Use of a Classroom Response System (CRS) for teaching Mathematics in Engineering with large groups

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The high number of students in a typical classroom represents a challenge for many didactic principles and for establishing best practices in university teaching and learning. The teacher finds himself with a varied set of requirements: analysing the students' prior knowledge and their alternative conceptions, maintaining motivation and keeping their constant attention, finding out about their opinions and getting them involved in the work, monitoring the learning and the tasks completed, or developing activities in the classroom to put key concepts into use in practical problems, etc. Within this context, Classroom Response Systems (CRS) have been researched due to their potential to improve teacher-student communication. In this work, we will describe the teaching strategies we have implemented in the Department of Applied Mathematics at the UPV/EHU (Spain) for teaching Mathematics in technical university studies, making use of a CRS to facilitate interaction in the classroom.

Keywords Clickers, Personal Response Systems, Classroom Response System; CRS; significant learning; Peer instruction; Calculus; problem solving

1. Introduction

Calculus, Algebra and Statistics are maths subjects with reasonably standard content within Engineering degrees that aim to equip students with the necessary mathematical skills that an engineer requires to do their job. A subject such as calculus in principle should not be particularly difficult for the students. As an annual course involving differential and integral calculus, much of its syllabus is already familiar to them: operating with elemental functions and their graphs and differential and integral calculus in a variable are part of the maths programme for Compulsory Secondary Education and Baccalaureate in Spain. Calculus also includes classic advanced topics from Mathematical Analysis for Engineering syllabus: multivariable calculus, graphs of functions of two variables, multiple and line integrals, differential equations, Laplace transform and Fourier series. For these advanced topics, although new for students, their fundamental difficulty lies in recognising a certain type of exercise from among a relatively narrow variety of typical situations and applying the corresponding algorithm to solve it. Traditionally the teacher formally presents the mathematical contents, illustrates the concepts and procedures with examples and application exercises and finally evaluates the students' learning with similar typical exercises.

However, this model has been questioned recently referring to conventional university teaching based on the belief that teachers transmitting information directly and completely is the only or best way of getting students to learn. In particular, the current conception of what it means to learn Maths comes up against this simple, instrumental vision of mathematical training. Current standards coincide that students learn Maths by actively building new meanings working from experience and prior knowledge and to help this construction they recommend carrying out activities intended to raise awareness of their knowledge and informal strategies, giving special importance to solving problems, development of reasoning and argumentation [1]. Students must work in an environment that encourages them to actively build Maths and learn to communicate through Maths as a way of thinking and making sense of their environment; to value Maths in its role within the human world; to explore, predict, make mistakes and correct them, to gain confidence in their own capability to solve complex problems; to experience a wide variety of inter-related situations that help them to acquire mathematical skills [2, 3]. These methodological ingredients profile a way of working in the classroom that encourages expressing their own ideas and confronting other people's ideas, in an environment that is rich in argumentation and justification episodes.

However, the high number of students in a typical classroom for first degree Mathematics (80-90 students in our case) represents a challenge for all these attractive didactic principles and makes it hard to establish best practices for teaching. The teacher is subject to a varied set of requirements: analysing students' prior knowledge and their alternative conceptions, maintaining motivation and keeping their constant attention, finding out about their opinions and getting them significantly involved in the work, monitoring the learning and the tasks completed, developing activities in the classroom to put key concepts into use in practice problems, etc. Within this context, Classroom Response Systems (CRS) have been researched over the last 40 years due to their potential to improve communication between teachers and students. A CRS is a computer system capable of compiling the answers from all the students to a question formulated by the teacher, in real time in the classroom. Current CRS technology allows students to individually select
an answer from among a set of proposals by pressing a key on a small personal transmitting device or clicker. The CRS system is completed by a receiver device connected to the teacher's computer and software that administers the question database, each student's answers to every question from each class session and their accumulated score, all for later monitoring and analysis.

It is possible ask the student about simple scientific facts or the results of applying formulas, but it is much more interesting to ask questions designed to test the student's comprehension or to demonstrate their misconceptions. The information obtained in this process can also be used by the teacher to guide later teaching and decide whether they should invest more time in exploring an idea or modify the planned teaching sequence. Once the teacher has the distribution of the individual answers in front of them, they have the chance to elicit group discussion and formulate the question again to analyse how the discussion has changed the answers, they can ask a student to explain why they changed their answer, etc.

