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ARTICLE

PROJECT TO IMPROVE LEARNING OF THE INTEGRAL USING INFORMATION TECHNOLOGIES

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PROJECT TO IMPROVE THE LEARNING OF INTEGRALS USING INFORMATION TECHNOLOGY

Project to Improve the Learning of Integrals using Information Technology

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Discipline:	*[X] Engineering Education and Interdisciplinary Development*

ABSTRACT

Currently, the use of information technology has facilitated learning in mathematics courses. This paper presents the implementation of a project as an activity in the Integral Calculus course to reinforce the teaching of the concepts of area under the curve and definite integrals through an application in the field of biology. A descriptive and quantitative approach was used to evaluate the effectiveness of the proposed project. Starting from a descriptive approach, the objective is to measure and evaluate the impact of this teamwork project on improving students' understanding of the topic through the use of information technology. In this study, a quantitative approach was used to numerically measure and evaluate the impact of this project on engineering students. To conduct these measurements, three instruments were used: a pre-test administered before the project began, a similar post-test taken by the students after the project was completed, and finally, a survey to gauge the students' experience after completing the proposed project. The Results section presents a comparative table showing the group's overall average, median, and mode of the grades obtained before and after the project's implementation. Graphs showing the percentages of responses obtained from the student survey are also included. Based on these results, an improvement in the group's overall understanding can be observed, as well as a more even distribution of student grades.

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Keywords— *Area under the curve, definite integral, applications of the definite integral, biological growth rates.*

ABSTRACT

Today, the use of information technologies has made it easier to learn mathematical concepts. This paper presents the implementation of a project within an Integral Calculus course designed to reinforce the teaching of area under the curve and definite integrals through an application in biology. A descriptive and quantitative approach was adopted to evaluate the project's performance. The descriptive component aimed to measure and assess the impact of this teamwork project on improving understanding of the topic through the integration of information technologies. A quantitative approach was used to numerically measure and evaluate the impact of this presentation-based project on engineering students. Three instruments were used for these measurements: a pre-test administered before the project began, a similar post-test administered after the students completed the project, and a survey to gauge the students' experience following the project's completion. The Results section presents a comparative table showing the group's overall mean, median, and mode scores obtained before and after the project's implementation. Graphs illustrating the percentage breakdown of student opinions from the survey are also included. These results indicate an improvement in the group's overall understanding as well as greater consistency in student grades.

Keywords— *Area under the curve, definite integral, applications of the definite integral, biological growth rates.*

INTRODUCTION

Various research studies have reported methodologies based on the implementation of web applications and information technology (IT) to visualize and facilitate the understanding and teaching of certain topics related to biology, physics, and mathematics within engineering curricula. Therefore, the use of these technologies has been important in fostering the development of critical thinking and improving students' skills in learning integral calculus.

For example, the study presented in [1] introduces an approach to facilitate the learning of solid-state physics through an interactive program and stereoscopic projection. This approach integrates three-dimensional visualization into the instructional process to facilitate the understanding of abstract concepts through interactive simulations, thereby providing a better understanding than traditional methods such as the blackboard or PowerPoint presentations.

In [2], the authors note that technology does not replace what should be taught and learned; that is, technology is a very useful tool for solving integrals—whether definite or indefinite—since without it, some problems would be very difficult to solve. This is without neglecting the paradigms that must be followed to logically explain and understand the solution process, as mentioned in [3].

In [4], it is stated that modeling in school discourse is conceived as a social practice that fosters the construction of scientific knowledge. Specifically in the area of mathematics, the reviewed studies report that the virtual laboratory promotes the development of skills for mathematizing real-world situations that can be applied outside the classroom—of course, based on the conceptual foundations covered in class. Furthermore, it facilitates the understanding of mathematical concepts themselves because, through ICT, dynamic interactive applications can be generated and cause-and-effect relationships observed; when complemented by a didactically intentional instructional design, students can be guided to draw their own conclusions [5].

In [3], the authors conclude that the use of GeoGebra substantially aids in problem-solving and serves as a tool to be used as a strategy in learning integral calculus.

In [6], the authors apply the definite integral to analyze the property of viscosity in fluids, with the aim of providing a guide for research and analysis in this complex field from the perspective of mathematical calculus.

In [5], the authors use a virtual mathematics lab to promote understanding of concepts in differential calculus. Their methodology consists of lab exercises, the use of simulators, and custom-designed applets.

In [7], instructional materials are designed using digital tools such as the Moodle platform, the Jamboard digital whiteboard, and the Samsung Notes app. By utilizing these digital resources and various platforms and applications, students gained several benefits, including teacher guidance and monitoring, feedback and/or reinforcement, and access to recorded classes.

In [8], the impact of the GeoGebra software on the teaching of differential and integral calculus in higher education is evaluated by analyzing self-regulation, metacognition, meaningfulness, perception of the environment, symbolic language, and reasoning. The study concludes that GeoGebra is an innovative tool that enhances mathematics learning.

In [9], the authors designed a quantitative methodology aimed at developing the ability to calculate definite integrals among students in the Bachelor's degree program in Accounting and Finance. Its practical application demonstrated favorable changes in the level of development of the skill under analysis.

Several other research studies report positive aspects of implementing information technology tools to reinforce the learning process in various fields of knowledge ([10], [11], [12], [13], and [14]).

In [15], the authors conclude that the use of mathematical simulators allows students to interactively visualize and understand concepts and processes related to integral calculus.

In [16], an interactive electronic module integrated with GeoGebra Classroom is designed to support students' conceptual understanding of integrals. The authors demonstrated the feasibility of using this interactive electronic module, integrated into GeoGebra Classroom, as a learning resource to help students conceptually understand integral calculus.

In [17], the authors indicate that students' use of mobile applications to visualize functions and other geometric objects in the plane and in space contributes to improved student performance in solving multiple integrals.

In [18], the authors conclude that mathematics learning mediated by digital technologies enables the effective and agile development of content for students. During the activity, they assessed improvements in problem-solving skills, peer communication, and the use of technological tools. Students' motivation, learning, and the development of soft and hard skills enhanced the quality of instruction and the learning process.

In [19], the authors implemented a teaching sequence for engineering students, using ICT tools such as a website. The implementation was carried out with the goal of improving students' understanding of the mathematical concept of area calculation through the definite integral.

