Improving professional skills in a multidisciplinary team of undergraduate engineering students through project-based learning

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Abstract. Even though undergraduate engineering education often considers laboratory experiments as its practical component, these activities may not contribute to the development of soft (professional) skills. At “Universidad de Ingeniería y Tecnología”, Perú, a series of courses called interdisciplinary projects has been created to promote the development of professional skills through project-based learning; herein, we report the experience of an interdisciplinary group of students focused on designing an indoor air filtration system to improve air quality and to reduce the spread of coronavirus diseases. Eight undergraduate engineering students were organized into three groups and worked collaboratively to learn about antiviral nanocomposites, user-centered design, and electromechanical systems design; they showed their progress and received feedback from each other through weekly meetings. In addition, they leaned on applications to organize the group work and share the bibliography consulted; finally, we collected feedback from these students on the proposed learning method. The positive impact of our problem-based learning approach on undergraduate engineering students is discussed.

1. Introduction

Engineering education prepares students by giving them the necessary tools for identifying and solving societal problems by applying scientific concepts. Inside the classroom students get theoretical knowledge, which is complemented with practical (laboratory) activities. However, these activities are almost exclusively executed under controlled environments which do not necessarily represent real-life conditions and therefore may not prepare the students for pressing challenges our society is facing [1]. Thus, in a professional context, students may enter the working environment with insufficient professional skills. For example, Direito [2] stresses the fact that soft skills are nowadays strongly required by the market, but these requirements may not be met as most engineering programs produce students with sufficient technical knowledge but at the same time with insufficient soft skills. Providing
engineering students opportunities to participate in real-life experiences will therefore help them acquire professional skills such as team organization, assertive communication, and project management capacity.

Project-based learning (PBL) is a methodology for promoting the learning process in students through the application of theoretical concepts acquired by the students to solve a realistic problem or challenge. At the Universidad de “Ingeniería y Tecnología (UTEC)”, Perú, series of courses called Interdisciplinary Projects has been incorporated into the undergraduate engineering curricula, with the objective of developing skills related to teamwork, communication, and critical thinking. In these courses, collaborative projects are proposed by students or faculty, and students from different engineering fields come together to propose a solution during one semester; previous publications regarding the nature of this course and the outcomes are available in the literature [3,4].

Under the current context of the COVID-19 pandemic, we proposed an interdisciplinary project related to the design of indoor air purification systems. Eight students from different disciplines worked together, guided by three leaders (graduate students or staff members) and a faculty overseeing the process; by forming three groups focused on user-centered design, antiviral filters based on nanomaterials and the design of an electromechanical system, a closer look to engineering design was provided. The perspective of students is summarized in the present article; it was collected through student surveys at the end of the course.

2. Methodology
This series of courses was implemented to promote the development of critical-thinking and creativity to solve real-life problems, and to reinforce effective communication and interdisciplinary collaboration skills of students. This series is composed of three mandatory courses, given in the first, second and third years. Each of these courses have two credits, which means that students must have sessions of two hours per week with the lecturer and/or with teaching assistants; additionally, students are expected to dedicate two additional hours outside of the class hours.

The evaluation considered three components, as described in Table 1; design and development of solutions (C1) is assessed by the lecturer, according to the students’ capacity to define and formulate a problem giving possible solutions in terms of feasibility and viability. Self-evaluation (C2) has the purpose of allowing the students to experience an introspection process that helps them to identify areas of improvements and strengths. In addition, it proposes student to participate in their own learning process and peer through critical judgements on the work of their peers. Project (P) is an assessment of the capacity of the team to achieve the goals outlined in the project; it is done by the lecturer.

| Component                          | Weight (%) |
|-----------------------------------|------------|
| Design and development of solutions (C1) | 40         |
| Self-evaluation (C2)              | 20         |
| Project (P)                       | 40         |

2.1. The case of study
To ensure an active participation of students from various engineering disciplines, projects are often focused on solving current problems; thus, we decided to propose a project around the challenges associated to the current pandemic. The coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is spread through many mechanisms being airborne and droplet transmission critical in indoor spaces [5,6]. Indeed, studies found that the virus persisted for several hours in the air, allowing a fast spread [7]. Thus, it is of utmost importance to ensure that the air is free of bioaerosols containing SARS-CoV-2, which is particularly difficult in closed environments.
In this sense, ventilation strategies to reduce indoor exposure have been complemented by filtration and other cleaning strategies [5,8]; however, it is important to have filtering materials which do not allow the survival of the virus and bacteria as it can be a source of pathogens. Silver nanoparticles have demonstrated antimicrobial and antiviral properties [9-11] and, therefore, they can be incorporated into a filter to potentially reduce the viral load in air. Since our research group has developed several nanocomposites and has tested their antimicrobial properties [12,13] we decided to transfer the knowledge from research into a project-based learning case. We proposed to develop a user-centered design of an air filter based on nanocomposites to reduce the spread of COVID-19 and other respiratory diseases in indoor spaces.

2.2. Description of the team and the strategies followed
A proposal based on various aspects of design required the formation of an interdisciplinary group of lecturers and leaders. Thus, the lecturer in charge of the group (JCFRR) invited the participation of professionals with experience in user-centered design (MRG), nanomaterials synthesis (LPM) and in electromechanical systems (DCH). Eight second-year students enrolled in this project, from industrial engineering, mechatronics engineering, and bioengineering. In the first session there was a welcoming session, where the students organized themselves in three groups and worked collaboratively. Each group worked on one of the following topics: user-centered design, antiviral filters, and electromechanical systems design. Every week they presented their progress and received feedback from each other. During the semester, students were introduced to two platforms:

- Notion (https://www.notion.so/) a tool useful for notetaking, project, and task management, all in one workspace.
- Mendeley (https://www.mendeley.com/), a reference manager that allows you to easily generate references, citations and to add bibliographies; both were used by students to facilitate their research work.

