PROCEDURAL/ROTE LEARNING VS MEANINGFUL LEARNING: WHICH DO FIRST YEAR UNDERGRADUATE STUDENTS PREFER?

M.P. de Sousa Oliveira

University of Aveiro, Center for Research & Development in Mathematics and Applications (CIDMA) (PORTUGAL)

Abstract

Teaching Calculus for 1st year higher education students, in particular those enrolled on Engineering studies has always been a challenge. Large classes, a variety of student profiles and a teaching staff with different personalities are obstacles that we have to face in coordinating a Calculus course.

Teachers believe students' prior knowledge of Mathematics is sufficient for them to understand the subjects that are supposed to be taught in these courses. They also think that their students are ready to undertake a complementary autonomous study, as long as they are given the right resources. However, students' perspectives don't seem to get along with teachers' perceptions.

In this article, we present a study carried out with 1st-year Calculus students enrolled on two different Engineering degrees, taught by the same teacher. Every week there were two different types of classes for two hours each. One was a "classical" class, where the teacher presented the topics, with slides and examples, usually with some discussion. The other took place in a special room with round tables, where students had some tasks to work on in groups and the teacher circulated amongst the groups to clarify the doubts that arose. Each table was given three coloured cards (green, yellow and red) similar to traffic lights so that the teacher could help the groups with more difficulties first.

The MOODLE platform was used to deliver the resources needed to accomplish a detailed study of the topics taught, including a "study guide"; videos explaining all the course concepts; a textbook I wrote covering all the course syllabus, with examples, solved exercises and suggested exercises with solutions and worksheets.

By the end of the semester, the students were asked to answer a survey regarding their experience with this course, focused on the types of classes and resources available for the study of the curricular unit. The different perspectives of the students enrolled in the two engineering degrees are somewhat unexpected. Although the access grades for the two engineering degrees are not so different, the answers given differ considerably, which is in line with the student's attitude in class and with the final grades in the course unit.

As a (mathematics) teacher, one of my deepest concerns is that students understand what they are doing and why, so, in my textbooks, I always try to explain all the procedures, but to my dismay, students claim for detailed answers to exams or worksheets, which they find the most useful resources to study.

In this paper, we will discuss the results of the survey applied by the end of the semester, and make some considerations on the changes required in the teaching methodology to engage more students in their own learning, but also to develop other skills, such as communication, reasoning, self-confidence, and essentially how to break with the paradigm of rote and procedural learning.

Keywords: Mathematics; Calculus; Rote learning; Procedural learning; Meaningful Learning.

1 INTRODUCTION

According to Hiebert & Lefevre (1986) and Hiebert & Carpenter (1992) cited in [1] "Procedural knowledge consists of formal language of mathematics, and of rules, algorithms and procedures used to solve mathematical tasks" and "Conceptual knowledge is knowledge which is connected to the other pieces of knowledge, and the holder of the knowledge also recognizes the connection. The connections between the pieces of knowledge are as important as the pieces themselves".

Morando and Torconi in [2] state that "Most students believe that mathematics is essentially a matter of calculations so to succeed it's sufficient to learn to reproduce a set of predetermined procedures. Indeed, a lot of students rely on the study method learned in high school, which is mostly procedural and not focused on comprehension and meaning, and use that as default for university courses."

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According to Novak (1994) as cited in [3] "Ausubel has made the clear distinction between rote learning where new knowledge is arbitrarily and non-substantively incorporated into cognitive structure (or we might say now, into long term memory, LTM), and meaningful learning where the learner chooses conscientiously to integrate new knowledge to knowledge that the learner already possesses."