In [20], the authors examined the types of errors students make when solving integration problems in calculus through the implementation of Project-Based Learning (PBL) using the GeoGebra software. They concluded that combining Project-Based Learning (PBL) with GeoGebra allowed students to visualize integral concepts dynamically and improve their geometric understanding of both definite and indefinite integrals.

This study examines the applications of integration by understanding its theoretical foundations and applying them to the analysis and solution of real-world situations. The purpose is to acquire the theoretical foundations of integration necessary for applying them to problems. In this context, a project is proposed within the Integral Calculus course to address the topic of the definite integral as a process of accumulation within a specific application in the field of biology. In this field, integrals can be used to model dynamic biological processes, biological growth rates, the spread of diseases, metabolic rates in organisms, and other changes over time or space. In this paper, specifically, the application of population growth rates was selected to develop the project.

The proposed project aims to reinforce learning on the topics of “area under the curve” and “definite integral” within the subject of Integral Calculus. This proposed project consists of three parts: the analytical calculation of a definite integral using traditional methods—that is, by performing calculations in a notebook; the second part involves verifying results using the interactive online mathematical calculation program GeoGebra [15]; finally, the third part consists of a group presentation on the topic, drawing on the creativity and initiative of the engineering students to develop and discuss the proposed activity and its corresponding analyses and conclusions. It is hoped that this project will help improve their collaboration and communication skills. Furthermore, this project is expected to foster the development of creativity in understanding, solving, and explaining a real-world problem, thereby contributing to their development as engineers.

To assess the effectiveness of the proposed project, three instruments were used: a pre-test administered before the project began, a similar post-test administered after the students completed the project, and finally, a survey to gauge the students’ experience after completing the proposed project.

METHODOLOGY

Generative AI Disclosure	*If AI (such as ChatGPT, Claude, or Gemini) was used to draft or analyze data, the model and version must be specified in the methodology section.* **AI was not used**
Responsibility	*Responsibility for the accuracy of the data must be declared, ensuring the absence of “hallucinations” or biases. We* ***declare ourselves responsible for the accuracy of the data.***
Research Design:	*Indicate the type of design used in the study and briefly justify why it is the most appropriate for answering the research question.* ***A descriptive and quantitative approach was used to conduct this research. Thus, one of the objectives of this research project is to measure and evaluate the implementation of a team-based project designed to facilitate learning on the topic of “applications of definite integrals” within the Integral Calculus course. To quantitatively assess the impact of this research, the evaluation instruments consisted of a written exam related to the topic (administered before and after the presentation) and a survey completed by engineering students.***
Justification of the sample:	*Describe the characteristics of the sample or participants (size, inclusion and exclusion criteria, type of sampling used) and explain why this sample is representative or relevant to the study’s objectives.* ***A quasi-experimental approach was used to conduct this research, with a group of 38 students enrolled in an Integral Calculus course during the January–June 2026 semester at the Technological Institute of Puebla serving as the case study. An assessment was administered before the project and another after the project presentations to validate its effectiveness in improving students’ understanding of the topic at hand.***
Instrument(s):	*Specify the instruments, techniques, or tools used for data collection (e.g., questionnaires, scales, interviews, standardized tests). Include information on their validity, reliability, and any adaptations made, if applicable.* ***Pre- and post-tests for the proposed project and a survey conducted among students***
Procedure:	*Describe in a clear and detailed manner the steps followed to conduct the research, from participant recruitment to data collection, indicating the conditions under which the study was conducted* ***These steps are described in this section***

Data Analysis:	*Explain the statistical or methodological techniques used to process and interpret the data obtained (e.g., descriptive analysis, inferential analysis, content analysis, software used), in accordance with the study's design and objectives.* ***To interpret the data, comparative tables of means and bar charts are used to analyze the survey results.***
Methodological limitations:	*Identify any restrictions or limitations of the study that may affect the generalizability or interpretation of the results, such as sample size, geographic scope, type of instrument, or any identified biases.* ***This study was limited to a growth function, in which the only parameter to be varied was time (variable t).***

A quasi-experimental, descriptive, and quantitative approach was used to conduct this research. Starting from a descriptive approach, the objective of this research is to measure and evaluate the implementation of a team project designed to facilitate learning on the topic "applications of definite integrals" within the Integral Calculus course. To quantitatively evaluate the impact of this research, several assessment tools were used. The assessment tools consisted of a written exam related to the topic (administered before and after the presentation) and a survey completed by engineering students. It is worth noting that these assessment tools were proposed, analyzed, discussed, and approved collectively by the Institute's Basic Sciences department.

To measure the results of the written exam, which is administered before and after the lecture, the exam consists of three questions based on the following problem: Given a growth rate of a certain population of individuals, described by the function $r(t)$, and the initial population $P(0)$, estimate the population at a certain point in time $P(t)$. Based on this problem, the questions are as follows:

1. *Define the population function.* Since the population function can be defined as the integral of the growth rate function, to answer this question the student must evaluate the integral of the function *r(t)*. To evaluate this integral, the student must identify and use the appropriate method from among those already covered in class.
2. *Calculate the population growth over a given time period.* To answer this question, the student must use their answer from the previous exercise and evaluate this expression over the interval from zero to the time period specified in the problem (interval [0, b]). This step involves solving the definite integral.
3. *Determine the total population at the end of this time period.* Once the estimate of the number of individuals during the specified period ($P(t)|_0^b$) has been obtained, the student must add the initial condition (P(0)), that is, the number of individuals currently existing prior to the future estimate.

The project proposed in this research paper contributes to strengthening the specific competency for the Integral Calculus course corresponding to Unit 2, which is: "Determine which method is most appropriate for solving a given integral and solve it using that method. Determine an antiderivative." In this practical example, the student must identify which integration method to use to solve the given integral. Furthermore, it also contributes to achieving the specific competency corresponding to Unit 3, which is: "Interpret problem statements to construct the function that, when integrated, yields the solution. Solve problems involving the calculation of areas, centroids, lengths of curves, and volumes of solids of revolution. Recognize the potential of integral calculus in engineering." In this practical case, the student must be able to interpret problem statements to solve an application problem in the field of biology using integrals.

The presentation project consists of the following four steps:

Step 1. This stage involves an analytical calculation by the team members and consists of a sequence of activities: identifying the function model that represents population growth, integrating the growth function, and finally evaluating it at different time intervals, thereby obtaining the resulting population estimates for specific time periods.

Step 2. This stage involves using GeoGebra to verify the results obtained by the teams of engineering students.

