

An Attempt to Bring Calculation Closer to Student Reality through Active Methodologies: 4E's

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Abstract: The Calculus I course has high failure rates in universities in Brazil and around the world, as well as at the School Engineering of Lorena (EEL). This article seeks to contribute to minimize this issue, adopting as a strategy the use of active learning methodologies. Active methodologies already established in the literature were searched, which served as the basis for the construction this work. A questionnaire was also applied to EEL students to map their most common difficulties and specially to know the students perspective on the current situation of the discipline. From the results of the questionnaire we sought to interpret what were the main factors that contributed to the high failure rates of the discipline in the EEL. From this analysis a procedure was elaborated that united the concepts of the previously researched methodologies, which were more adequate to face the problems highlighted by the questionnaire, aiming to contribute appropriately to the improvement of the discipline learning.

Keywords: Calculus, Engineering, Peer instruction, Problem based learning

Introduction

It is no secret that the Differential and Integral Calculus discipline has high failure rates, since this is not a current problem. Wrobel (2013) shows us that between 1996 and 2000 the failure rate of important Brazilian university, as such as, Fluminense Federal University varied between 45% and 95%, as well as at the Federal University of Rio de Janeiro where this same rate was 42% in the first half and 48% in the second half of 2005. The School Engineering of Lorena (*Escola de Engenharia de Lorena - EEL*), as well as many other universities in the country, are not exempt from this reality.

The discipline of Calculus I is of great importance in courses of exact areas, where it often occupies a prerequisite position for many other disciplines, thus having a great weight for the continuity of the students course (Paula et. al, 2016). The importance of passing Calculus I for the continuity of the course, coupled with the high failure rates (which are well known by students), builds in students a peculiar view of the discipline, where the major challenge is obtaining approval and learning becomes only a necessary part of accomplishing this goal. This atmosphere around the dreaded Calculus I makes the learning needed in this discipline a background, which does not mean that the current method of teaching does not work. However, in the current scenario the situation is common in which the student takes Calculus I for the purpose of passing and not necessarily learning.

Rezende (2003) makes us think over on what we want from the calculus course. Do we want a course in which technique prevails? Or do we want a course in which the meanings are well established? The author explains that a consensus among teachers is that students entering undergraduation do not generally have a well-established mathematical basis, which is characterized by mathematical techniques: polynomial factorization, algebraic calculations, trigonometric relations, etc. This problem exists, however it is not unique to Calculus I, as this discrepancy also exists for other higher education subjects, but even so, not all of them have alarming results as in Calculus. In contrast to the techniques of basic mathematics "The semantic field of the basic notions of calculus has much more to do with the notions of "infinity ", " infinitesimal ", " variables "[...] (REZENDE, 2003, p.18). Meanwhile, Berry and Nyman (2003) propose to relate the understanding of concepts of derivative through graphs or in other words "graphical links between the derivative of a function and the function itself"

through the use of graphing calculators. Given this, what do we want to produce with the Calculus I course? Students able to calculate the most complex derivatives, integrals or limits? Or individuals able to use concepts and ideas to create solutions? Through this article, we sought to understand more about the scenario of the discipline of Calculus I in an attempt to contribute to the improvement of its teaching.

Active Teaching Methodologies

In order to propose an improvement to the current scenario of calculus teaching, we sought to study in the literature what is already being done, with a special focus on the active teaching methodologies that will be introduced below.

Problem Based Learning

Problem Based Learning (PBL) is a well-known and established teaching methodology which follows the principle one learns by doing, that is, instead of learning a concept passively, absorbing and accumulating information that is being transmitted, learning is built through practice, facing a real life situation. In the PBL methodology students are arranged in teams which in turn receive a problem situation in which the concepts of the discipline are required to solve it. The problem situation is based on cases experienced by professionals working in the profession intended by students (Pereira et. al, 2017; Milss and Treagust 2003; Santos et. al, 2018). This approach allows the development of various transversal skills, such as teamwork, professional and social responsibility, communication, among others. In addition, the PBL is able to bring theory closer to practice by promoting knowledge that goes beyond the technical-scientific, placing the student in an active position in their learning and giving them the opportunity to see the reality of their intended profession. Another highlight of the PBL is that students are placed in a position in which autonomous study is of paramount importance for problem solving, as to solve it, teams will need to develop research to better understand the situation and thus be able to propose a solution and optimize it (Oliveira and Romão, 2018a; Oliveira and Romão, 2018b; Silva et. al, 2019; Alves et. al, 2019). Therefore, the methodology promotes multidisciplinary knowledge, since in order to reach the solution, it is necessary to have knowledge that goes beyond those addressed by the discipline in question (Ribeiro, 2008).

