knowledge
Attribute 2	AE2 Use mechanical engineering design methodologies for the development of mechanical and electromechanical systems, as well as thermal and manufacturing processes, that comply with technical and environmental standards	AE2-I1 Develops engineering projects that meet specific needs
		AE2-I2 Apply your design knowledge to solve engineering problems
Attribute 3	AE3 Analyze and interpret data, as well as plan and develop experimental procedures and draw conclusions	AE3-I1 Adequately develops experimental procedures
		AE3-I2 Analyze information and interpret data to draw conclusions
Attribute 4	AE4 Communicate effectively orally and in writing with different audiences	AE4-I1 Prepares written reports with the requested structure
		AE4-I2 It is expressed orally before different audiences with due structure and clarity
Attribute 5	AE5 Make decisions that allow them to solve the problems that arise in their professional life, recognizing their ethical and professional responsibilities, as well as assessing the economic and social consequences	AE5-I1 Assumes ethical responsibility in its projects and work carried out
		AE5-I2 Analyzes and assesses the social and economic impact in accordance with current regulations
Attribute 6	AE6 Recognize the need to acquire, understand and put into practice cutting-edge scientific and technological knowledge that complements and updates their academic training, through courses, diplomas and graduate studies	AE6-I1 Produces bibliographic documentation on innovative and cutting-edge topics in mechanical engineering
Attribute 7	AE7 Work in teams that develop tasks or projects, in a timely manner, and complying with specific design parameters	AE7-I1 Develops team tasks and projects
		AE7-I2 Meets the guidelines established in tasks or projects

Source: Made with data from UNAM, 2023.

Based on the evidence, we conclude that the project-based hybrid learning model strengthens professional training in engineering students and that it is feasible to apply a conceptual model that establishes a relationship between the project-based learning methodology and disciplinary field of a subject and the relevant pedagogical techniques applied in a hybrid environment. Therefore, it is also feasible that this method can be applied in other areas of engineering (industrial, civil, informatics, mechatronics) using their own learning objectives and within the corresponding value in the interaction of the teacher/facilitator/tutor-student pairing.

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