Step 3. This stage involves a free-form presentation of their exploration of the topic and conclusions drawn from the results obtained.

Step 4. This step involves conducting the survey individually.

GeoGebra was selected for this research project because it is a robust program that enables calculations related to integral calculus. It is also worth noting that GeoGebra is free to use and easily accessible to engineering students, as they can access it from any internet-connected device they have available for work without the need for installation.

The purpose of this survey is to collect data to analyze the functionality of the proposed project. The questions included in the survey are as follows:

1. In your opinion, does using GeoGebra improve understanding of the subject?
2. In your opinion, is GeoGebra easy to use?
3. Do you think that using GeoGebra as a tool for graphing functions and performing mathematical calculations could be useful in other courses in your degree program?
4. In your opinion, was this activity a positive experience for you?

A quasi-experimental approach was used to conduct this research, as a group of 38 students enrolled in an Integral Calculus course during the January–June 2026 semester at the Technological Institute of Puebla served as the case study. The criterion used to select students for this experiment was to choose a group led by one of the authors of this paper as a pilot group to perform the measurements described above, in order to evaluate the effectiveness of the proposed project within the Integral Calculus course. The following section describes the mathematical solution to the problem posed in this research project.

Preliminaries

Some applications of integrals in the field of biology relate to the growth or decline of certain processes. In particular, we will address the case of the biological growth rate of a population. Given the function *r(t)* that describes the growth rate of a population, we can calculate or use the area under the curve over a certain period of time (or interval [a, b]), which in this case would be an example of a cumulative sum that would give us the population (P(x)) over this interval.

$$\int_a^b r(t)\,dx = P(t)|_a^b = P(b) - P(a) \qquad \text{Ec. (1)}$$

The antiderivative of this function, obtained by applying the fundamental theorem of calculus, is shown in Equation 1 (see Eq. (1)). This application helps students develop skills in calculating indefinite integrals by using properties, immediate integrals, rules, or methods of integration to find the antiderivative ([16] and [17]).

Example 1. A bacterial population grows at a constant rate of r(t) = (4t + 2)(t - 1) bacteria per month. The current bacterial population is 15,000. What would be the estimated population in 12, 18, and 24 months?
Analysis: The bacterial population (the function P(t)) can be approximated by calculating the integral of the function corresponding to the growth rate, which would give us the population at each time period. Finally, we add the current population (P(0) = 15,000), thereby obtaining an estimate of the population to date. To integrate the function, it can be rewritten as:

$$\int_a^b r(t)\,dx = \int_a^b (4t+2)(t-1)dt = \int_a^b (4t^2 - 2t - 2)dt \qquad \text{Ec. (2)}$$

Using this expression, we can apply direct integration formulas, specifically the power rule, to integrate each term of the expression, thereby obtaining the antiderivative:

$$P(t) = [\frac{4}{3}t^3 - t^2 - 2t]|_a^b \qquad \text{Ec. (3)}$$

For the first period, which corresponds to the estimated population over 12 months, the interval to be calculated is [0, 12]. To calculate the definite integral, substitute b = 12 and a = 0 into Eq. (3), yielding:

$$\int_0^{12} r(t)\,dt = \left[\frac{4}{3}(12)^3 - (12)^2 - 2(12)\right] - \left[\frac{4}{3}(0)^3 - (0)^2 - 2(0)\right] \qquad \text{Ec. (4)}$$

Performing the calculations analytically yields an approximate value of 2,136 individuals. However, this represents only the population generated during this period; therefore, the initial population must also be added (as indicated in Eq. (5)).

$$P(12) = 15000 + \int_0^{12} r(t)\,dt \qquad \text{Ec. (5)}$$

Finally, the estimated population for this period would be 17,136 individuals.

After performing the calculations analytically, in Stage 2 students must verify their calculations using the GeoGebra tool. To perform this verification, they must enter the instructions shown in Figure 1 to confirm that the definite integral over the interval [0, 12] approximates the value calculated in the previous stage. In this stage, students can rely on the participation of their teammates to achieve this goal together.

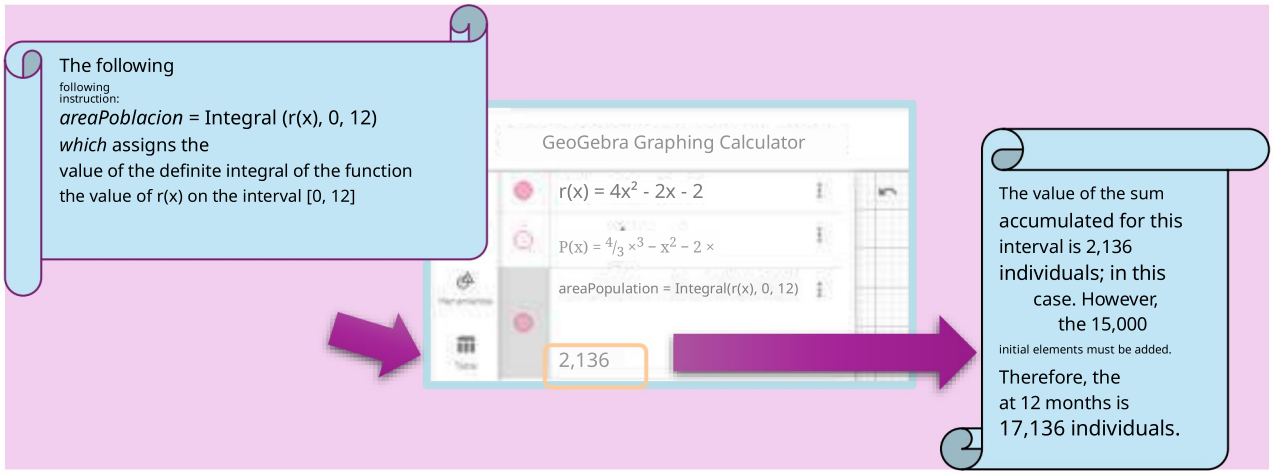


Figure 1. *Instructions entered into GeoGebra to calculate the area under the curve over the interval [0, 12].*
Source. *Created by the author.*

