3D printing as a motivator didactical resource for engineering students

Impresión 3D como recurso didáctico motivador para estudiantes de ingeniería

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Abstract

3D printing technology has become increasingly popular in various fields, including education. One of the main benefits of incorporating 3D printing technology into mathematics teaching is its ability to provide students with a concrete representation of complex concepts such as three-dimensional geometric shapes. This project used a filament 3D printer to create physical objects from an electronic model that is created using computer-aided design software. A pilot test was carried out with two students from the first semesters of engineering. Through the Problem Based Learning methodology, a strategy was proposed to calculate the volume of a three-dimensional body. Two sessions were used to learn the operating principles of an additive 3D printer, as well as its calibration and basic operation. In the laboratory sessions, the participants demonstrated mastery in manipulating the 3D printer, managing to print and use the three-dimensional models to visualize the resolution of the mathematical problems posed. From an interview, the students expressed that they felt motivated with the use of the printer. A unique teaching material was obtained, which opens the range of possibilities for the culture of generation of new teaching material.

3D printing, Revolution solids, Prototyping

Resumen

La tecnología de impresión 3D se ha vuelto cada vez más popular en diversos campos, incluido el educativo. Uno de los principales beneficios de incorporar la tecnología de impresión 3D en la enseñanza de las matemáticas es su capacidad de proporcionar a los estudiantes una representación concreta de conceptos complejos como las formas geométricas en tres dimensiones. En este proyecto se empleó una impresora 3D de filamento para crear objetos físicos a partir de un modelo electrónico que se crea utilizando software de diseño asistido por computadora. Se realizó una prueba piloto con dos estudiantes de los primeros semestres de ingeniería. A través de la metodología de Aprendizaje Basado en Problemas se planteó una estrategia para calcular el volumen de un cuerpo tridimensional. Se emplearon dos sesiones para aprender los principios de funcionamiento de una impresora 3D de adición, así como su calibración y operación básica. En las sesiones de laboratorio, los participantes demostraron dominio en la manipulación de la impresora 3D alcanzando a imprimir y utilizar los modelos tridimensionales para visualizar la resolución de los problemas matemáticos planteados. A partir de una entrevista los estudiantes manifestaron sentirse motivados con el uso de la impresora. Se obtuvo un material didáctico único, que abre el abanico de posibilidades a la cultura de generación de nuevo material didáctico.

Impresión 3D, Sólidos de revolución, Creación de prototipos

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Introduction

3D printing technology has become increasingly popular in various fields, including education, and has brought design and manufacturing to a large population, initiating a movement called Maker (Morales Martínez and Dutrénit Bielous, 2017). This technology has proven to be feasible and cost-effective for the construction of prototypes and parts that benefit learning (Rúa R., et al, 2018).

In Mexico, high failure and dropout rates have been observed in the subjects of integral and vector calculus in the first two years of an engineering programme, which has been the subject of ongoing attention (Soto Hernández, et al, 2014). In these subjects, 3D printing technology can offer an alternative solution to traditional teaching methods.

The use of 3D printing is a creative application that favours the imagination and creative thinking of the student, which is the first instance to initiate a project.

The sequence in creative thinking is the succession of stages or phases that are carried out to generate a new and innovative idea or solution, including the use of tools and techniques to promote creativity or the generation of ideas.

In 3D printing, the concern to achieve as a specific purpose the creation of physical objects from a digital model requires a process that involves the participatory action of students. The use of software helps to create three-dimensional objects, and then the detailed elaboration of the nuances already defined in the development of the preliminary screen of the design software takes place. From here, the chosen idea is put into practice using a 3D printer.

One of the main benefits of incorporating 3D printing technology in mathematics education is its ability to provide students with a visual representation of complex concepts (Quezada Batalla, et al, 2018).

For example, 3D printing can be used to create physical models of functions, graphs and geometric shapes (Dilling and Witzke, 2020), which can help students better understand calculus concepts (Candia Garcia, 2022) such as solids of revolution, areas or volumes.

Engineering students may experience cognitive difficulties when studying solids of revolution and multiple integrals in integral calculus. These difficulties may be due to a number of factors, including the conceptual complexity of the concepts involved and the need for spatial visualisation. This capacity for spatial imagination can be difficult to develop, especially for students who do not have a good understanding of geometry from a young age.

This spatial perception involves visualisation, understood as the set of images, processes and skills necessary for students "to produce, analyse, transform and communicate visual information related to real objects, models and geometric concepts" (Roura and Ramirez, 2021, p. 539).