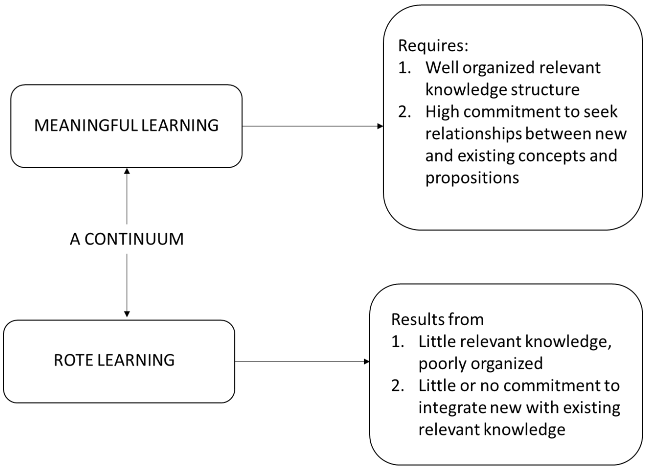

Figure 1: Meaningful learning occurs on a continuum, depending on the quantity and quality of relevant knowledge. [3]

Novak in [3], states that "If we learn strictly by rote, essentially no integration of new concept meanings occurs, and existing cognitive structure is not elaborated or reconstructed".

As experienced teachers, we know that autonomous work, linked to previous concepts, promotes learning in a more effective way, however, many students don't share the same belief and keep on studying, just reproducing procedures they have seen in some solved exercises, without understanding the concepts underlying the answers.

A brief analysis of some students' answers on exams, shows the poor learning outcomes of a Calculus course. They get acquainted with the procedures but no meaning for them is used. For instance, in the case of numerical series, they know some of the criteria that are to be applied to determine whether the series converges or not, however most of them don't understand the meaning of convergence, as seen in this example.

Example 1: In an exam the students were asked to prove the convergence of a given series and they wrote that the series was equal to the criterion they had to use:

$$\sum_{n=1}^{+\infty} \frac{4n}{n^3+1} = \lim_{n\to\infty} \frac{\frac{4n}{n^3+1}}{\frac{1}{n^2}} = 4$$

and what they were supposed to say, using the comparison test,

$$\text{"}If \lim_{n\to\infty} \frac{a_n}{b_n} = L \; for \; L \in \mathbb{R}^+ \; then \; the \; series \sum_{n=1}^{\infty} a_n \; and \sum_{n=1}^{\infty} b_n \; are \; both \; convergent \; or \; both \; divergent\text{"}$$

was that

$$As \sum_{n=1}^{+\infty} \frac{1}{n^2} \; converges, and \; the \; limit \; of \; the \; quotient \; is \; in \; \mathbb{R}^+, the \; series \sum_{n=1}^{+\infty} \frac{4n}{n^3+1} \; also \; converges.$$

Another common error is the use of language. In Calculus course we studied improper integrals and numerical series, and in both cases, the issue was convergence. A student wrote in his exam: "it is a <u>proper</u> integral of the first <u>series</u>" meaning that "it is an <u>improper</u> integral of first <u>species</u>".

Several attempts have been made over the years to fight this type of attitude, namely the flipped learning model in some less conceptual topics. In terms of evaluation this initiative was quite successful, in particular because these classes ended with an individual assessment moment. However, the other subjects taught weren't that successful.

This academic year, the university's physical conditions provided a collaborative work environment with the creation of a room prepared only for group work classes, with round tables. I decided to implement a different operating model from previous school years. The curricular unit's weekly workload is 4 hours, divided into two 2-hour blocks. One of the blocks was taught in a normal room (NR) and the other in the room created for group work (GR). In the NR class, the theoretical results and some examples were illustrated and few exercises were solved in that class. In GR classes, students, in groups, had to complete a set of tasks defined by the professor, consisting of some exercises from worksheets that were previously made available in MOODLE. In total there were 9 classes (each with about 50 students enrolled) taught by four different teachers. In my case, I taught two classes during the entire semester and a third only in the second half of the semester.

The aim of this study is to understand, in the students' perspective, the advantages/disadvantages of the model of classes implemented and the improvements to be made in order to engage students and change the way they face Mathematics.

2 METHODOLOGY

The experience that I propose to present involves only the three classes I taught, since, even though I was responsible for the discipline, teachers are different in their way of interacting with the students and the results of the survey could be biased by this fact.