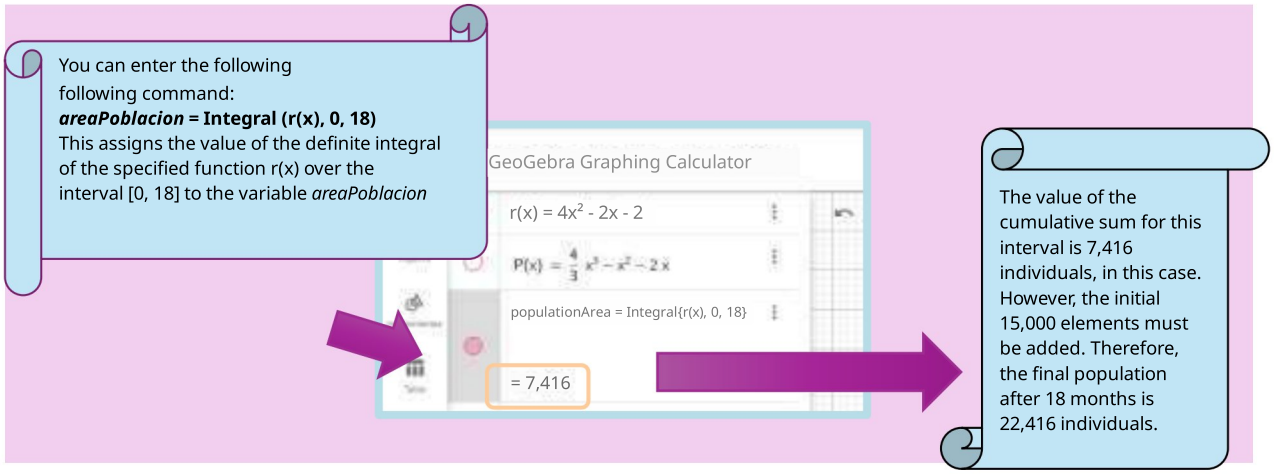


Figure 2. *Instructions entered into GeoGebra to calculate the area under the curve over the interval [0, 18].*
Source. *Created by the author.*

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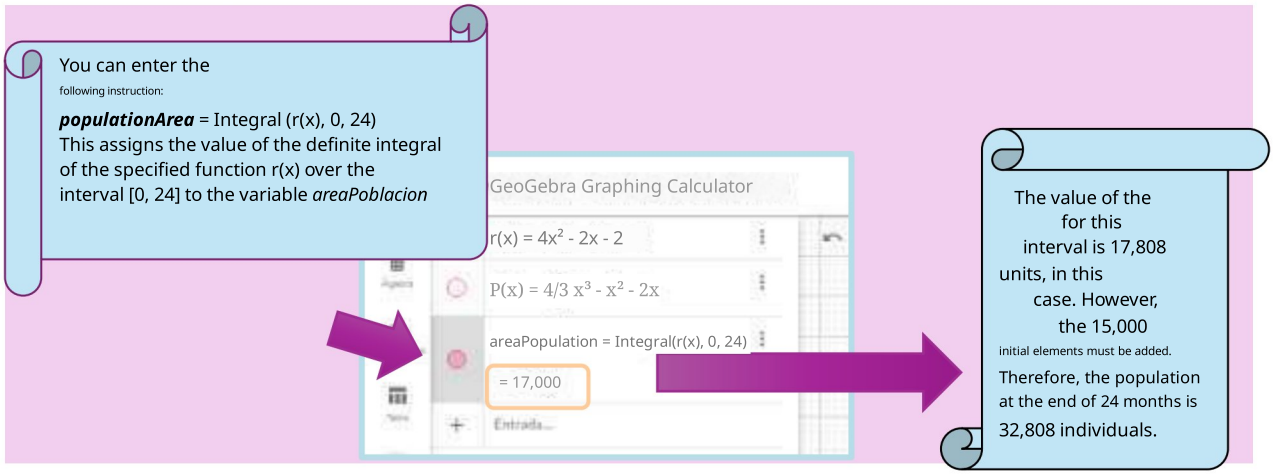


Figure 3. *Instructions entered into GeoGebra to calculate the area under the curve over the interval [0, 24].*

Source. *Created by the author.*

From Figure 1, it can be seen that, for this example, the definite integral over the interval [0, 12] is 2,136, which matches the analytical data. Similarly, to estimate population growth over 18 months, one would evaluate the definite integral over the interval [0, 18] using GeoGebra, as shown in Figure 2. In this case, the estimated population value of 7,416 individuals within this period—obtained both analytically and in GeoGebra—should match. To this number of individuals, we must add the 15,000 from the initial condition, which would result in an estimate of 22,416 individuals for 18 months.
Finally, for the case of the estimated population at 24 months, Figure 3 shows the GeoGebra instructions for calculating the population of individuals over this period. This number of individuals (17,808) must also be added to the initial condition of 15,000, resulting in a final population of 32,808 individuals.
Figures 4, 5, and 6 show the graphs obtained in GeoGebra, where students are expected to observe and justify their conclusions regarding how the definite integral relates to the accumulation process in the field of biology, particularly in this application of population growth analysis.

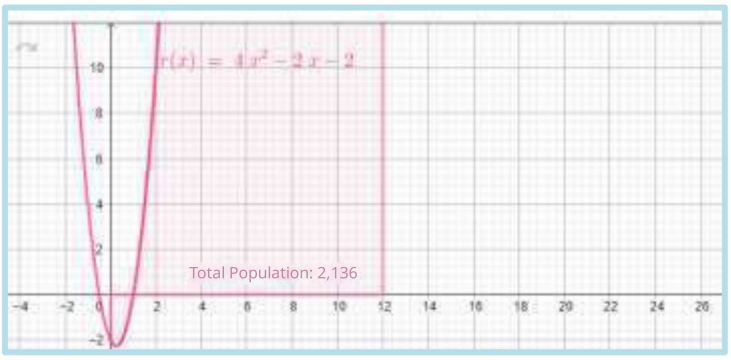


Figure 4. *Resulting graph in GeoGebra showing the area under the curve over the interval [0, 12].*
Source. *Created by the author.*

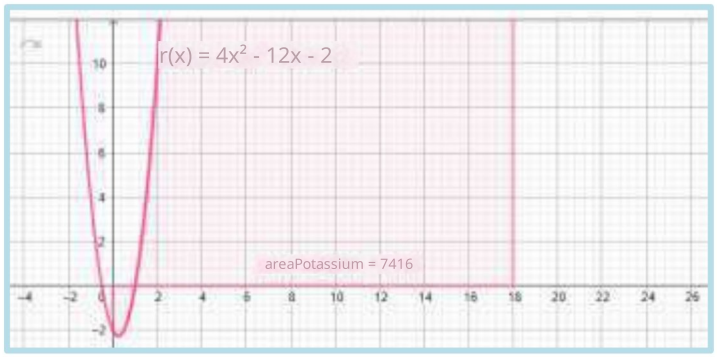


Figure 5. *Resulting graph in GeoGebra showing the area under the curve over the interval [0, 18].*
Source. *Created by the author.*