However, by using real three-dimensional forms, a mental image or illustration is recorded, through the relationship of the objects in their physical or geometric form to scale, being a benefit in the generation of knowledge and retention so as not to have only a provisional memory of the content.

Hence the importance of the proposal to use 3D printing technology, as it allows the creation of customised models that can be adapted to the specific needs of each problem or exercise. This level of customisation can enhance the learning experience as well as the understanding of the concepts involved and spatial visualisation skills.

A filament 3D printer was used in this project. This machine uses an additive process to create physical objects from a digital model that is created using Computer Aided Design software. The digital model is divided into thin layers and, as it is printed, each layer of filament is layered on top of the other to generate the height of the model.

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The filament is fed through a nozzle which is heated until it melts. The molten plastic is then deposited on the print bed, layer by layer, until the desired object is created. Its use for generating didactic teaching models for mathematics goes beyond the traditional way.

In addition, learning mathematics using active methodologies such as PBL -Problem Based Learning- can help students develop a deeper understanding of mathematical concepts, as it requires them to apply their knowledge and skills in a real context.

This methodology focuses on problem solving as a way of learning. In PBL, students are faced with a real or simulated problem that they must solve using their knowledge and skills. The teacher acts as a facilitator who guides students in the problem-solving process.

In the development of PBL practices, the incorporation of digital tools and instruments allows the implementation of innovative and attractive learning environments that can attract the attention of the student community. The use of the PBL approach forces students to demonstrate sufficient generic and disciplinary competences to develop and build the high-level thinking skills commensurate with the demand of the problem (Surya and Syahputra, 2017).

Therefore, this strategy seeks to strengthen the desirable competences in engineering students, considering the different learning styles. In addition, it encourages their development to successfully follow their school career, while promoting understanding and interest in the management of innovative technologies used in the productive sector.

With this background, the need to carry out a pilot test with engineering students who are studying the subjects of three-dimensional figures, their configuration and modelling, their perception and characteristics was proposed, since, with figures drawn on a surface, or even on a flat screen simulator, students have problems visualising such elements, and, even more so, associating the bodies with their mathematical models. 3D printing provides a real, palpable model.

Materials and methods

A pilot test was conducted with two engineering students of the Tecnológico Nacional de México, campus Ciudad Madero -ITCM- during the second semester of 2023.

The first student -1CIQ- of second semester of Chemical Engineering in the subject of Integral Calculus; the second student -2CVI- of third semester of Industrial Engineering in the subject of Vector Calculus. Both students were chosen at the convenience of the same lecturer, who chose the topic of solids of revolution for 1CIQ, while 2CVI was assigned a problem of triple integrals in Cartesian coordinates. At the end, they used a semi-structured interview to find out the students' perception of this teaching strategy.

Following the PBL methodology, when they arrived at the subject chosen during the regular courses, the teacher set them a problem to calculate the volume of a three-dimensional body. Simultaneously to the development of the topics in the classroom, six sessions were held in the 3D printing laboratory.

Two sessions were used to learn the principles of operation of the Ender 3 Pro 3D printer, as well as its calibration and basic operation, following the recommendations of Blanco Prieto (2020). The next four sessions consisted of developing three-dimensional models in the free-to-use application Tinkercad and using the 3D printer's Crealty software, which is used to divide the model into layers and generate the G-code. In these sessions they also became familiar with adjusting the printing parameters, such as object size, resolution, printing speed, taking care of the humidity in the environment affecting the filament.

As the students had the knowledge about the printing process they received the assigned problem, they used the Tinkercad application to create a three-dimensional model of the solid of revolution or volume solid by means of multiple integrals.

Subsequently, the students proceeded to print the three-dimensional model using the 3D printer with printing volume 220 x 220 x 250 mm, using 1.75 mm PLA filament. This material is one of the most widely used biodegradable polymers (Ayrilmis, Kariz and Kwon, 2019; Palazzo, 2016) as it is less polluting in the emission of particles and organic solvents such as aldehydes, benzenes and others (Azimi, et al, 2016).

Figure 1 shows the print volume, print bed, print head and LCD control screen of the 3D printer. It is worth mentioning that this printer is characterised by its ease of operation, affordable cost and simple assembly.