In GR classes, a set of 3 cards was distributed to each table (group) to be used throughout the class: a red one to signal that the group was unable to perform the task at hand; a green one to signal that the group was working autonomously and did not need the teacher's support and a yellow signaling that the group had doubts but that these did not prevent the continuation of the work. This strategy helped me to pay attention to the groups that had more difficulties first, because at a glance I could identify the needs.

In NR classes, although I had to teach all the syllabus subjects, I tried to engage students using Mentimeter (an interactive presentation software) or a simple hands up voting to promote discussion.

In order to support the study, the MOODLE platform (it is the Learning Management System in use by the university) was used to provide all the necessary learning resources, which are listed below.

Textbook – with all the concepts studied in the Calculus I course, explanations, some demonstrations, example, solved exercises and proposed exercises.

Worksheets – used for completing the tasks in GR classes.

Study Guide – freshmen usually feel lost with all the information they have to deal. The guide indicates for each topic under study, the corresponding section of the Textbook, the link to a video presenting the concepts and the tasks proposed to consolidate the learning of the topic.

Knowledge tests – online knowledge tests (a total of 7) were prepared on each of the chapters, with some randomness in the multiple-choice questions. The students could access each test 5 times and, after submitting the answers to all the questions of a test, they had access to a detailed answer for each of the questions that made up the test.

Videos – "homemade" videos by the professors involved in the course, on all topics taught along the semester.

Exams from previous academic years – all the exams, some with detailed answers, since 2013/2014.

There were also links to some resources like GeoGebra with several examples (e.g. animated gifs on the Riemann sums), a wiki on prerequisites for a Calculus course, slides used in the classes, and other documents teachers shared with their students. The MOODLE Forum was the communication tool for all the participants.

3 RESULTS

The classes' names are A, B (this class I only taught half of the semester) and C. A and B from the same engineering degree, we'll denote it by E1, and the great majority of students in C is in a different engineering degree we'll denote by E2.

There were 51 students registered in each of the classes A and B and 50 in class C, and before the first assessment test (which occurred on the 15th November), class A had a mean of 42.3 of students attending the classes, class B had 38.4 and class C had 41.6; after that the number of those who attended decreased, A class to 35.4, B class to 29.9 and class C to 39.4 (the minor decrease).

By the end of the semester, my students were asked to answer a survey on the functioning of the classes that consisted of 14 questions: 7 open answer questions and 7 multiple choice questions. The number of respondents to the survey was 13 in class A, 7 in class B and 24 in class C. It's worth noting that class C was much more proactive in their responses, both in number of respondents and in comments, but they also had better marks on Calculus I...

3.1 Multiple choice questions

The first question was "Is this the first time you are taking Calculus I?" with the options yes/no. 37 answered yes and 7 answered no.

Regarding the class model the students prefer, they were asked to choose one model amongst 3 given or to choose another not listed (which no one selected).

Expository lectures (TC - Traditional classes where the teacher presents the concepts, explains and gives examples) was only chosen for 4 respondents in class A; lectures with an expositive part and a problem/exercise solving part (individual or group) (MC – Mixed classes) was the selected for most students (9 in class A, 6 in class B and 12 in class C); one traditional lecture + one teamwork class (SC – separate classes, model used in Calculus I) was the choice of 12 students from class C and 1 from class B. It's worth observing that there are still students who prefer the traditional lecture, and that the respondents of class C divided their opinions between the two more active models, MC and SC.

Question 3 was about class attendance and the majority of the respondents attended to almost all classes (either regular or group classes). However, their degree of satisfaction with both types of classes differs substantially as shown in Table 1 where the answers to Question 4 are registered.

Question 4: On a scale of 1 to 5 (1- completely dissatisfied, 2- unsatisfied, 3-satisfied, 4- very satisfied, 5- completely satisfied) indicate your degree of satisfaction with the different types of classes that took place in Calculus I.

Table 1. Degree of satisfaction with both types of classes.

