



## **ACE: Innovative Educational Model to Teach Physics and Mathematics for Engineering Students**

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# ACE: Innovative Educational Model for Teaching Physics and Mathematics to Engineering Students

Session topic: Innovation and best practices around the globe

## Abstract

This paper presents details of the implementation of an educational innovation in an international context. In Mexico, we designed a classroom that we call the ACE classroom. ACE comes from the Spanish acronym for “Aprendizaje Centrado en el Estudiante” (Student-Centered Learning); also, the pronunciation of the acronym in Spanish is identical to that of the verb “do”, and thus conveys the idea that students learn by doing in this classroom. The ACE classroom we designed is similar to the SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs) classroom, but with some innovations.

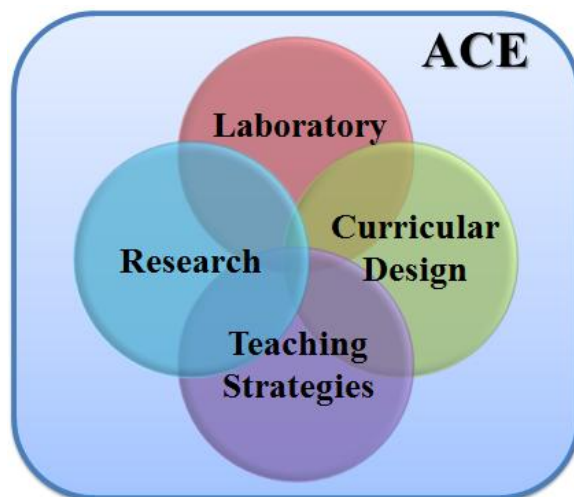
The structure of the room, the design of materials and the use of active learning strategies in ACE aim to improve student learning in physics and math classes for engineering students. Physically, ACE is equipped with circular tables, whiteboards, projectors, a document camera, video cameras, and portable tablet-computers and calculators, among other technologies. The ACE setup is designed to facilitate access to any part of the room; the use of laboratory equipment on the tables promotes collaboration and student-centered learning. ACE has been used to teach different subjects. In this paper we will focus on teaching physics, calculus and differential equations for engineering students. For these subjects, the ACE setup encourages us to implement strategies that we would not be able to apply in other classrooms. In physics we use tutorials for introductory physics and peer instruction. In mathematics we use modeling; which is the use of physical phenomena to foster a visualization of mathematics as a tool to be used in the analysis, modeling and simulation, and interpretation of non-routine problems in real contexts.

We have conducted research on learning concepts and technology, communication and problem solving skills. Students are given a standardized test for both pre- and post-testing to assess their learning of concepts. Technology skills are evaluated from the analysis of student behavior during the activities. Communication skills are assessed by analyzing videos of students' interactions during classes. Finally, problem solving skills are evaluated with established and validated rubrics. The results are that students in ACE have higher learning gains compared to similar students in other environments, and in addition to learning concepts, students also acquire technology, communication and problem-solving skills.

## Introduction

Educational research in the disciplines has shown that teaching based on active learning is more successful than teaching based on the teacher's traditional presentations. Richard Hake<sup>1</sup> showed in a study of 6,000 students that, regardless of students' level of knowledge upon starting the course, or what year they were in at the university, those in active-learning classes attained a higher level of learning than that of students in traditional classes. Meyers and Jones<sup>2</sup> argued that active learning encourages students to participate in activities that promote cognitive modification or acquisition of knowledge. This paper presents a classroom in which learning is

active every day, technology is used in the service of teaching, and the teacher is a guide that facilitates student learning.



*Figure 1.* The ACE classroom combines research, curricular design, teaching strategies and laboratory in the same environment.

The design of the ACE classroom is based on research initiated by Robert Beichner from North Carolina State University in the SCALE-UP project<sup>3</sup>. Like the ACE classroom, there are many other similar classrooms located in the United States and throughout the world. In general, these classrooms all share the basic elements proposed in the SCALE-UP project, differing only in the number of tables (due to room size) and the technology they have. Due to their characteristics, such rooms are ideal for teaching sciences such as physics, mathematics, chemistry and biology. However, we have found that other areas such as language or literature also reap the benefits of the setup and overall environment that is created in these classrooms<sup>4</sup>.

For several years, Beichner conducted research and experimented with on different classrooms designs in order to enhance learning. The SCALE-UP classroom is the result of this extensive investigation. Beichner and other creators of similar rooms have shown that active learning strategies used in this environment are very successful<sup>5</sup>. Among the results that have been documented are an increase in learning, and a decrease in the failure rate, mainly of women and minorities in the United States<sup>4</sup>.

Many of the strategies in the ACE classroom are based on educational research in the disciplines. For example, in ACE is taught with strategies based on models<sup>6,7</sup>, tutorials for introductory physics<sup>8</sup>, peer instruction<sup>9</sup>, workshop physics<sup>10</sup>, model-eliciting activities<sup>11</sup> and generative activities<sup>12</sup>, among others. These strategies have been designed by researchers of the discipline (physics or mathematics) working in academic departments at universities, and are based on rigorous research that has been documented to improve student learning through the use of these strategies.