Peer Instruction

Peer Instruction (PI) seeks to explore the exchange of knowledge between students, while utilizing technology to make the class more dynamic and to make the teacher aware of the learning level of the class in real time (Mazur, 1997). The methodology works as follows: first the teacher gives a brief explanation of the main subject of the lesson. A Concept Test (CT) is then applied to the subject explained, usually being a multiple-choice question. Using some means of voting (mobile applications, websites, etc.) students answer the CT. If less than 30% of students get it right, the teacher should review the whole concept with the room and apply the same CT again. If more than 70% of the students answered correctly, the teacher makes a brief review based on the mistakes made and can then proceed to the next class topic or apply a second CT judging by the understanding of students. Already if the hit range is between 30% and 70%, students should join in pairs and discuss among themselves about the issue and then vote again. With the result of the vote the teacher can show it to the students by explaining the test answer, seeking to address the most common questions and errors (Müller, 2013; Crouch and Mazur, 2001). Having experience and knowledge of the subject makes the teacher see the content very differently from the students. In some cases what is clear to the teacher is extremely complex for the student. Given this, PI seeks to get students to interact with each other and share their views with their peer partner, so as much as each one understands the content in their own way, everyone is seeing it for the first time and can explain and teach each other. Thus, in addition to thinking about what is being learned, students have contact with new ways of thinking, making the shared knowledge complement each other and students become active in their learning process (Crouch et. al, 2007; Cummings and Roberts, 2008).

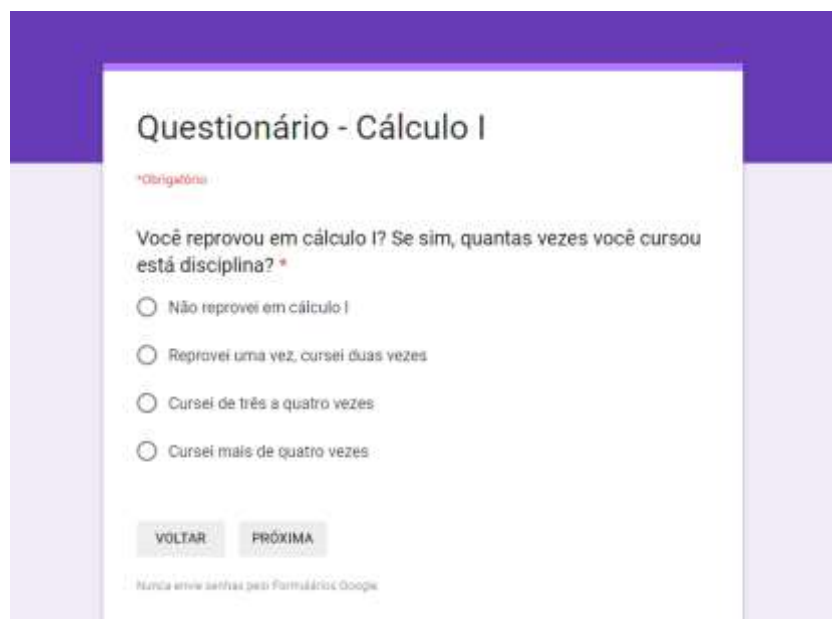
Think Pair Share

Think Pair Share (TPS) arose from a common classroom situation when the teacher asks a question for the class and at most one or two students answer, or no student at all. What TPS proposes to us is that for this interaction to work, students need time to think, and time to share their thoughts with a colleague, so that they both build a more elaborate response and share it with the classroom (Kaddoura, 2013; Slone and Mitchell, 2014; Sunita and

Halkude, 2016). As in PI, the teacher proposes a discussion through questions that have the role of guiding the student in the subject to be learned. Students then have time to think on their own and then come together in pairs to discuss and share their ideas, which will later be presented throughout the room (Reis and Barreto, 2017). Unlike PI, however, the goal of the discussion is not to get the answer right, but to get students to think about it, discuss ideas, and get in touch with different ways of thinking as they share their ideas with each other. In addition, as these ideas are shared into the classroom, possible questions may arise and be discussed, consolidating knowledge. Reis and Barreto (2017) explains that the TPS approach implies working not only with the technical knowledge of the subject to be addressed, but also with the students' inherent knowledge, built from their experiences and worldviews. Thus, the goal to be achieved with TPS is to expand the students' worldview while discussing a subject that is of interest to them.