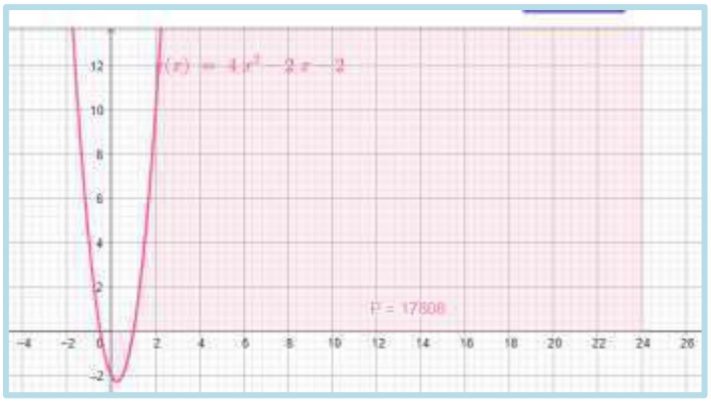


Figure 6. *Resulting graph in GeoGebra showing the area under the curve over the interval [0, 24].*
Source. *Created by the author.*

Figure 7 shows a graph of these three populations over the different time periods evaluated.

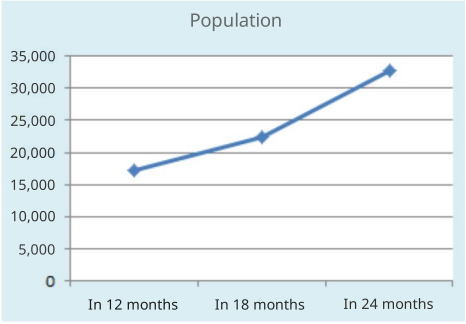


Figure 7. *Estimated population for 12, 18, and 24 months.*

Source: Author's *own work.*

Example 2. The rate of spread of the flu (population growth rate) per month is given by r(t) = $\sqrt{10^{3x}}$ people per month. The current population is 2,600. What would be the estimated population in 3, 5, and 7 months?
Analysis: The population (the function P(x)) can be approximated by calculating the integral of the function corresponding to the growth rate (Eq. (6)), which would give us the population at each time period. Finally, we add the current population—which in this example is 2,600 (P(0) = 2,600)—to obtain an estimate of the population to date.

$$\int_a^b r(x)\,dx = \int_a^b \sqrt{10^{3x}}\,dx = \int_a^b 10^{\frac{3}{2}x}\,dx \qquad \text{Ec. (6)}$$

Using this expression, we can apply the integration formula shown in Eq. (7)

$$\int a^u \, du = \frac{a^u}{\ln(a)} \qquad \text{Ec. (7)}$$

Thus, to apply the formula in Eq. (7), a substitution can be made where $u = {}^3/_2 x$ and $2\,du / 3 = dx$. Finally, the resulting integral (antiderivative) would be:

$$P(x) = \left[\frac{2}{3}\left(\frac{10^{\frac{3}{2}x}}{\ln(10)}\right)\right]\Big|_a^b \qquad \text{Ec. (8)}$$

For the first period, which corresponds to the estimated population over 3 months, the interval to be calculated is [0, 3]. To calculate the definite integral, substitute b = 3 and a = 0 into Eq. (8) to obtain:

$$\int_0^3 r(x)\,dx = \left[\left[\frac{2}{3}\left(\frac{10^{\frac{3}{2}(3)}}{\ln(10)}\right)\right]\right] - \left[\left[\frac{2}{3}\left(\frac{10^{\frac{3}{2}(0)}}{\ln(10)}\right)\right]\right] \qquad \text{Ec. (9)}$$

Performing the calculations analytically yields an approximate value of 9154.19, which in this case we could round to 9154 individuals. However, this is only the population generated during this period, so we would also need to add the initial population (as indicated in Eq. (10)).

$$P(3) = 2600 + \int_0^3 r(x)\,dx \qquad \text{Ec. (10)}$$

Finally, the estimated population for this period would be approximately 11,754.19 individuals.

As in Example 1, in Stage 2 students must verify their analytical calculations using the GeoGebra tool. To perform this verification, they must enter the instructions shown in Figure 8 to confirm that the definite integral over the interval [0, 3] approximates the value calculated in the previous stage.

From Figure 8, it can be seen that, for this example, the definite integral over the interval [0, 3] using the GeoGebra program is 9,155.44; this value approximates the analytically calculated result of 9,154.19, although it varies slightly due to the number of decimal places used.

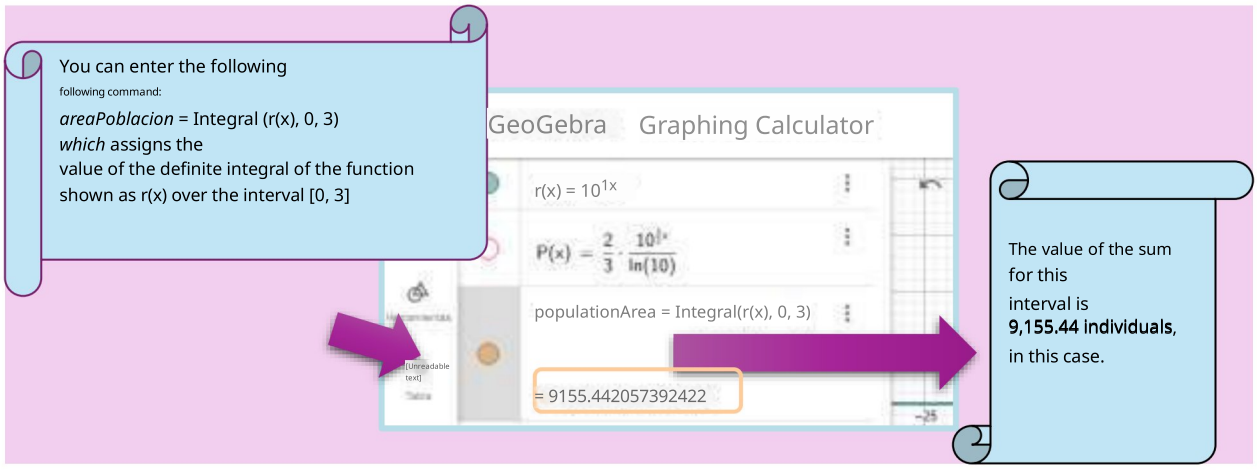


Figure 8. *Instructions entered in GeoGebra to calculate the area under the curve on the interval [0, 3].*
Source. *Created by the author.*