	Class A					***Class B***					***Class C***				
	1	***2***	***3***	***4***	***5***	***1***	***2***	***3***	***4***	***5***	***1***	***2***	***3***	***4***	***5***
NR	0	2	2	7	2	0	0	4	3	0	0	1	10	9	4
GR	2	5	3	0	3	0	0	3	4	0	0	2	5	12	5

In this case there is no convergence on the answers given, especially class A demonstrates a degree of satisfaction with group classes lower than the others and class C a greater satisfaction with group classes.

On Question 5 they were asked if the teaching environment of the different types of classes hindered learning (D), facilitated learning (F) or neither hindered nor facilitated learning (ND) and the answers are collected in Table 2.

Table 2. Teaching environment and learning outcomes.

	Class A			***Class B***			***Class C***		
	D	***F***	***ND***	***D***	***F***	***ND***	***D***	***F***	***ND***
NR	0	7	6	0	6	1	0	14	10
GR	7	2	4	1	4	2	3	18	3

Once again, the opinions diverge, however, there are no students saying that the environment in a normal classroom hinders learning, but 11 of the inquired argue the opposite regarding the group classroom.

3.1.1 Resources available for the course

To understand how students prepare themselves for exams and what resources that are more useful to them, the survey included some questions on this topic.

Regarding the resources available, the most important is the course textbook which was written by the teachers and was available online, on MOODLE platform. This textbook has examples and solved exercises for almost all the syllabus contents, as well as a section with exercises in all the chapters. We tried not to use too much scientific language, understandable for students that are not used to *read* mathematics.

Along with this textbook, other resources to help students guide their study were available online, such as multiple-choice tests with detailed answers, a study guide, videos, worksheets and exams from previous years (some of them with detailed answers). Students were asked about the resources' usefulness in their study and how frequently they used them.

The first question about the use of these resources was:

Question 12: How often did you use the various resources made available in the UC e-learning?
N-never; R - rarely; AV - sometimes; F – frequently

As the answers don't present substantial differences between the three classes, the results are presented all together in Fig.2.

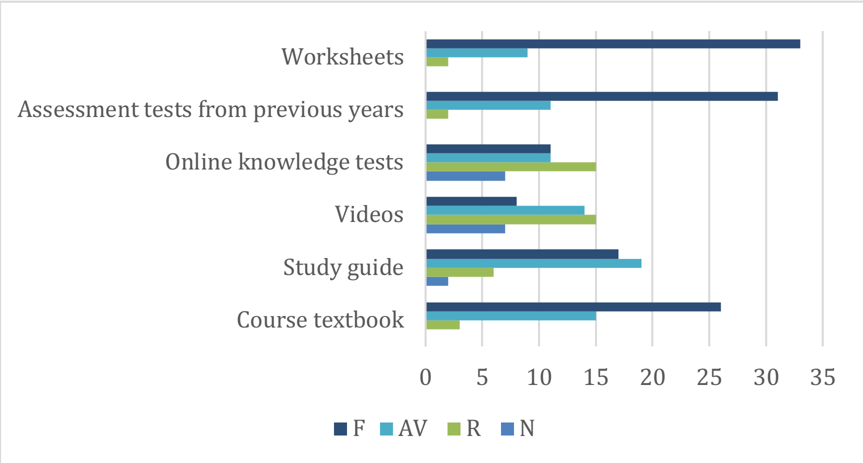

Figure 2: Frequency of the use of the resources supporting the course.

As we can see, students prefer exams and worksheets rather than the course textbook. Surprisingly, the online tests which had detailed answers weren't very used.

The other question was about the usefulness of the resources, and the answers (in Fig.3) illustrate that the choice is assessment tests from previous years.