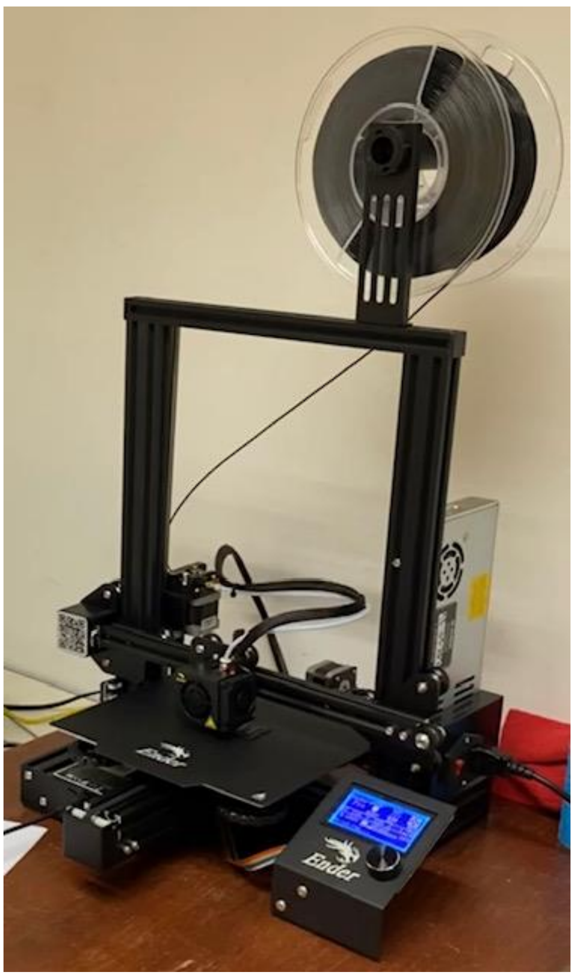

Figure 1 Ender 3 Pro 3D printer.
Source: Own elaboration

Once the model was printed, they proposed a solution to the assigned problem. Subsequently, an interview was conducted with the students to evaluate their experience with the use of 3D printing as an auxiliary tool in the visualisation of models. In this way, through the insertion of 3D printing, prototypes developed by the students were obtained.

These served as a means of testing the topics covered in the Integral Calculus and Vector Calculus class sessions.

Results

The results obtained in this experience have been divided into two sections: 1) the generation of the prototype, 2) the resolution of the problem and 3) the evaluation of the experience.

Generation of the prototype

The students acquired skills to design and manufacture didactic material using a 3D printer that "has surpassed the virtual simulation... with the advantage of being able to touch and move it" (Cárdenas Escamilla and Alva Rangel, 2018, p. 102).

In the lab sessions, students demonstrated mastery in manipulating the 3D printer autonomously. This was evidenced by their ability to create three-dimensional models with Tinkercad and adjust the printing parameters from Creality.

In addition, they were able to solve the problems they encountered, such as the initial calibration of the 3D printer, as well as identifying the menu options on the LCD screen of the 3D printer. Some situations were related to the levelling, placement and change of filament when it broke due to some cause such as humidity. A drying box was acquired for this situation.

The adjustment of 3D printer parameters such as the number of layers to integrate the object, and thus the fineness of the finish, ended up being decided by the capacity of the equipment and its processing time. Undeniably, trial and error was present throughout the process. The decision on the type of base or support to be used, as in an object whose structure has protruding parts, is indispensable to ensure that the printing is properly completed (Imprimakers, n.d.).

On the other hand, the decision on the type of filler or mesh to be used for printing was associated with the time required, but also with the stability and hardness of the object, which, in this case, was decided by a triangular mesh.

Mayén and colleagues (2022) have insisted on the need to study in depth the property of these materials such as PLA and the treatments they undergo such as the thermal one used in 3D printing. All of the above, considering the angle of the lattice and the temperatures to which it is exposed in additive manufacturing.

In this case we are dealing with didactic prototypes, but when talking about manufacturing situations for industrial purposes, the need mentioned is evident (Taib, et al, 2023).

In the Integral Calculus course, we started with participant 1CIQ who designed a cylinder in Tinkercad, shown in Figure 2. The dimensions were 2 cm radius and 6 cm height, within the capabilities of the 3D printer, and he was asked to determine the volume of this solid of revolution by means of definite integrals. This full-scale model made it possible to identify the real shape and measurements of an abstract model, as mentioned by Cárdenas Escamilla and Alva Rangel (2018), through the approach of an engineering application problem.