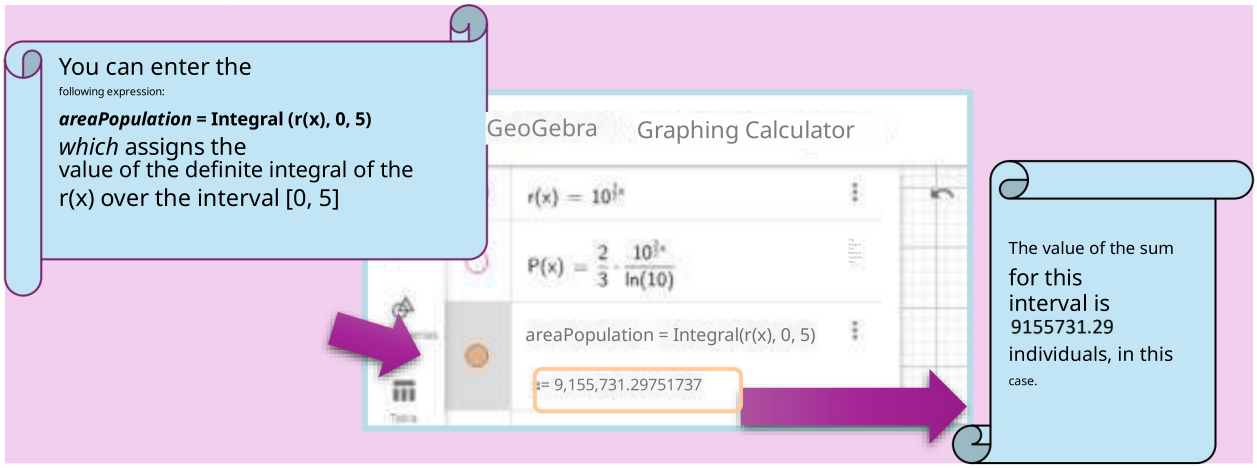


Figure 9. *Instructions entered in GeoGebra to calculate the area under the curve on the interval [0, 5].*

Source. *Created by the author.*

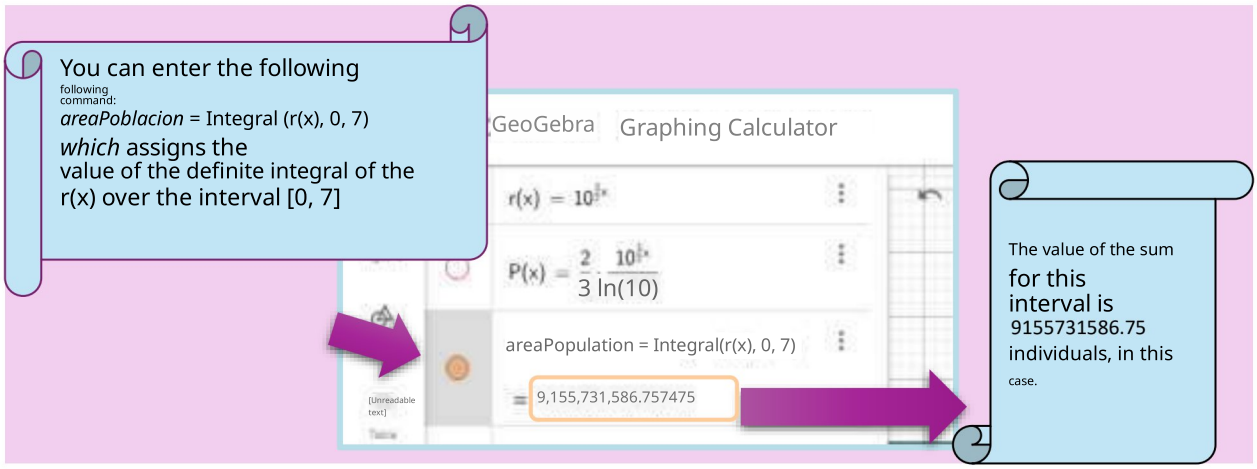


Figure 10. *Instructions entered into GeoGebra to find the area under the curve on the interval [0, 7].*

Source. *Created by the author.*

Similarly, to estimate population growth over 5 months, one would evaluate the definite integral over the interval [0, 5] using GeoGebra, as shown in Figure 9. In this case, the approximate population value of 9,155,731.30 individuals within this period—obtained both analytically and in GeoGebra—should match. To this number of individuals, we must add the 2,600 from the initial condition, which would result in an estimate of 9,158,331 individuals for 5 months.

Finally, for the estimated population over 7 months, Figure 10 shows the GeoGebra instructions for calculating the population of individuals during this period. This number of individuals (approximately 9,155,731,586.76) must also be added to the initial population of 2,600, resulting in an estimated final population of 9,155,734,186.76 individuals.

Figures 11, 12, and 13 show the graphs obtained in GeoGebra, similar to those that students must develop, explain, and justify in their presentation project. Figure 14 shows a graph of these three populations over the different time periods evaluated (3, 5, and 7 months).

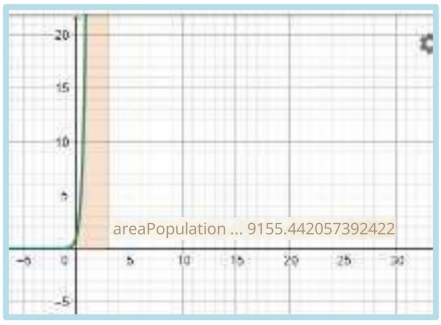


Figure 11. *Resulting graph in GeoGebra showing the area under the curve on the interval [0, 3].*
Source. *Created by the author.*

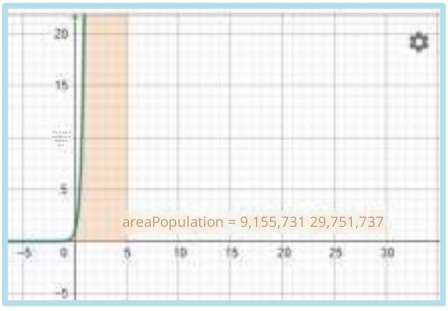


Figure 12. *Resulting graph in GeoGebra showing the area under the curve over the interval [0, 5].*
Source. *Created by the author.*