Question 13: Regarding your learning, please rate the resources provided NU - not at all useful; PU - poorly useful; U - useful; ONE - very useful; EU - extremely useful

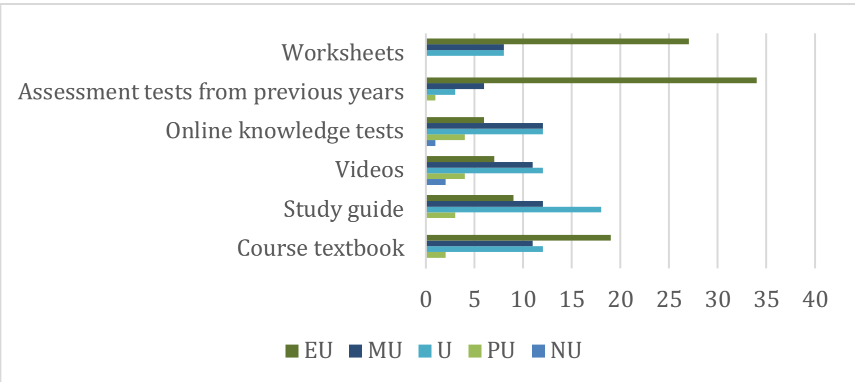

Figure 3. Usefulness of the resources.

The habits from secondary school and the generalized opinion that studying Mathematics is solving exercises is completely in line with the answers given. The course textbook was only found extremely useful for 36% of the inquiries.

3.2 Open questions

The purpose of these open questions was to get the students' perspectives on the classes used this year. It should be noted that many students mixed up the answers, mentioning negative points within the positive ones, giving suggestions on the negative points, and not answering exactly what was asked. What we present below is a global analysis and a reorganization of the answers given.

3.2.1 Classes in a normal room

The first question was "Please indicate the three points that you preferred in this type of class and why?"

In general, the students referred to the quieter atmosphere in these classes compared to group classes, the overall clarification of doubts as being more efficient, and the learning process was facilitated with the teacher's exposition and the use of examples and exercises solving. Some also mentioned the interaction generated in these classes between the teacher and the students.

The second question was about the three negative points in this type of class and some students have rightly complained about the teacher's disorganization when exposing the material on the board. Personally, I like the discussion and pointing out some observations, but I admit that it does not remain a proper board for a good copy.

A point mentioned by many respondents was the scarcity of solved exercises and too much theory (although most of the concepts were presented with examples). The class duration is also a negative factor pointed out by several students, some suggested a break, others a reduction of class time. The high number of students per class is yet another factor of dissatisfaction. Several students mentioned the fact that the classrooms do not have good conditions of visibility for the board, which is actually true given the size of the classrooms and the high number of students in class (about 40).

The opinions about the slides used in these lectures were divided between slides with little explanation and well-structured slides.

Regarding changes to be made, most of the respondents asked for more exercises to be solved on the board. Reducing the length of the lesson or putting a break and the number of students per class was another factor mentioned, which is directly related to the reference of some students to have less noise in the classroom. Some also suggested that there should be more organization in the exposition of the material.

3.2.2 Classes in a group room

The same questions as the ones in the previous section were made about the classes that took place in the group room.

Overall, the interaction between students and students and teachers was the positive factor most often mentioned, promoting a more relaxed, collaborative and close atmosphere among students and with the teacher.

Many of the students claimed that discussing with classmates helps them to understand their doubts and discover others that they would not realize if they worked alone, besides, the explanation to their classmates and the teacher's explanation to small groups helps to consolidate learning.

Several mentioned the autonomy developed with this type of class. The students in class C also referred that the complementarity with the regular classroom brings benefits for learning the contents.

Two students wrote about the social aspects, saying that this type of class helps the integration of students in the university and fosters bonds among them, and the other two mentioned the benefit of the use of coloured cards in the clarification of doubts by the teacher.

Regarding the negative points in this kind of classes, the consensus was that the teacher could not respond in time to all the questions raised during the lesson, and the other reason given by nearly all students was the excessive number of pupils in the class.

Many students mentioned the noise in these lessons and the distractions that occurred, "too much talking and not enough work", making the lessons unproductive. Two even mentioned that they did not learn anything in these classes.

I can add here the notable difference between groups, and even between classes: class C, overall, worked well, with only one or two groups with less autonomy. The other two classes, particularly A, had much more difficulty in concentration and autonomy and did not progress without the presence of the teacher.