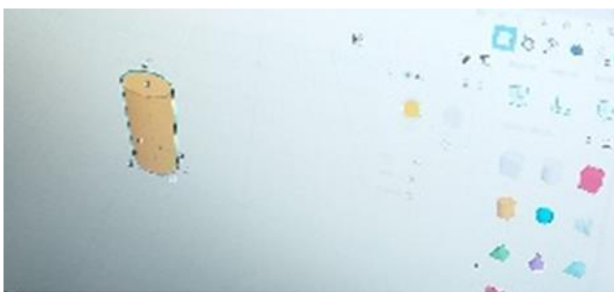

Figure 2 Tinkercad design of a straight circular cylinder
Source: Own elaboration

In the case of student 2CVI of the Vector Calculus course, the teacher asked him to determine the volume of a rectangular parallelepiped of 3 x 4 x 3 cm in Cartesian coordinates, by means of the triple integral approach. Figure 3 shows the process of constructing the model in Tinkercad.

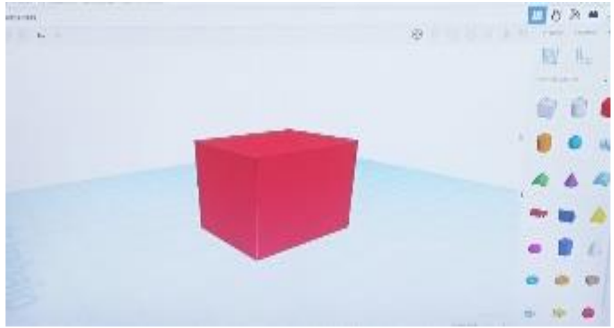

Figure 3 Tinkercad design of a rectangular parallelepiped
Source: Own elaboration

After the models were completed by both students, the corresponding segmentation was carried out using the 3D printer's own Creality programme. The necessary base and the characteristics that allow a feasible and viable printing were also integrated. These elements are associated with the printing time, which for practical purposes should not exceed 3 hours, which is why the process of defining the parameters must be considered in the process of defining the parameters.

In the same way, Creality defines the type of base for the adhesion of the first layer of PLA melted by the printer, which is an additional element to ensure that the print does not detach from the base during the printing process, and is automatically generated in the segmentation stage, as shown in Figure 4.

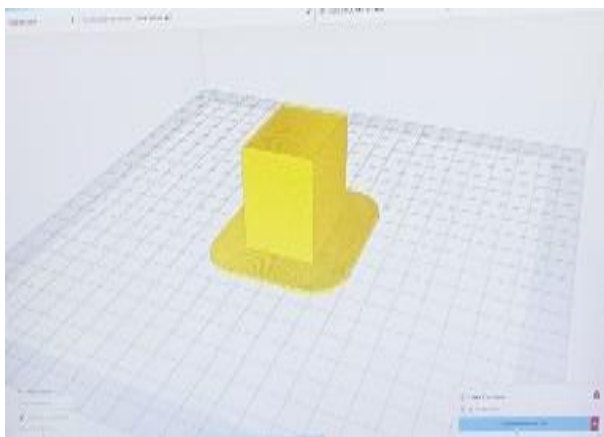

Figure 4 Segmentation of the rectangular parallelepiped in Creality
Source: Own elaboration

Problem solving

Both products developed in the virtual space focused on the visualisation of concepts included in the subject matter of the class, in order to facilitate the understanding of the abstract contents.

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This highlighted the importance of direct experimentation and manipulation of objectives, first through the geometric construction of the contents involved, in order to break down the resistant barrier to learning these subjects.

For the first case, the student 1CIQ, the teacher chose a cylinder, as it is a geometric figure frequently used in chemical engineering applications, such as containers in the petrochemical industry, which is predominant in the ITCM environment.

The course lecturer asked the student 1CIQ to use the mathematical model shown in Equation 1 for the manual calculation of the volume of the solid of revolution that represents the cylinder of the case.

$$V = \pi \int_0^h r^2 \, dx \quad (1)$$

While it is true that this problem could have been solved in a simple way with basic geometric formulae, the aim was to check the result with the physical model easily.

Considering the data provided, with a height -h- of 6 cm and radius of 2 cm, student 1CIQ solved the problem as shown in Figure 5, obtaining a volume of 75.39 cm^3.