### **Description of ACE**

The ACE classroom was funded by internal resources from both the Research Chair in Physics Innovation and Research and the University President; and external support granted by Hewlett-Packard through their HP Innovations in Education project. This company provided much of the equipment of the room, and the University remodeled the space and provided the rest of the equipment. Instructors have invested a great deal of time in developing activities and pilot studies to determine the impact of the classroom on their courses. Figure 2 shows images of the environment of the ACE classroom.



*Figure 2.* Images of the ACE classroom showing students working in activities during the implementation of teaching strategies using some of the available equipment.

Equipment available: the room has a set of technologies and innovations that makes it unique.

- Circular tables. The room has eight circular tables of 2.0 meters in diameter and 1.2 meters high. The perimeter of the table can seat nine students and form three collaborative groups of three persons, achieving a capacity of 72 students grouped in 24 teams. The diameter of the table also allows each collaborative group to have enough space for laboratory equipment and be able to perform experiments in the classroom. The table height allows instructors to interact with each collaborative group in a relaxed manner and thus avoid having to stoop to advise students. The shape and distribution of the tables allow easy access to all students, thus enhancing the role of the instructor as facilitator of learning.
- Projection screens. The room has four projection screens on different walls of the room. With this arrangement students are able to see what is being projected from any angle without looking at the instructor directly.

- Hewlett-Packard tablet-type laptop computers. Each collaborative group has access to a HP tablet PC computer with a digital pen. The laptops have selected specialized software to support learning (Maple, MatLab, etc.). The portability of laptops and the connectivity in the room allow students to develop models or schemas in class and present their work in a dynamic way.
- Texas Instrument calculators with a navigation system. Each collaborative group has a TI-Nspire calculator. The classroom has a system (Navigation System) that allows the calculators to connect to a central computer, thereby facilitating the sharing of information among the 24 teams, projection of student work on the classroom screens in real time, sending and receiving of experimental data, and surveying of students.
- Voting system. An automatic voting system can be used in classes to implement Peer Instruction<sup>9</sup>.
- Whiteboards. On three of the four walls in the room, there are whiteboards offering discussion space to the collaborative groups. They can present their findings to other group members or to the whole classroom, since images displayed on the individual whiteboards can be captured by a camera and projected on the screens.
- Document camera. A document camera is available to present work on the screens. This camera is useful for clarifying or presenting solutions to problems worked on by different collaborative groups.
- Teacher tablet. At the teacher's desk there is a tablet to make notes on class presentations, or to project the real time solution to a problem on the screen using the digital pen.
- Demonstration table. Next to the teacher's desk, there is a table for interactive lecture demonstrations<sup>13</sup>. The table has three video cameras focusing from three different angles and projecting the demonstration on the classroom screens. Thus, even if the students are not facing the table, they are able to watch the demonstration.
- Videoconferencing. This technology allows the participation (in real time) of an external instructor who is able to share their knowledge and interact with students from a remote location. Demonstrations in the ACE classroom can also be transmitted to other classrooms on Campus.
- Wireless and wired internet. The classroom is equipped with a high speed internet connection, both wired and wireless, that facilitates internet searches, video review and use of the class digital platform, among other activities.
- Research table. For research purposes, there are three video cameras and three microphones at one of the tables. Video and audio recordings of the interactions of the three collaborative groups at the table can be made, thereby transforming the ACE classroom into a laboratory for educational research.

Several SCALE-UP-type classrooms have been developed based on the original design proposed by Beichner<sup>4</sup>. However, each has elements that distinguish it from the others. As described above, there are elements of the ACE classroom that make this room a unique learning space. Furthermore, ACE is a living laboratory of educational research where student interactions can be analyzed for different projects that aim to measure communicative interactions, problem solving skills, interactions that show the students' reasoning on a topic and a great number of other projects that are intended to further our understanding of how to improve the teaching and learning processes.

## Physics and Math in ACE

The ACE classroom has been used for physics and mathematics classes. In the Department of Physics we have taught Introduction to Physics and Electricity and Magnetism. In the Department of Mathematics we have taught Introduction to Mathematics and Differential Equations.