Profile of Calculus I Engineering Students

In order to propose improvements to the teaching of Calculus I, we sought to map the main difficulties of the students in the discipline, as well as their opinions about the context in which it finds itself. The means adopted to obtain this information was the application of an online questionnaire to the students of the Engineering School of Lorena in the second semester of 2018, using the Google Forms (see Figure 1). The questionnaire was divided into two parts, the first part containing personal questions (see Appendix 1) such as: how often did the student attend Calculus I, his / her background in elementary school, his or her opinion on the main causes of failure in Calculus I, and suggestions for improving learning in subject. In the second part, technical aspects related to concepts of basic mathematics (see Appendix 2), limit and derivative were evaluated.



The image shows a screenshot of a Google Form titled "Questionário - Cálculo I". The form is in Portuguese and contains the following text: "Obrigatório" (Required), "Você reprovou em cálculo I? Se sim, quantas vezes você cursou esta disciplina?" (Did you fail Calculus I? If yes, how many times did you take this discipline?). Below the question are four radio button options: "Não reprovei em cálculo I", "Reprovei uma vez, cursei duas vezes", "Cursei de três a quatro vezes", and "Cursei mais de quatro vezes". At the bottom of the form, there are two buttons: "VOLTAR" (Back) and "PRÓXIMA" (Next). A small note at the bottom says "Nunca envie senhas pelo Formulário Google" (Never send passwords through Google Forms).

Figure 1. Questionnaire Illustration on Google Forms (in Portuguese)

The goal was to diversify the data collected, knowing both the vision of students who have recently taken the course, as well as veteran students. For this, the questionnaire was applied to two different publics: in the first were classes that were studying Calculus II, and therefore had studied Calculus I recently (there are one or two semesters of the time of application of the questionnaire). This first public answered both parts of the questionnaire. Simultaneously the questionnaire was applied to students from more advanced periods, who in turn had studied Calculus I for more than three semesters. In this second public, only the personal part of the questionnaire was applied, since the technical questionnaire evaluated concepts to which veteran students had not been in contact for a considerable time, and which could be not so accessible in memory. In all 185 people answered the personal questionnaire and 71 answered the conceptual questionnaire. Importantly, participants anonymity was maintained.

As part of the personal questionnaire, the students were asked which factors contributed most to the high failure rates in Calculus I. Among the various reasons given by both veteran students and those who have recently completed Calculus I, it was found that a particular factor stood out in both audiences: The lack of dedication and / or interest in the discipline, pointed out by 59.2% of new students and 55.3% of veteran students. Another

relevant question concerns the basic education of the interviewed students, in which it was possible to verify how different the number of students from public schools compared to those who studied in private schools, as shown in Figure 2.

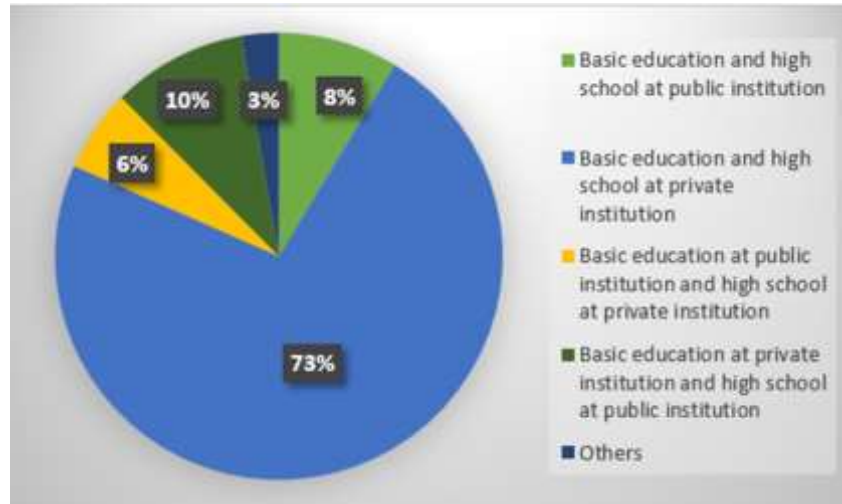


Figure 2. Description of Basic Education of Students Interviewed

When asked what could be done to improve learning in the discipline, Figure 3, students pointed out three factors: a lesser focus on concept demonstrations and a greater focus on applying them to the intended profession; use calculation concepts to solve real situations; and the creation of a preparatory discipline that preceded Calculus I. These data indicate that students perceive a great distance between what is developed in Calculus classes and the profession desired by them, simultaneously express a lack for relating concepts learned from reality.