From the broad research currently being done on the use of CRS in higher education, [4] compiles a continually updated bibliography on the research into specific disciplines, bibliographic reviews, studies on the perceptions of the students and a comparison between the different CRS system manufacturers. [5] summarises many studies on Mathematics, Chemistry and Humanities that provide information about the positive results obtained in the university classroom in relation to students' active participation and interest, improvements in understanding complex subjects, promoting discussion and interaction, helping students to measure their own level of understanding, helping teachers to understand students' difficulties, working outside the classroom and improving the questions that are formulated. Methodological proposals that include some of the aforementioned aspects can be found, for example, in the area of Physics in teaching known as "Peer Instruction" [6, 7]. A CRS work environment with a constructivist focus can stimulate students to speculate, reason, argue, justify, explore the meaning of the concepts and share the new knowledge with their classmates guided by the teacher. As [8] indicates, the challenge involves designing instructional sequences and learning environment conditions that help pupils become members of epistemic communities.

During the 2010-2011 academic year, we have been working in the Department of Applied Mathematics at the University of the Basque Country (Spain) designing teaching capable of improving first year maths students' attitudes. We are aiming to strengthen student participation by proposing interesting conceptual tasks and managing the activity using a CRS. Then we will show the general lines of the work carried out and its founding, and we will discuss the results obtained.

2. Research-based practices for effective CRS use

In order to design our teaching and learning strategies, we wish to avoid anecdotal or discipline-specific suggestions for effective CRS use. Instead, we seek to provide research-based evidence of their effective use. Below we will summarise some significant findings that appear insistently in the recent research on effective CRS use.

[9] carried out a wide-reaching work involving over 10000 students on common pedagogical practices among teachers and attitudes and beliefs among student clicker-users across campus. They report on correlations between student perceptions of clicker use and the ways in which this educational tool is used by teachers. This data suggests practices for effective clicker use that can serve as a guide for teachers who integrate this educational tool into their courses. They make two suggestions to teachers that are supported by their work: 1) encourage students to discuss with their peers during clicker questions and create environments that get students to discuss the work; and 2) ask conceptual questions appropriate for most students' level of knowledge. Student attitude is strongly affected by the extent to which teachers encourage and succeed in generating peer-discussion during the administration of clicker questions. Students have a much more positive attitude towards the usefulness of clickers if teachers encourage discussion and are able to get a large proportion of students discussing the subject. Likewise, student attitude is also improved when students are actively participating in discussions with their peers, as opposed to being passive or working independently. In addition to students finding conceptual questions more useful than other types of questions, the proportion of students on a course who claim to be actively participating is correlated against the average student rating of usefulness of conceptual clicker questions within a course, suggesting that conceptual questions are most useful when students discuss the questions with their peers. [10] realised the impact that Mazur's innovations have had on teaching Physics at Harvard, based on “Peer Instruction” (PI) that we referred to previously. A PI class session is divided into a series of short presentations, each focussed on a central point, followed by related conceptual questions. The students have one or two minutes to formulate their answers individually and communicate them. Each student then discusses their answers with their classmates next to them, trying to convince them that their answer is correct. During the discussion, typically lasting between two and four minutes, the teacher moves around the class, listening to the discussions. Finally, the students give a new answer (that might have changed) and the teacher explains the solution, and moves on to a new topic.

Regarding the way of constructing the ConcepTests, some suggestions recognised in the bibliography are: (1): They must have a specific target (show knowledge, show preconceptions, seek out synthesis or conclusions, establish relations between two concepts, establish cause-effect relationships, etc.); (2) They must constitute a challenge for the students. They must not be easy; (3) They can be multi-factor (taking different factors into account to answer them); (4)
They can sequence several questions to cover a reasonably complex topic; (5) They can improvise questions formulated by a student.