There were also some who expressed dissatisfaction with the physical conditions of the classroom.

The suggestions to improve this kind of class include more time to carry out the tasks followed by an explanation for all the students; more teachers in the classroom or decreasing the number of students per class, including dividing into shifts, thus decreasing the number of groups.

Many respondents would prefer a part of the lesson to be devoted to solving exercises by the teacher and some others would rather prefer two different lessons by the teacher: a theory lesson and another where the teacher would solve exercises.

There are even students who say that they don't like working in groups (which was visible in class), and there are some who say that they didn't like their group, although they were free to choose the group to work.

A large part of the respondents thinks that the resolutions of all exercises should be made available on MOODLE.

3.2.3 General comments

On Question 14 they were asked to write their suggestions or comments that, in their perspective, would help to improve the functioning of the course.

Implementing small assessment tests throughout the semester to help in the assessment and study, was one of the recommendations most referred. The resolutions of all the exercises from the worksheets, tests from previous years and the exercises from the course textbook was repeated request.

There are also some students who even prefer the traditional model of theoretical-practical lessons, but most of them would prefer a lesson divided into two parts and in which the teacher made more resolutions on the board. In group C, several respondents suggested dividing the lessons into groups by turns, with a consequent reduction in the number of students in the classroom and others wrote that increasing the number of lessons of this type could improve learning.

3.3 General survey and assessment results

By the end of each semester, all students from our university have a general survey (not mandatory) they should answer regarding the subjects they have taken in that semester. Part of the survey focuses on the evaluation of teachers' performance and another part on the student’s self-performance.

The number of respondents is much lower than the total number of students enrolled in the course (only 24.91% of respondents). Once again, the courses with the best results in the evaluation stand out: only 20.86% of E1 responded to the survey, whereas E2 had a total of 45.24% answers.

About the workload of Calculus I (corresponding to 6 ECTS), students from E1 had a mean of 5.79, with a median of 5 and a standard deviation of 2.5 and E2 students had a mean of 5.97, a median of 6 and a standard deviation of 1.61 (much closer from the real 6ECTS allocated to the course).

Another module of questions is about self-evaluation concerning the curricular unit, consisting of a set of 5 questions that should be answered on a scale of 1 to 9:

- P1 - Motivation for the course unit
- P2 - Overall level of satisfaction with your performance
- P3 - Number of times you have contacted the teacher(s) outside contact hours / face-to-face sessions during the semester
- P4 - Regularity in monitoring the work of the curricular unit throughout the semester
- P5 - Degree of attendance in the assistance to the OTs[1] (refer to the number of OTs fixed in the schedule)

The results are gathered in Fig.4 (course E1) and Fig.5 (course E2).

OT – every week there is one hour scheduled for students to clear doubts.

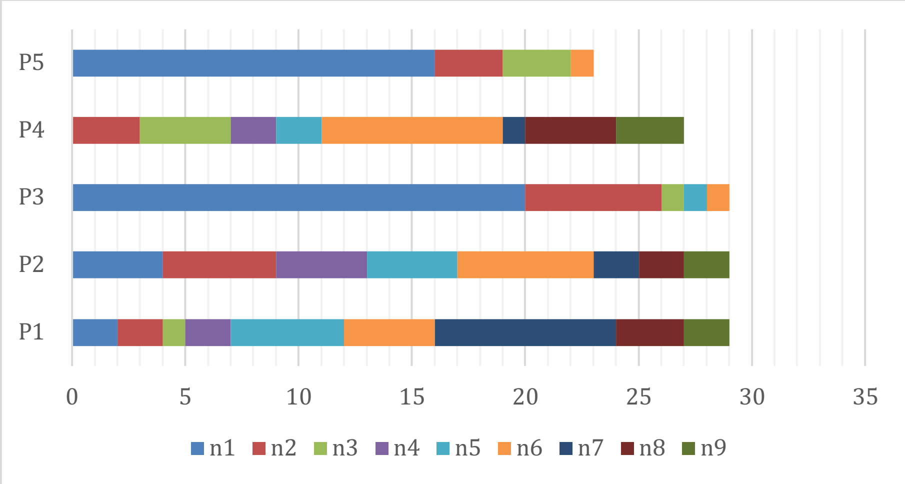

Figure 4: Self-evaluation results for course E1.