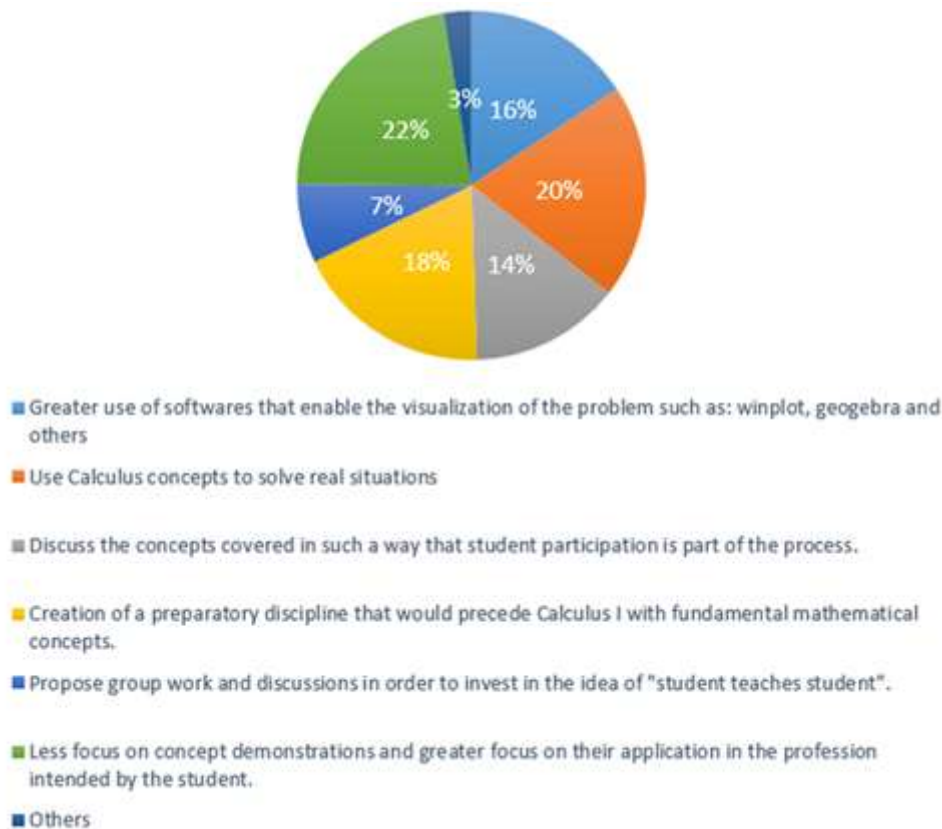


Figure 3. Student Feedback on What Might Help in Calculus I Classes

In the technical part of the questionnaire, we sought to measure the degree of understanding of students about certain concepts often used in Calculus. In one question, several function graphs were shown and students were asked to tick only the function graphs of type $y = f(x)$. In this question 40% of the students made a mistake. When asked what is derived from a function, 48% of students did not have a correct answer. These results lead us to understand that a significant part of students who have already studied Calculus I, do not satisfactorily understand the concepts they frequently use, for example, derivatives and rate of change that are contents used in various Calculus disciplines.

A Proposal of Teaching Methodology: 4E's

The methodology proposed here uses concepts from the active methodologies previously described, to minimize the main teaching difficulties exposed by EEL students through the questionnaire. The 4E Methodology (*4E: Estimular, Explicar, Exercitar e Experimentar – in portuguese*) consists of four main steps: to Stimulate, to Teach, to Exercise and to Experiment, in which the student will be encouraged to interact with the class, will learn concepts and exercise them and of course put them into practice within their profession intended. The main goal of 4E's is to make Calculus I no longer explain itself in isolation, but become tangible for the learner, closer not only to the intended profession, but also to the reality of student and for this to occur it is necessary to be bold enough to reflect on what is the reality of these students and to find ways to interact with this reality through Calculus.

From the data of the questionnaire, it was perceived in the engineering student a lack for visualizing the concepts of Calculus, not that these concepts are not taught and exercised, this actually occurs. However, this lack is related to another kind of visualization, one that be palpable and compatible with the student's experiences, generating genuine interest in addition to necessary interest in approval. The present methodology proposal intends to build a model of classes that can adapt to the rhythm of the teacher, as the classes becomes more interactive for the students. One of the goals of the methodology is to make students broaden their thinking through interaction with each other. For this to happen the classes are taught with students arranged in pairs, and the whole classes the pairs are exchanged. The intention is to make sure that during the classes there are times when the pair discuss and work together on a question and that with the rotation of the pairs the student has contact with various ways of seeing and solving a problem. The steps required to apply 4E's and their relationship to existing methodologies will be described below and are illustrated in Figure 4.