Regarding the use of CRS systems in universal maths teaching, [11] adapt Peer Instruction to teaching Calculus and discuss the results obtained. Data suggests that the use of PI along with what they call Good Questions can benefit students in terms of their level of mathematical comprehension. These authors identify the characteristics of a Good Question: (1) They stimulate the students' interest and curiosity; (2) They help students to demonstrate their lack of comprehension; (3) They offer students frequent opportunities to make conjectures and argue their validity; (4) They use the students' prior knowledge and their misconceptions; (5) They provide the teacher with a tool to frequently measure what the students are learning; (6) They support the teacher's effort to promote an active learning environment. [12] describe introducing CRS into a large maths class for Engineering, designed to promote greater interaction with students. One of the conclusions drawn is that CRS is a powerful tool with which to explore innovating ideas in mathematics teaching. [13] show how CRS can produce positive results in the usual university teaching conditions: large classes, passive students, lack of interaction.

3. Teaching mathematics using a CRS for promoting student interaction

Below we will describe the most significant aspects of the Problem Based Learning (PBL) methodology [14] that we have implemented in the Department of Applied Mathematics in the UPV/EHU (Spain). PBL compiles the methodological components that the research highlights in order to provide students with a participative working environment encouraging them to look in greater depth at mathematical meanings and to share their ideas.

We used a CRS to make interaction easier, both between the teacher and the students and among the students. We have selected a CRS from the firm Interwrite due to the solidity of its clickers, the reliability of the software and the small size of the receiver, similar to a pen-drive connected to a USB port. The students come to class with a clicker that they are assigned at the start of the year. Each clicker identifies the student uniquely, allowing the teacher to accumulate information on each of the answers they have entered over the course.

A typical 50 minute class develops as follows: The first 3-7 minutes are used to look over the work required to prepare this class that students should have done at home. This homework consists of studying the textbook [15] looking at the theoretical aspects that are going to be worked on in class and carrying out typical exercises. The students must answer 2-3 multiple choice questions individually using their clickers and get a mark for answering correctly. After each question, students are given immediate feedback. The questions formulated in this section of the class are generally simple, on mathematical facts, definitions or application of algorithms. Example 1 contains a typical question of this type, in this case on the double integral for a real function z=F(x,y).

**Example 1.** Consider the function \( F(x, y) = \frac{1}{5} (5 - x - y) \) whose graph is shown in the diagram. For each value of \( y \in [0,1] \), calculate the area \( A(y) \) of the shaded region in the diagram.

**Answers:**

- **A:** \( A(y) = \frac{9}{10} - \frac{x}{5} \)
- **B:** \( A(y) = \frac{4}{9} + \frac{y}{5} \)
- **C:** \( A(y) = \frac{9x}{4} + \frac{1}{5} \)
- **D (correct):** \( A(y) = \frac{9}{10} - \frac{y}{5} \)

Fig. 1 Illustration of example 1

Over the next 5-10 minutes of the class, the teacher reviews the theoretical aspects that the students studied previously, highlights relationships with other concepts, interpretations, practice applications, etc. The next 25-35 minutes of class are dedicated to work with ConcepTests on the theoretical aspects being studied in the session. ConcepTests aim to involve students in problems that require key concepts to be applied or that test how much they have understood. Students receive marks for participation. ConcepTests can be used in different ways. For example, each student can be asked to think about the situation that has been presented, select an answer from among the proposals and be prepared to justify and defend this answer. Or, the teacher might choose student discussion in small groups and a subsequent full class discussion. The distribution of the class's answers, in the form of a bar chart, shows...
the teacher whether the students have grasped the concept, or if the topic needs more discussion or examples. As indicated by [7], unlike the common practice of asking informal questions during a lecture, which typically engages only a few highly motivated students, the more structured questioning process of PI involves every student in the class. Examples 2 to 5 are situations that have been effective in terms of generating classroom discussion, because they involved a lot of the class and took up the assigned time. In example 2, students must be capable of recognising and using the key concepts of line integral, conservative vector-based field, potential function, potential difference and contours. The teacher can also elicit a classroom discussion on the value of the integral over each of the two sections into which trajectory C can be broken down, the section that coincides with a contour and the remaining section. The results that we obtained were B: 3%, C: 60%, D: 37%. Note that the majority of the students understood that the chosen value had to be calculated as the potential difference between points M and N. However, a significant number of them calculated this difference with the wrong sign, as they did not consider the direction of the path of the curve.