2.3. Collection of student feedback
In order to receive feedback from students about the implementation of the interdisciplinary projects course, a series of surveys was carried out. Its structure contains three main aspects: course expectations, soft skills, and course development during the semester. The first section considers the expectations of each student and the level of satisfaction (including highly positive, positive, neutral, negative, and highly negative) after taking the course. The second section focuses on how the tools taught during the course (i.e., Notion, Mendeley) and group meetings, have helped to develop the interdisciplinary project. On another hand, it was also considered the improvement of soft skills of each student after taking the course. Finally, the last section addressed the difficulty and time requirements of the course from a student’s perspective.

3. Results and discussions
The first team focused on user-centered design, making interviews to potential users to ponder their interest in having an indoor air purification system and the desired characteristics; the data collected were about targeted areas/rooms where purification systems are needed and the characteristics of the product (shape, size, color, and extra functions for an air system). The results were shared with the rest of the group.

The second team focused on the antiviral filter development started with a literature review on several supports for silver nanoparticles and protocols for their synthesis and impregnation; after evaluating several supports for silver nanoparticles and receiving feedback from other groups, they chose cotton for their efficiency, adaptability, and simple usage. They built a prototype and made an air filtration test.

The third team started working on ANSYS simulations of different air filters design on several places in a room to determine the best design and position for the system. After several iterations with the feedback of other groups, they proposed a final design for the air filter system with a control component.
At the end of the semester, when the design was finished, surveys and interviews with potential users were done to assess the functionality and convenience within users; each group reported their results in a final document with an article structure and, among them, a poster and pitch presentation of the proposed air-filter. The survey allowed us to determine the general opinion of students towards this course; the results show that 6 students qualify the experience as “highly positive” and 2 as just positive (75% and 15% respectively). Based on a feedback session, students mentioned the skills they considered they developed through the course; the results are shown in Table 2.

Results showed in Table 2 that students consider assertive communication as the skill that has been better learned within the group. This aspect influences positively the performance of the team, likely because team members were students from different majors and wanted to improve their communication at a professional level. Team organization and team planning were the second and third skills that were highlighted by the students. Students mentioned that they learned that it is very important how a team is organized and how plans must be designed and followed, distributing responsibilities, and defining project deadlines. In this regard, they considered that notion is an important tool that helped them to achieve good team organization and planning skills; as indicated in Table 2, the collaboration with peers was not perceived as well developed, likely because they kept work independently once the duties were assigned.

Students also considered that the tools employed for facilitating teamwork and organization contributed to the project. In this sense, 50% of the students indicated that the use of Mendeley was highly positive, while 37.5% of the students consider it positive, with 12.5% being neutral about it; many stated that they had started using Mendeley for other projects since this experience. On the other hand, 62.5% of students rated Notion as positive for allowing the organization of weekly activities, 25% considered it had a neutral effect, and 12.5% rated it as negative; overall, these results show that the use of tools such as Mendeley and Notion affects positively the work students do in interdisciplinary groups.

| Table 2. Skills developed through the course, according to students. |
|-------------------------------------------------------------|
| Skills                       | Percentage of acceptance (%) |
| Assertive communication   | 37.93                        |
| Team organization          | 31.03                        |
| Team planning capacity     | 24.14                        |
| Collaboration with peers   | 6.90                         |

The aspects where improvements were needed are shown in Table 3. According to these results, schedule conflicts (overlapping with other activities) was the biggest issue within the working groups. This was originated from the fact that the meetings for each group were difficult to schedule as they had completely different class hours. Also, students mentioned that the duties associated with the project were very time-consuming, as they had to learn about specific topics where they had no previous experience.

This perception is also related to the second and third aspects (excessive academic load and lack of previous knowledge) since the novelty of the topics and the learning process required significantly more time than that expected for a two-credit course; some students mentioned that in some weeks they dedicated similar time to this course than to four-credit courses. In addition, as a result of the absence of good communication, one student mentioned that during the first weeks they would develop similar tasks within the group, but this aspect was improved at the same time that team organization and team planning skills were improved throughout the course.

| Table 3. Aspects where improvement is needed, as collected from the survey. |
|-------------------------------------------------------------|
| Comments             | Frequency | Percentage (%) |
| Schedules overlapping   | 3          | 37.5           |
| Excessive academic load | 2          | 25.0           |
| Lack of previous knowledge | 2          | 25.0           |
| Similar tasks          | 1          | 12.50          |
4. Conclusions
An improvement in soft skills of undergraduate engineering students (i.e., assertive communication, team organization and planning) has been achieved through project-based learning. By focusing on solving pressing needs of society (e.g., achieving better indoor air quality in the context of COVID-19 pandemics), students are more easily engaged and motivated throughout the experience. This study case demonstrates that students can readily realize the importance of assertive communication, team planning and collaborative work through projects. The organization of the team in groups, each led by an experienced specialist, helped in having an open communication and allowed for directing the project more efficiently. It is important to highlight that the main drawback was that the learning process was excessively time-consuming, especially for acquiring the knowledge in areas outside their field of study and for learning to use tools for team management and bibliography management. Overall, students have shown positive responses towards the learning process in an interdisciplinary project focused on solving real-life problems.

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