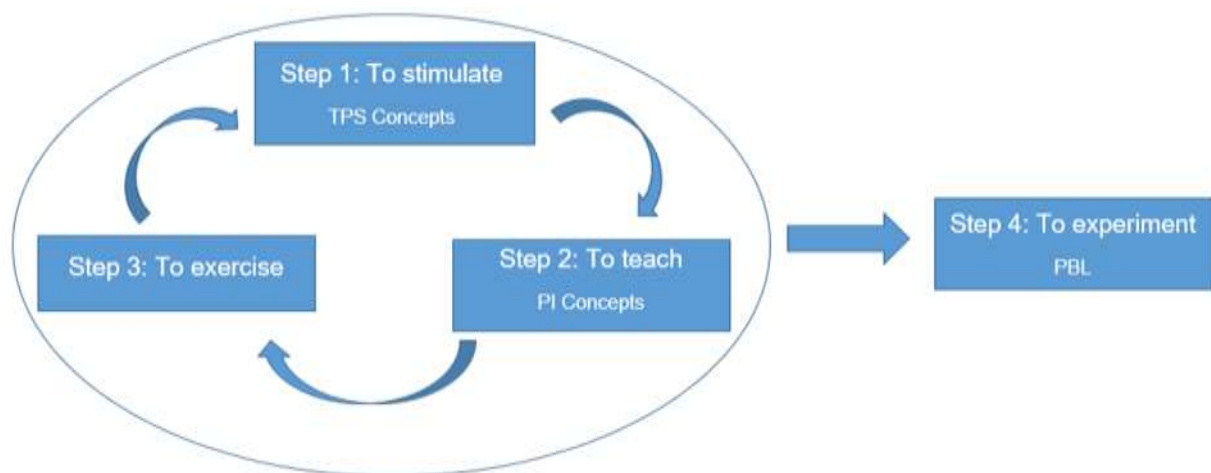


Figure 4. 4E's Step Cycle

Step 1: To stimulate (Estimular)

As in a traditional methodology, during a semester several concepts are taught class by class and that finally make up a subject of the discipline. To teach derivative for example, it is necessary to teach various contents that in turn make up the subject "derivative". Keeping in mind the notion of how the discipline is composed, step 1 will be applied every time a new subject is addressed. As the name implies, the purpose here is to stimulate the student by instigating him and bringing him to class. For this the teacher should ask the class an initial question that has to do with the topic that will be addressed in class.

The question should be straightforward and simple, not requiring sophisticated calculations or analysis of various data. The goal is for the student to express his own logic and share it with the pair. So that this works requires time for students to think as well as at TPS (about 1 to 3 minutes). The teacher should ask the pairs what their answers are, encouraging the pupils to respond in their own words, then write down the ones that repeat the most and also the ones that escape the pattern. After the theoretical explanation (contemplated in step 2) the teacher explains the correct answer to the initial question, comparing it with the students answers and showing what was coherent and what was wrong.

In this process, the student will share their thinking and also listen to someone else argument. Later, this common sense of the students will be confronted with what the theory says about that situation, causing a change of perspective from something that the student already knows. The pair change enriches this process as the student will come into contact with various ways of thinking. An effective way to create good initial questions is to look for everyday things, such as Instagram, a social network that is very much present in student lives. Why not lead students to reflect on how to measure the influence generated by an Instagram profile? In addition to being something familiar to students, it is a question that opens discussion about rate of change because to measure this influence, it is necessary to look at the engagement rate, which in turn is a related rate. It is also possible to show with this situation how to interpret data by showing picture profiles known by students, showing that the largest number of followers does not always mean higher popularity, and how the engagement rate depends on the frequency of posting. Situations like this, which seem to be far from the classroom, can serve as raw material for the application of important concepts of calculus.

Step 2: To teach (Explicar)

After to note the answers of the pairs, the teacher will start the second step, explaining the theoretical concepts and making demonstrations relevant to the subject, as in a so-called "traditional" calculus class. It is worth noting that at this stage the teacher can work simple exercises as a way of demonstrating theory, but exercise solving should not be the main focus, for that there will be a specific step for solving more sophisticated exercises. An interesting way to check if students are really understanding the class is through conceptual testing combined with a voting system, just like at Peer Instruction. The teacher can at the end of one step of the explanation apply a CT, and through some mobile app or online platform, as well as Google Forms itself, where students vote for the alternative they think is right and the teacher has access to statistics of hit and miss in real time. Following the logic of IP, depending on the percentage of hits, the teacher can repeat the same CT, apply another CT with the same theme or go to the next step of explanation, always answering the most recurring doubts between applying a CT and other.