**Example 2.** Where \( F(x,y) \) is a function that allows continuous partial derivatives \( F_x(x,y), F_y(x,y) \). Considering the contours for \( F(x,y) \) shown in the diagram and curve C between points N and M. Calculate the value of \( \int_C F_x(x,y)dx + F_y(x,y)dy \). Answers: A: \( 0 \) B: \( -5 \) C (correct): \( -9 \) D: \( 9 \)

![Fig. 2 Illustration of example 2](image)

Regarding example 3, we use this situation to demonstrate an error committed by students that we see in written tests. The mistake consists of supposing that the even exponent in the analytical expression of \( y(t) \) implies that the periodic function is also even, leading to wrong answer B. In our case, the results obtained were B: 93%, C: 7%, generating a conflict of opinions in class that revealed that most of the students were wrong.

**Example 3.** Consider the periodic function \( y(t) \) from period \( 2\pi \) defined by \( y(t) = t^6, t \in (0, 2\pi) \). What can we say about the Fourier series for \( y(t) \)? Answers: A: It only has sine terms. B: It only has cosine terms. C (correct): It has sine and cosine terms.

The situations for examples 2 and 3 were worked on in small student groups in class and after voting, there was a general discussion where each group justified the chosen option. On the other hand, in examples 4 and 5 the teacher asked the students to think about the situation individually and to vote for the answer that they believed was correct. After seeing the answer bar chart, each student should discuss it with a classmate close by who chose a different answer, attempting to convince them to change. In the situation in example 4, the first vote as clearly won by result A: 21%, B: 21% C (correct): 58%. In the second vote, there were 100% correct answers. So then, it seems that the pair-work discussion had a positive guidance effect on incorrect answers. However, the result of the pair-work discussion was not always positive. The situation in example 5 was used to detect a common error among students in handling complex numbers. The error consisted of assuming that the imaginary part of the complex number \( z = x + yi \) is equal to \( yi \) instead of \( y \). After individual reflection, the distribution of answers that was obtained was A: 63%, B (correct): 37%. After the pair-work discussion, the vote result was A: 76%, B: 24%. So then, surprisingly, some of the students who were initially correct were convinced by the students who were wrong. Fortunately, the teaching strategy gives a third chance to nail the question: the general discussion with final teacher intervention.

**Example 4.** Consider the complex number \( z \) shown in the diagram. Which of the following statements is true? Answers: A: \( \theta = \arctan \left( \frac{y}{x} \right) \) B: \( \theta = 2\pi + \arctan \left( \frac{y}{x} \right) \) C (correct): \( \theta = \pi + \arctan \left( \frac{y}{x} \right) \)

![Fig. 3 Illustration of example 4](image)
**Example 5.** To calculate the solution to the equation $\text{Re}(z)+\text{Im}(z)=i$, is the following calculation correct?

"Where $z=x+yi$. $\text{Re}(z)=x$, $\text{Im}(z)=yi$. Substituting in the equation: $x+yi=i$. Therefore $x=0$, $y=1$, meaning that $z=i$"

**Answers:**
- A: It is correct. **B (correct):** It is not correct.

After the work session with ConcepTests, the teacher dedicates the last few minutes of class to presenting a problem situation that justifies introducing the new concepts to be studied in the following class. Then he explains the homework that the students must do to prepare the next class. This homework might involve studying theoretical contents, doing some exercises or other activities. It is worth adding some information on the study material that is provided to the students to support their homework. This material is compiled in a textbook plus a course in Moodle [15]. Together they make up an activities programme that can be followed individually or in a team, where the mathematical concepts are constructed by progressing through solving problem situations (PBL). Different types of activities are proposed: theoretical exercises, application exercises, tasks to be done on the computer, self-assessment exercises, word searches and mathematical crosswords, among others. The evaluation for all these class and homework tasks represents 40% of the final mark obtained in the subject. The remaining 60% is obtained in a final written exam.