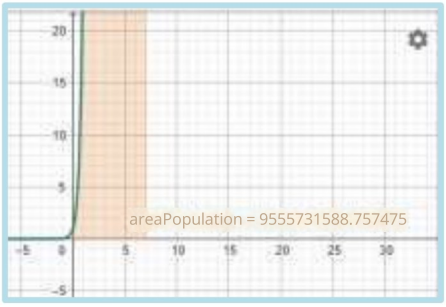


Figure 13. *Resulting graph in GeoGebra showing the area under the curve on the interval [0, 7].*
Source. *Created by the author.*

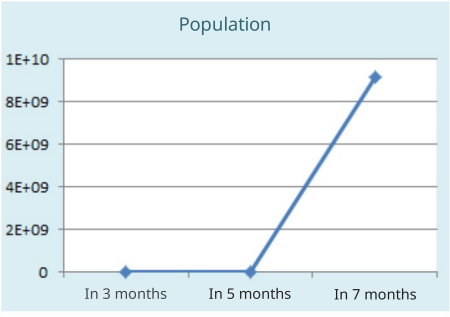


Figure 14. *Flu spread over 3, 5, and 7 months.*

Source. *Prepared by the authors.*

RESULTS

To evaluate the proposed project's impact on the performance of this Institute's engineering students, the scores obtained before and after the project were compared; the results are shown in Table 1.

Table 1. *Table of results obtained by the study group.*

	Score Average of the group	***Median***	***Range***
assessment before exposure	64.2	74	56
Assessment after exposure	94.8	100	27

Source. *Prepared by the author.*

Table 1 shows the quantitative results obtained by the study group on a pre-test administered before the proposed project was carried out (and after the instructor had explained the topic using traditional methods). On this pre-test, the group achieved an average score of 64.2/100, with a median of 74/100 and a range of 56 points.

Subsequently, presentations were held, in which teams of students participated to present their analytical calculations, GeoGebra models, and conclusions.

Finally, after completing the proposed project to improve understanding of the topic "applications of definite integrals" within the Integrated Calculus course, a second assessment was conducted. Table 1 shows the results obtained from this second assessment. Based on these results, the group achieved an average score of 94.8/100, with a median of 100/100 and a range of 27 points.

The results shown in Table 1 reveal an improvement—from 64.2 to 94.8 points—in the group averages obtained by the students as part of the proposed experiment for the Integral Calculus course. There was also an improvement in the group median, which rose from 74 to 100 points.

Regarding the range—which provides information on how far apart or close together the minimum and maximum scores are within the group—it can be observed that this value decreases after completing the team project, thereby achieving a more uniform level of knowledge within the study group.

To gather feedback based on the participants' experience, a survey was conducted; its results are shown in Figures 15, 16, 17, and 18.

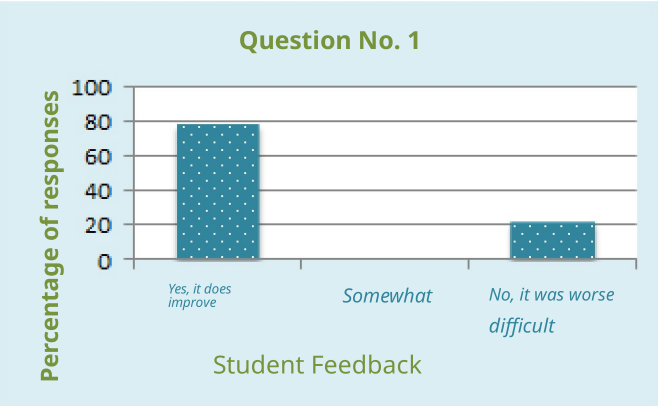


Figure 15. *Percentage of responses to question number 1: In your opinion, did your understanding of the topic improve as a result of working on the project?*

Source. *Compiled by the authors.*

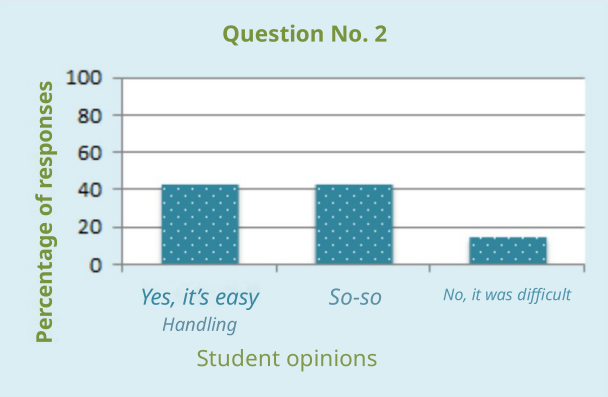


Figure 16. *Percentage of responses to question number 2: In your opinion, is the GeoGebra tool easy to use?*

Source. *Compiled by the author.*

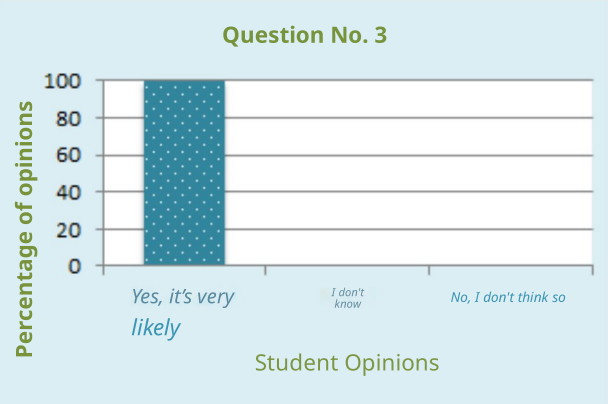


Figure 17. *Percentage of responses to question number 3: Do you think that using GeoGebra or another tool for graphing and performing mathematical calculations could be useful in other courses in your degree program?*
Source. *Compiled by the author.*