At each CT applied the pairs will discuss and must reach consensus and vote for one of the alternatives. The CT being multiple choice speeds up the process of student responses, as well as allowing the teacher a more immediate view of students' difficulties. But for this to happen the CT must be prepared in order to give feedback to the teacher in such a way that the wrong alternatives reveal the possible difficulties of the students. There are several sources of CT available that are already applied in class, as well as the Good Questions Project, a Cornell University platform with a database of CTs for Differential and Integral Calculus. This process is interesting because even those students who were not paying attention in class are induced to repeat the process until the vast majority of the class has performed satisfactorily. In this case, the student who has difficulty in the subject also has the opportunity to receive the explanation more often remedying their difficulties through the immediate correction of the CT's.

Step 3: To exercise (Exercitar)

In this step the concepts explained in the previous step will be used to solve more sophisticated exercises. At this point it is important to establish a coherence of exercise difficulty so that the difficulty of the exercises solved in class is sufficient to train the students to make the exercise lists and, consequently, is sufficient for the resolution of the test. The student uses mainly the exercises of the notebook and the lists to measure the degree of demand that the discipline demands and their degree of understanding about it. Therefore, it is interesting to keep this transparency in the difficulty level of the exercises, because the students count on it.

Communicating with students during the semester is critical so that Step 3 is used to solve the exercises on the list where students have the most difficulty. For this, it is interesting to check the exercises that are often taken by students to the monitor of discipline. This strategy eliminates the most common doubts among students and

can make their study process more productive. The first three steps are cyclically repeated (Figure 3) until the content of a given subject is terminated, for example, until the content of Derivatives is finished. The teacher can apply the three Steps in a single class or repeat Steps 1 and 2 for a certain amount of content and then apply a lesson with Step 3 alone, adapting the 4E's to their class pace. The important thing is to follow the order in which the steps happen.

Step 4: To experiment (Experienciar)

Step 4 does not focus on defining concepts and exercising them as in the previous steps, but on getting students to experience how these concepts are used in their intended profession, putting them into practice through a real problem. After to finish one of the topics approached in class (for example: Derivative), students will be challenged to apply these concepts through a situation experienced by a professional in their field, as well as in the PBL methodology. At this time, students form teams and each team receives a problem situation, which in turn requires students to apply the concepts previously discussed to reach the solution.

As with PBL, multidisciplinary character is encouraged at this stage, as conceptual knowledge will not be the only one needed to arrive at the solution. Thus, in this process students will have contact through research with interdisciplinary topics, enabling the student to understand their profession more broadly. Teamwork is also important for students to develop soft skills such as leadership, conflict management and others. Another interesting factor is that the turnover of the pairs causes interaction between students, so that when teamwork is required, this interaction is already consolidated, positively influencing Step 4. This allows students to discover with whom they work best, facilitating team building. An interesting example of the application of PBL in calculus concepts can be view in Alves et. al (2019). This work shows a work done by EEL students, where after teaching and setting the topic of Defined Integrals these students used this concept along with software and technologies already known as GeoGebra and Google Earth to calculate the area of a region suffering from flooding problems in Macaé, RJ/Brazil. This experience, besides proposing the visualization of Calculation concepts in real situations, is also a social measure, since calculating the area that suffers flooding, contributes to the monitoring of these risk areas, which other hand turn is necessary for propose an action plan. Experiences like this make students discover for themselves how it is possible to interact with the world around them in a different way by absorbing new knowledge.

Conclusions

This article sought through a questionnaire to identify the main difficulties of students in the discipline of Calculus I, as well as to know which factors most influence the high rates of failure of the subject from the perspective of the student and also how this problem could be faced. Along with this analysis, it was searched in the literature for already established active methodologies that could contain concepts that could serve as a basis for dealing adequately with the situation. In general, students believe that there is a very large gap between the subject and what is of interest to the student, in the sense that Calculus I is not seen as an integral part of the knowledge of the profession intended by the undergraduate student, but rather as a mandatory step to achieve it. To minimize such issues, this paper presented an approach that combines three methodologies: PBL, PI and TPS. It is expected that the proposal orient teachers seek to add new teaching trends to their classes in order to make the teaching-learning process more dynamic and meaningful to the student.