### 4. Methodology

#### 4.1 Sample and organisation of the teaching

The teaching described was implemented during the 2010-2011 academic year in the Polytechnic College of San Sebastián, University of the Basque Country (Spain). It was applied to one of the four groups of 80-90 students in first year Engineering, within the subject of Calculus. These groups of students were made at random. The subject carries 12 ECTS credits, with four class hours a week over 30 weeks. The weekly distribution of calculus teaching is organised, in the same way as for other degree subjects in the School, as follows: 2 hours of classroom teaching with the full group of students; 1.5 hours in the classroom with half the students; 0.5 hours in the computer lab with a third of the students. Then, the subject teacher must give a total of 6.5 hours of class a week to the different subgroups of students that are formed. The class with the full student group is called a 'master class' and uses conventional teaching for theoretical presentations. In our experimental teaching, the master class is used to discuss the meaning of the concepts by using the ConcepTests. The class with half the students is known as 'classroom practical' and in conventional teaching it is used for solving exercises involving greater interaction with students. In our experimental teaching, the classroom practical is used to look at situations that present interesting features or problematic situations in the form of a ConcepTest or open statements. The lab class with just a third of the students is called 'computer practical' and in conventional teaching it is used for students to learn how to use a software package to automate calculations, draw graphs, etc. In our experimental teaching, the computer practical is used to look in greater depth at the meaning of the concepts and to use the computer as a tool for study and solving problem situations. We also use the three teaching modes to evaluate (with immediate feedback and discussion) the class work and homework done by the students.

#### 4.2 Evaluation of the teaching methodology

When evaluating our experimental teaching we wished to find out what the students thought about the use of the clicker in the classroom. We were aiming to compile the students' perception of how the clicker had been used as an enabling element in the classroom to create a feeling of participation, to show their errors and difficulties and to improve their self-confidence. To do this, we adapted the questionnaire that [16] validated experimentally. The appendix contains the 22 questions asked anonymously at the end of the course. The students have to indicate how much they agree with each of the statements (Agree/Neutral/Disagree).

On the other hand, we wished to find some evidence of improved student learning. This was proved by means of a pre-test/post-test design, given to both the experimental group and a control group of students that had received traditional teaching. The aim was to compare the results obtained by both groups, as the only significant difference between them was the type of teaching they had received. The pre-test was only worthwhile if students were aware of the concepts involved at least at an elementary level. Consequently we drew up questionnaires on the local study of functions and on the concept of integral of one real variable. Both topics appear in the curriculum for Secondary and Baccalaureate teaching in Spain and they are part of the evaluation for University entrance tests so they are familiar to students. As we wished to use questionnaires that had already been validated experimentally, we took 16 conceptual questions adapted from [17], different to those used in our ConcepTests. As an example, appendix 2 shows three of these questions.
5. Results

Figures 4 to 6 show the distributions of the students' answers for each of the five blocks into which the opinion questionnaire is divided (appendix 1). As we can appreciate, the designed teaching seems to generate a positive score in most questions researched. In particular, students have clearly perceived the role played by CRS to give them the chance to look in greater depth at the meanings and to reveal their misconceptions (Q1, Q2). The students also value the teaching received higher than traditional teaching, in key aspects such as greater capacity for remembering contents (Q7), access to their classmates' ideas (Q8), active participation (Q10), entertaining tasks (Q14) and motivation (Q17). The students also perceive that teaching in this way requires greater effort than traditional teaching (Q18) and a greater responsibility for the actual learning (Q20). It should also be highlighted that the students think that the evaluation procedure used to measure learning is appropriate (Q21). However, students do not perceive the use of the tasks carried out on the computer, so this is an aspect to improve.

![Graph 1: Distribution of answers from the "Conceptual Understanding" and "Learning" blocks.](image1)

![Graph 2: Distribution of answers from the "Interaction and Discussion" and "Enjoyment" blocks.](image2)

![Graph 3: Distribution of answers from the "Planning" block.](image3)

Regarding the pre-test and post-test, for both the experimental and control group we have calculated the average normalized gain [7], \( <g> = \frac{S_{\text{post}} - S_{\text{pre}}}{100\% - S_{\text{pre}}} \) to evaluate the gain obtained after the teaching where \( S_{\text{pre}} \) is the score obtained in the pre-test and \( S_{\text{post}} \) is obtained in the post-test. The average values of normalized gain obtained were \( <g> = 0.30 \) for the control group and \( <g> = 0.48 \) for the experimental group, producing a significant difference in favour of the latter. As an example, table 1 shows the percentages of correct answers obtained for the three items in appendix 2.
Table 1  Results obtained for the items in appendix 2