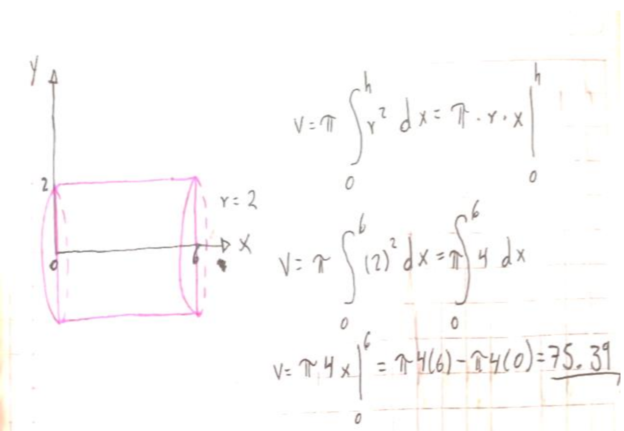

Figure 5 Volume calculation using the mathematical model.
Source: Notebook of student 1CIQ.

The straight circular cylinder was printed by student 2CIQ as shown in Figure 6 where the base where the additive process started can be seen. Figure 7 shows the finished object.

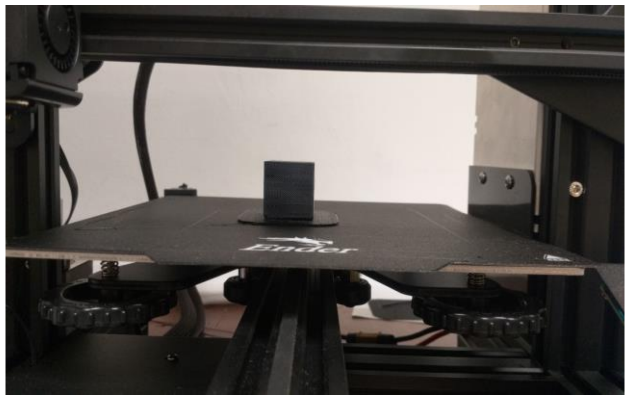

Figure 6. Impression of the straight circular cylinder.
Source: Own elaboration

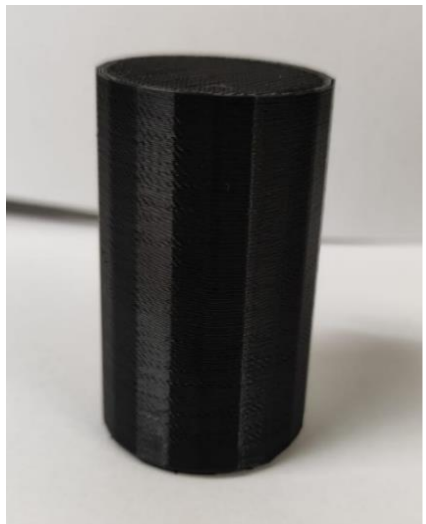

Figure 7. Straight circular cylinder printed on Ender 3 Pro 3D printer
Source: Own elaboration

For the second case, the 2CVI student of Vector Calculus, the problem dealt with the calculation of the volume of a rectangular parallelepiped. Therefore, the teacher asked him to use the mathematical model of Equation 2, which consists of a triple integral.

$$V = \int_B^D \int_B^A \int_B^H dx \quad (2)$$

This implied that the student had to locate the rectangular parallelepiped in three-dimensional space. Therefore, he had to define the Cartesian coordinates that limited the object, based on the measurements provided in the problem to be solved. The coordinates of the points were: A (3, 3, 7), B (3, 3, 4), D (3, 4, 6) and H (- 1, 3, 4), as shown in Figure 8.

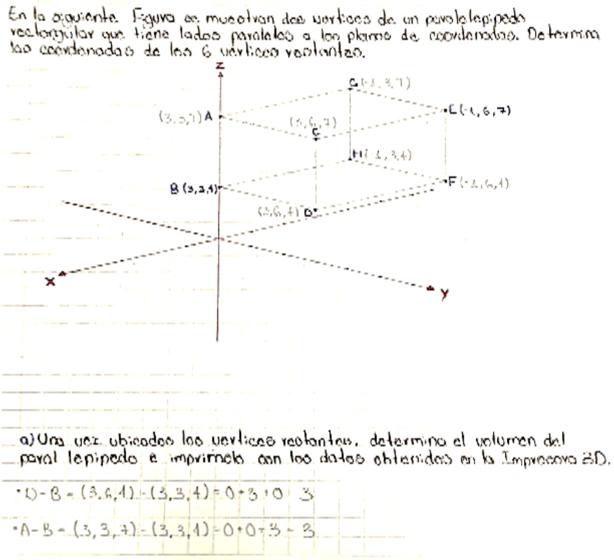

Figure 8 Notebook design
Source: Student's notebook 2CVI

Figure 9 shows the printed rectangular parallelepiped and you can see the triangular lattice of its surfaces, which implies that it is not a compact object, filled with material, but one that has only the surfaces that limit it. This has several benefits, including printing time and material savings, a smaller amount of PLA filament, a smaller amount of PLA.