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Appendix 1. Personal Assessment Questionnaire for Calculus I Students

01 – Which of the following factors do you think contribute the most to high calculation disapproval rates I?
(Check 3 options)

- Absence of dedication and/or interest
- High school focus solely on higher education entry
- Elementary and / or secondary education with lag in education
- Classes with too many students
- Lack of relationship between the content covered in Calculus I and the profession intended by the course
- Type of test applied by the teacher
- Intrinsic difficulty of matter (very difficult content)
- Applied teaching methodology is inefficient
- Lack of time to study
- Others

02 - Did you fail Calculus I? If so, how many times have you taken this course?

- a) I didn't fail Calculus I
- b) I failed once, I attended twice
- c) I took three to four times
- d) I attended more than four times

03 - Before joining EEL, you studied at:

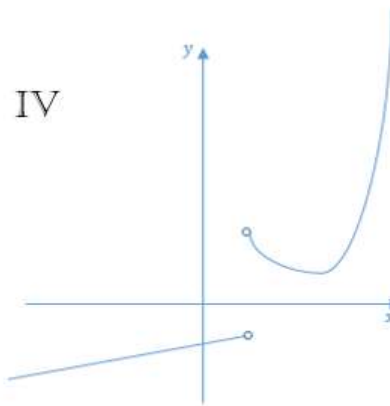
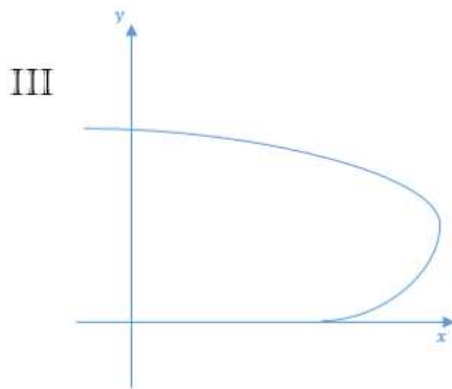
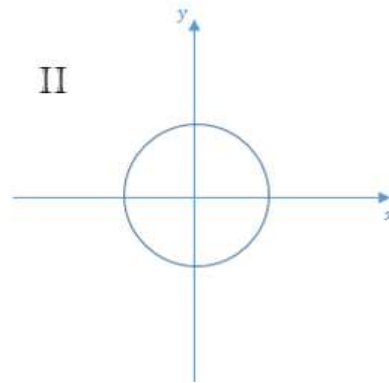
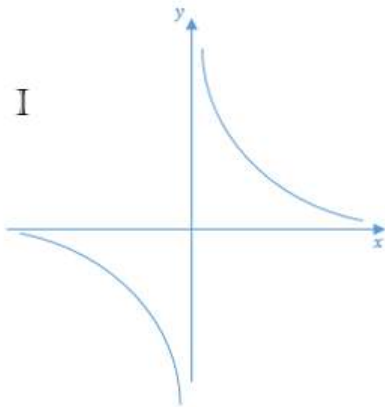
- a) public school in elementary and high school
- b) private school in elementary and high school
- c) public school in elementary school and private school in high school
- d) private school in elementary school and public school in high school
- e) others

04 - In your opinion, which of the following methods would improve the Calculus I teaching methodology?

- Increased use of software (winplot, geogebra and others) that enables the visualization of the problems.
- The use Calculus concepts to solve real situations
- The discuss the concepts covered in such a way that student participation is part of the process.
- Creation of a preparatory discipline that would precede Calculus I with fundamental mathematical concepts.
- To propose works and group discussions in order to invest in the idea of "student teaches student".
- Less focus on concept demonstrations and greater focus on their application in the profession intended by the student.
- None
- Others

Appendix 2. Conceptual Questionnaire of Calculus I

05 - From the following graphs, check the alternative that contains only graphs that represent a function of type $y = f(x)$.



- a) Only I
- b) I, II and IV
- c) III and IV
- d) I and IV
- e) I, II and III

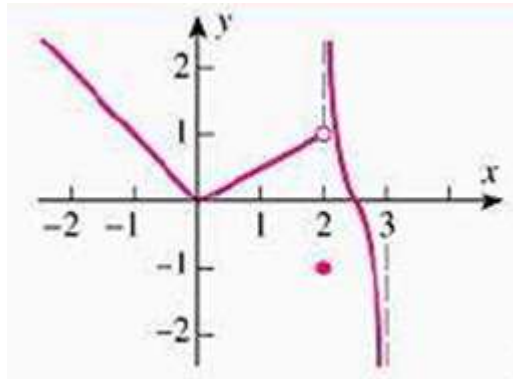
06- From the following statements about linear functions:

- I. Linear functions always have a zero rate of change
- II. Linear functions always have constant rate of change
- III. Linear functions are always polynomials
- IV. A linear function has 2 real and equal roots with opposite signs.
- V. The graph of a linear function is always a straight line.