<table>
<thead>
<tr>
<th>Item</th>
<th>% correct answers in control group</th>
<th>% correct answers in experimental group</th>
</tr>
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<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
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</tr>
<tr>
<td>2</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>9</td>
</tr>
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</table>

6. Conclusions

A PBL methodology has been implemented revolving around the students working with carefully created conceptual tests. In our experimental teaching, the traditional presentation class has been completely replaced with discussing problems and conceptual questions in student groups, managed by the teacher. Within the participative work environment thereby constructed, a CRS has also played an important role as it has been used to make the students’ ideas visible alongside their misconceptions. The CRS has also been used to evaluate homework, providing a highly valuable tool for the teacher to find out the real status of the class at all times. The students awarded high scores to the teaching received and the use of the CRS and evidence has also been compiled concerning an improvement in learning compared to what is obtained by means of the traditional presentation method of teaching. Our next task will be to obtain wider-reaching evidence that there is an improvement in students’ learning.

Appendix 1. Opinion questionnaire

Conceptual Understanding
Q1. The clicker allowed me to be more aware of my difficulties to understand the concepts than with traditional classes.
Q2. The clicker helped me to understand which concepts were behind the problems set.
Q3. When a question is set to answer with the clicker, I knew what to do; I knew what was expected of me.

Learning
Q4. The clicker allowed the teacher to be more aware of students’ difficulties when trying to understand the concepts than with traditional classes.
Q5. A class with clickers is more demanding for the teacher than a traditional class.
Q6. Working in my group, listening to other students give explanations with their own words helped me to understand.
Q7. I can remember more after a class using clickers than after a traditional class.

Interaction and Discussion
Q8. The clicker let me find out what my classmates thought more than in traditional classes.
Q9. I think that it is best to use the clicker anonymously, meaning without it being known in class who has chosen which answer.
Q10. I have been more actively involved in the work in a class with clickers than a more traditional class.
Q11. The discussion of clicker problems with other students has helped me to understand better.
Q12. The members of my group got actively involved in solving clicker problems.
Q13. Participative work in my group of students helped to provide a better quality solution to problems.

Enjoyment
Q14. With the clicker, the class seems more fun than traditional classes.
Q15. The fact that you see the clicker problem results bar chart helped me to increase my confidence in my capacity to answer questions correctly.
Q16. I believe that the clicker must be used in other subjects as well.
Q17. I felt more motivated to pay attention in a class using clickers than a traditional class.

Planning
Q18. Looking at the subject like this, it requires more work from the students than a more traditional approach.
Q19. I find it appropriate that the teacher sets the prior reading on the lesson and exercises as homework.
Q20. This approach to the subject makes the student more responsible for their learning than with a more traditional class.
Q21. The way in which it has been evaluated is appropriate for the teacher to know if the students have learnt anything.
Q22. The computer practical helped me to understand the concepts better.
Appendix 2. Examples of pre-test and post-test items

Item 1. For the function \( y(x) \) whose graph is shown in the figure 7, what is the sign of the second drift in the points \( x=a, x=b \) and \( x=c \)? Answers: A: +, 0, - B (correct): -, 0, + C: -, 0, - D: +, 0, + E: +, +, - F: -, -, +

![Fig. 7 Illustration of item 1](image)

Item 2. The figure 8 shows graphs for the speeds of two cyclists that start from the same point and go round a track in the same direction for 3 minutes. When does cyclist 2 overtake cyclist 1?
Answers: A: At a point between 1 and 1.25 minutes. B (correct): At a point between 1.25 and 2 minutes. C: At a point between 2 and 3 minutes.

![Fig. 8 Illustration of item 2](image)

Item 3. The figure 9 shows the graph of a function \( y(x) \), and it gives the value of the shaded areas. If \( F'(x) = y(x) \) and \( F(0) = 10 \), what is the value of \( F(5) \)? Answers: A: 17 B: 4 C: 1 D: 13 E: (correct) 11 F: 16

![Fig. 9 Illustration of item 3](image)

References