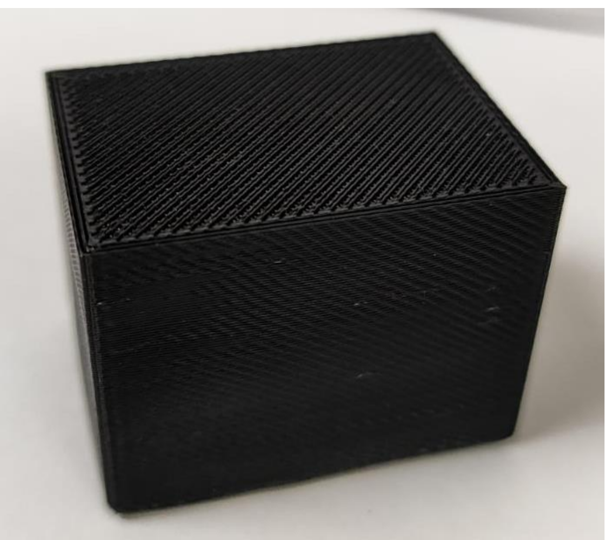

Figure 9. Rectangular parallelepiped printed on the Ender 3 Pro 3D printer
Source: Own elaboration

In this problem, the student applied vector concepts, that is, making this model allowed the student to determine vectors between points, magnitude of a vector, in addition to the calculation of the volume, the final objective of this didactic strategy.

Having the printed model, as shown in Figure 9, allowed an associative mental construction between the representation in two-dimensional space - blackboard or notebook -, the electronic version in computer modelling and the real object. This leads to a better appropriation of the subject, minimising conceptual doubts and favouring the specific and generic competence of the subtopic in each of the courses.

Evaluation of the experience

During the development of the activity, a marked interest and concern was observed on the part of the students to continue using the 3D printer in other subjects. Based on this genuine interest observed, it is possible to infer that having three-dimensional models to present students with problems and situations with which they can interact in a concrete way strengthens associative spatial skills. These are basic for the approach and resolution of application problems not only in mathematics.

The results of this stage show that the participants were able to use the printed three-dimensional models to solve the problems posed, improving their learning experiences, as stated by Suardíaz Muro, and colleagues (2021).

When the participants were interviewed, they had favourable comments about the experience, in which they stated that they felt motivated. In addition, they expressed their satisfaction at having acquired technological skills and having developed generic competences in the use of technology that previously seemed very complex. They also considered using this tool in the future in their professional life.

From the perspective of the teacher who participated as an advisor to the students, "3D printing can be applied in engineering subjects and is indispensable for design subjects..., it makes the class more dynamic" (Hernández Mendoza, 2023). Likewise, the professor considers that, in many cases, elements or parts that are difficult to obtain are needed and printing facilitates their acquisition. Furthermore, the prototypes can continue to be used for the next semesters in other subjects that allow for designing, building, innovating and perfecting the handling of the Ender 3 Pro printer.

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Conclusions

The experience exceeded expectations for all that was learned. Although it was only a pilot project with two students in two different subjects and from two different careers, it was a practice of close collaboration between students and teachers.

This initial effort of teachers and students is necessary to innovate and be creative in order to understand the teaching and learning process of basic sciences. This way, a unique didactic material was obtained, which opens the range of possibilities to the culture of generating new didactic materials with products that can be designed and built in class.

In both subjects there was the experience of seeing the exhibition in the classroom of the material as a finished product, with its own characteristics of the production process, which motivates teachers to incorporate the methodology used as PBL.

The application or teaching of the course with the support of 3D printing changes the learning environment and generates motivation for student involvement. The didactic strategy is to change the application methodology to give way to model design and fabrication. 3D printing has the potential to revolutionise the way Integral Calculus and Vector Calculus are taught and learned.

By creating physical models of abstract mathematical concepts, students can gain a deeper understanding of these concepts and develop a more intuitive sense of how they relate to the physical world.

While challenges remain, such as the cost and accessibility of 3D printing technology, the potential benefits make it an exciting area of exploration for educators and students alike.

A subsequent challenge is to have more equipment to extend it to whole groups and other subjects, in order to be in a position to carry out some didactic intervention where it is possible to analyse more precisely the benefits of using this type of technology in engineering programmes.

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