Which of the previous statements are correct?

- a) I, II, III and V
- b) II and V
- c) II, IV and V
- d) Only V
- e) III and V

07 - Use the graph of $y = f(x)$ below to determine the limits.



Source: Anton, H. et. al, (2012)

$$\lim_{x \rightarrow 0} f(x) =$$

- a) 1
- b) 0
- c) -1

$$\lim_{x \rightarrow 2^-} f(x) =$$

- a) 2
- b) -1
- c) 1

$$\lim_{x \rightarrow 2^+} f(x) =$$

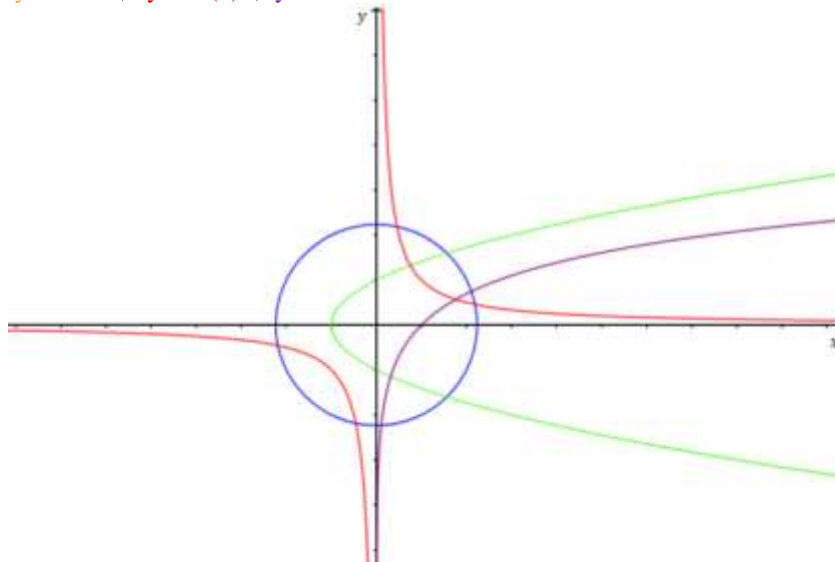
- a) $-\infty$
- b) 2
- c) $+\infty$

$$\lim_{x \rightarrow 3^-} f(x) =$$

- a) $-\infty$
- b) -2
- c) $+\infty$

08 - Match the graph presented to each equation according to color:

- a) $x^2 + y^2 = r^2$; $y^2 = x + 1$; $y = \ln(x)$; $y = 1/x$
- b) $2x^2 + y^2 = r^2$; $y^2 = x + 1$; $y = \ln(x)$; $y = 1/x^2$
- c) $x^2 + 2y^2 = r^2$; $y = x^2 + 1$; $y = \ln(x)$; $y = 1/x$
- d) $x^2 + y^2 = r^2$; $y^2 = x + 1$; $y = \ln(x)$; $y = 1/x$



09 – Suppose the cost in R\$ of drilling x meters (m) for an oil well is $C = f(x)$.

- a) What are the units of $C'(x)$?
- b) In practical terms what is the meaning of $f'(x)$ in this case?
 - a) Perforated depth variation rate by cost
 - b) Drill depth variation rate
- c) What can be said about the cost of drilling when the sign $f'(x)$ is negative? And when it's positive?
 - a) Negative: depth by cost is falling; Positive: Depth by cost is rising
 - b) Negative: Cost per depth is falling; Positive: Cost per depth is rising
 - c) Negative: Cost per depth is rising; Positive: Cost per depth is falling
 - d) Negative: depth by cost is rising; Positive: Depth per cost is falling

10 – From the following statements about what is a derivative of a function $y = f(x)$:

- I. It is the line tangent to the function curve at point P
 - II. It is the instantaneous rate of change of y with respect to x at point P
 - III. It is the slope of the secant line to the function in the range in which the image varies.
 - IV. It is the rate of change of y over any given interval Δx .
 - V. It is the angular coefficient of the line tangent to the function curve at point P
- a) only II
 - b) I, II, IV and V
 - c) IV and V
 - d) III and IV
 - e) II and V