With the exception of questions P5 and P3, the degree of dispersion in the answers is greater in E1 than in E2 and also, students from E2 are more motivated for the study of Calculus than E1 students, taking into account the answers given to P1 and to P4.

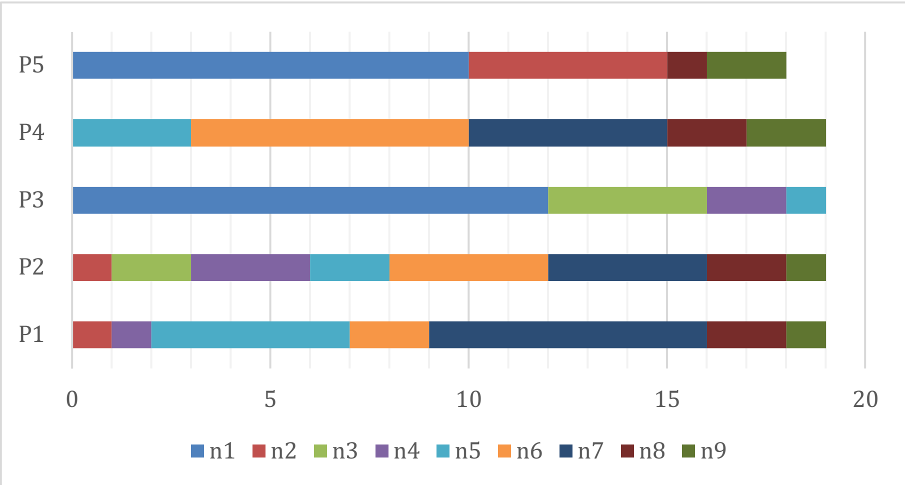

Figure 5: Self-evaluation results for course E2.

Concerning my performance as a teacher, only 28.10% (in a universe of 153 students from my three classes) answered the survey. The answers are also on a scale 1 to 9 and the questions are:

- P18 - Ability to stimulate and motivate students for the curricular unit
- P19 - Creation of a favourable climate for learning and the active participation of students
- P20 - Encouraging student autonomy
- P21 - Student work follow-up
- P22 - Mastery of syllabus contents
- P23 - Organization of contents and activities during contact hours
- P24 - Teacher's punctuality
- P25 - Availability for students
- P26 - Clarity in teaching classes
- P27 - Teacher's relationship with the student
- P28 - Compliance with the assessment rules agreed with the students
- P29 - Overall evaluation of the teacher's performance

The answers given are gathered in Fig.6.