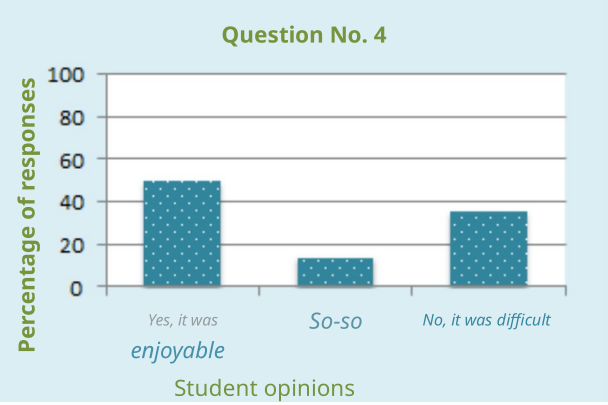


Figure 18. *Percentage of responses to question number 4: In your opinion, was this teamwork activity a positive experience for you?*

Source. *Compiled by the authors.*

DISCUSSION

Furthermore, based on the results of these surveys, it can be observed that, since engineering students taking Integral Calculus are in the early semesters of their degree programs, most have not had exposure to information technology tools focused on mathematical calculations—such as GeoGebra—and therefore this exercise presented a certain degree of difficulty and challenges (see Figures 16 and 18). However, they recognize the need to use these tools, as they will be useful in other courses within the program (see Figure 17). For this reason, even though completing this assignment required significant effort in some cases, the experience proved positive, equipping them with new skills that will be useful for future courses in their engineering program.

Finally, regarding the results obtained using the proposed methodology, it can be observed that there is an improvement in learning the topic of “applications of definite integrals” (see Figure 15). This conclusion aligns with the results reported in some other studies that also use information technology tools to improve teaching processes in the field of mathematics.

Finally, regarding the results obtained using the proposed methodology, it can be observed that there is an improvement in learning the topics of “Area Under the Curve” and “Applications of the Definite Integral.” This conclusion aligns with the results reported in several other studies that also use information technology tools in the field of mathematics. For example, in [14], the authors conclude, based on the experiments conducted, that students perceive artificial intelligence tools as useful and essential for developing technological competencies. Additionally, in [5], a virtual laboratory is created to reinforce the subject of differential calculus, which addresses specific topics in this field, such as the calculation of derivatives. Based on their results, the authors demonstrate that these interactive scenarios promote self-directed understanding of concepts in the Differential Calculus course.

CONCLUSIONS

Based on these results, we can conclude that the development of this project advances and strengthens the curriculum for the subject of Integral Calculus by incorporating new, sustainable approaches that utilize information technology.

This project is expected to aid in the understanding of the topics described in the context of a real-world application within the field of biology, as well as to contribute to the development of certain skills, such as: the ability to work in teams, discuss different points of view, speak in public, and clearly express ideas. In this case, by comparing average grades, it is evident that implementing this project within the Integral Calculus course has made a significant contribution. In addition to enhancing students’ analytical and problem-solving skills for addressing other real-world problems within the subject, this contributes to their professional development.

Based on the results obtained in this research study, a proposed area for future work is the implementation of the methodology used to address other topics within the Integral Calculus course, such as: applications of the arc length of a curve in the plane, calculation of surface areas, and calculation of work, among other topics.

DATA AVAILABILITY STATEMENT

Study data:	The exams and surveys from which the statistics are calculated are physically retained; however, this document shares only the statistics relevant to supporting the conclusions presented.
Protocol / Code / Questionnaire:	Described within the text.
Funding Source:	There is no source of funding.

Conflict of Interest:	The authors declare that there is no conflict of interest regarding this manuscript.

Ethical Approval:	Not applicable.

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Writing – Revision and Editing	José Oscar Laguna Cortés, Selene Hernández Rodríguez, Erika López Sánchez, María Patricia Torrijos Muñoz
Visualization	José Oscar Laguna Cortés, Selene Hernández Rodríguez, Erika López Sánchez, María Patricia Tirojos Muñoz
Supervision	José Oscar Laguna Cortés
Project Management	José Oscar Laguna Cortés

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12 national articles

6 articles international

10 years of industrial experience

SNII Level I

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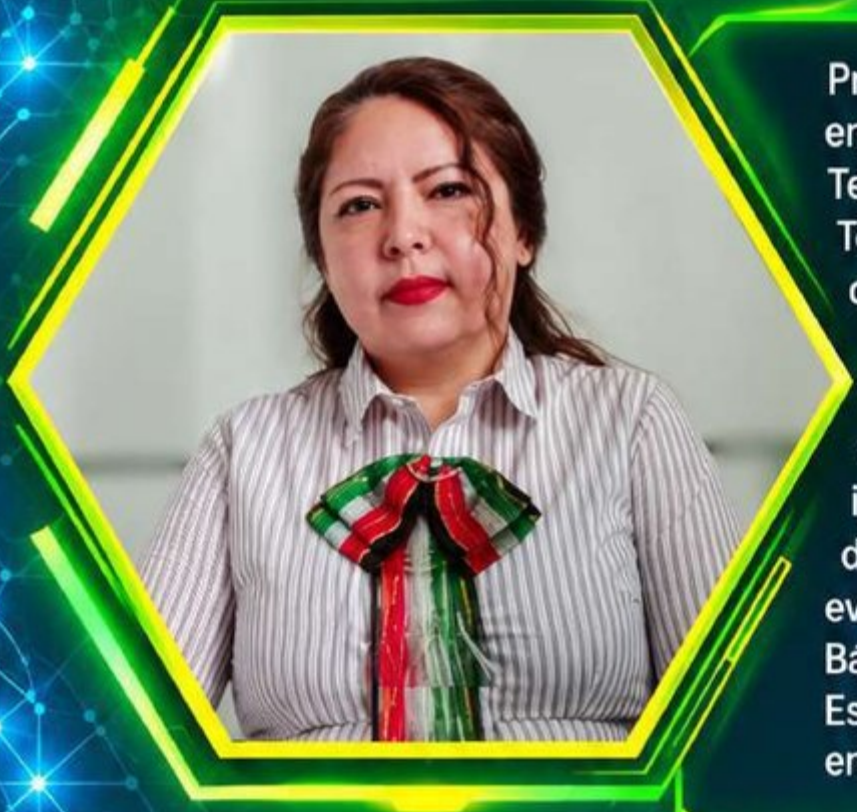
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8
national articles

3
articles international

5
years of experience in programming

Ph.D. in Computer Science

ENGLISH

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7
articles published

6
years of publications

Engineering Biochemistry

Microorganisms applied to soil

ENGLISH

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11 national articles

2 articles international

5 years of industrial experience

PRODEP Desirable Profile

ENGLISH

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2 national articles

1 international article

5th semester

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