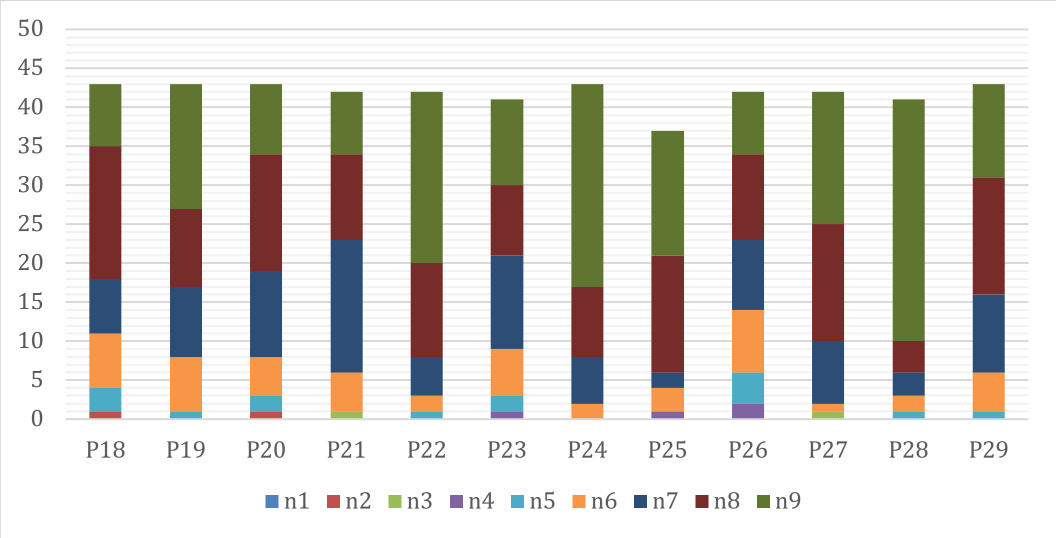

Figure 6: Teacher's evaluation.

Once again, considering my organization and clarity in exposition, my marks were rather low, with a median of 7 in both questions P23 and P26 and means of 7.44 and 7.12 respectively. The answers to P21 (median of 7 and mean of 7.43) are in line with the survey I used, in particular with the argument that "the teacher could not respond in time to all the questions raised during the GR classes".

Regarding the social relationship with students (P19, P25 e P27) they recognize my availability, as well as the concern I have with them.

3.3.1 Assessment results

In Calculus I the assessment consists of two written tests, one in the middle of the semester and another after classes finish or a final exam by the end of the semester. The great majority of students chooses the two tests, but if they fail, they still have another opportunity named the appeal exam.

Although the numbers in each course are very different, comparing in percentage, the results in E2 were much better than in E1 (see Fig.7). Comparing the three classes I taught, although class B was better than A, class C presented much better results with an approval tax of 91.89% (see Fig.7).

Figure 7: Assessment results by class and by course.

4 CONCLUSIONS

The use of assessment tests from previous years was the resource students found more useful for their learning and the recurrent request for solved exercises, leads to the conclusion that what they really want is procedural/rote learning. Often, I tell my students that they lose too much time trying to remember an exercise similar to the one they have to solve, instead of thinking about the problem they have to deal with and what concepts they should use, however, as Soiferman says in [4] "It is important to remember that most first-year students come to universities direct from high school where they did not have to make many decisions and the decisions they had were limited. Many of the students had been very successful in high school and expected the same level of work, the same amount of time devoted to assignments, and the same level of camaraderie from friends.” She also refers that “They expected that their professors would get to know them and that they would be welcomed into the new learning environment” Curiously one student mentioned that my effort in knowing the names of all students facilitates the learning process as it makes it more personal.

The different attitudes shown in courses E1 and E2 are related to their expectations regarding the course they are enrolled in. While students from E2, which is a recent degree, made an informed choice of career paths and what was expected of them as students, most students from E1 chose it because it is a traditional course they have always heard about, and as Hassel and Ridout pointed out in [5] “students generally come to university with few expectations and with little notion of how to be successful; they often view it as a continuation of secondary school.”

”Mathematics lecturers cannot (and should not) only draw on their own experiences of teaching and learning (in traditional ways), but should be encouraged to ask: what means ‘hands-on’ or ‘challenged-based’ learning in mathematics education (in such engineering courses), and how can I design, teach and assess such learning? How can I use (or design) educational technology and digital resources usefully and beneficially for enhanced student engagement and learning? To design for and enact these considerations needs time and resources, and support from the institution/university.” [6]

My goal is to answer these questions, but I have to be aware of the different engineering courses enrolled in Calculus. Introducing games in classes, following the suggestion in [2], is a way of engaging students. In response to the student’s request of solved exercises, I intend to ask each group of students to write a detailed answer to a set of exercises and exchange these works between groups to be corrected. The final work (after the teacher’s supervision) will be published in MOODLE.

Above all, it is our obligation as teachers to provide students with autonomy and self-confidence, fostering a favourable learning environment where students feel free to make mistakes and ask any questions that hinder their progress in the learning process.

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