- Introduction to Physics. Students, supported by computational and mathematical tools, build models of real situations, verify their validity in other physical situations and make changes if necessary. Collaborative work is used to build new concepts and to strengthen problem-solving skills, making each table a small learning community. The course includes experiments that are conducted in groups, transforming the room into 24 experimental stations where students capture information from natural phenomena, take measurements with high precision instruments, and develop models from computational resources. We also use simulations and open source software to help visualize and make calculations. Thus, in this course we combine the elements that form the foundation of today's scientific work: theory, experimentation and computation.
- Electricity and Magnetism. The E&M course in the ACE classroom is designed to integrate various teaching and learning strategies that have been reported in the literature. Some of these strategies include Peer Instruction (8) and Tutorials (7). These strategies and collaborative group work activities are performed to acquire both conceptual understanding and problem-solving skills. In the ACE classroom, students build concepts related to electric and magnetic interactions through the development of scientific reasoning.
- Introduction to Mathematics. This course revisits concepts and methods of basic mathematics in order to connect and extend this knowledge to higher mathematics. Mathematics is presented as a tool for the analysis, modeling, and interpretation of non-routine problems in simple real contexts. The strategies applied, such as problem solving, collaborative learning, generative activities and modeling, are based on a constructivist approach to learning. In particular, the ACE classroom has technology that facilitates the students to take on problems and situations that foster the construction, consolidation and application of knowledge and that will give them the opportunity to develop skills in their professional lives. Thus, this promotes the perception of mathematics as a unified field of study that is useful for modeling real phenomena, the role of students as constructors of their own knowledge, and the role of the instructor as a facilitator in this process.
- Differential Equations. The Differential Equations (DE) course in the ACE classroom favors the modeling of physical phenomena such as mass-spring system, a mixture of saline water in tanks, electrical circuits (resistance-capacitance and resistance-inductance-capacitance) through experimentation and simulation. The study of algorithmic processes has less of a role in the ACE DE course than in a traditional DE course. Various research studies have reported a strong analytical component in DE courses<sup>7,14</sup> which makes students think of DE as a purely algebraic process. By emphasizing the modeling process implicit in each of the phenomena described above, students and future engineers are more likely to value DE as a tool for modeling various problems.

## Abilities and skills

Currently, a set of pilot studies are underway to assess the impact of the ACE classroom on the teaching/learning processes.

### *Use of technology skills*

The ACE classroom makes a great deal of technology available to students. We conducted an exploratory study to observe their skills in using one of the available technological tools in the classroom, the graphing and programmable TI-Nspire calculators.

Teams were formed of 3 students each, and they then completed a worksheet in which they were asked to graph four functions of different order (linear, quadratic, cubic, and fourth) in a cinematic context. The day of the activity there were 18 teams of 3 students, for a total of 54 students. The following observations were made:

- In the first problem, the students are asked to graph a linear equation. 44% of students in the ACE classroom used technology to graph the equation and all did so successfully, getting the correct result. The remaining 56% did not use the available technology. Of these, 10% missed the result. That is, all students using technology to graph the function answered correctly, but this was not the case for all the students who tried to graph it on their own.
- In the case of a quadratic equation, only 17% of the students decided to use technology to solve the problem. Of these, 66% obtained the correct result. The remaining 83% of students decided to solve it analytically and 17% of them failed in the attempt, reporting an incorrect result.
- To graph a cubic equation, 89% of students used the calculator. 75% of them did it correctly and reported the result. The 11% who tried to do it analytically failed in their attempt. That is, none of the students who tried to solve the cubic equation analytically obtained the correct result.
- Finally, they were asked to graph a fourth order function. In this case, 78% of students chose to use technology to graph the function. Only 50% got the correct result. Interestingly, of the 22% who chose not to use technology, 50% failed in the attempt. In this particular case, the decision to use technological tools was not the determining factor in achieving a greater number of correct results.

### *Problem-Solving Skills*

One of the advantages of the ACE classroom is the ease with which activities that promote problem-solving skills can be implemented. A comparative study was designed to explore the skills developed by students enrolled in the ACE classroom (experimental group) and students enrolled in the same course taught in traditional classrooms (control group). The course selected was Electricity and Magnetism (E&M), in which students in the ACE classroom perform the same activities and tutorials as those enrolled in the E&M course in traditional classrooms. The difference is that in the ACE classroom, strategies other than tutorials are used to focus on the conceptual content of the course. To ensure random data selection, the problem to be solved was assigned during the laboratory sessions. We gave four versions of the same test in each session. We managed to have the same number of students in each group as shown (experimental and control) and the same number of responses by type of test. We obtained a total of 54 pairs of

tests, pairs comprised of a student enrolled in the E&M course taught in the ACE classroom, and another student who took the same type of exam in the same lab group, but who was enrolled in an E&M course taught in a traditional classroom.

The solution to the problem was reviewed using the rubric given by Docktor<sup>15</sup>, which considers five categories: physics approach to the problem, useful description, specific application of physical concepts, mathematical procedures and logical progression. The rubric assigns values from 0 to 5 for each category, with 5 indicating a satisfactory performance in the category and 0 null performance. Also we considered two not applicable grades, NAP when the category is not applicable for the design of the problem and NAS when the category does not apply because the student does not consider it necessary to solve the problem.

The category physics approach to the problem was not analyzed, since 104 of the 108 records obtained (over 96%) indicated NAS (not applicable). For the other categories, discarding records that were deemed not applicable, we used a *student t test* to find differences. The results are displayed in Table 1. The only significant difference was in mathematical procedures with a significance  $p < 0.1$ . According to the student t statistic, the average score of students in the traditional classroom is slightly higher. Table 1 shows that the significance in mean difference in mathematical procedures is small. It is concluded that the problem-solving skills of students are similar in both cases. We hope that instructors acquire more experience using the ACE classroom so that problem-solving skills are better acquired in the ACE classroom in the future.

Table 1  
*Four statistical characteristics assessed in solving problems.*

		Students N	Mean $\mu$	Standard deviation	Sig. (2 tails)
useful description	Traditional	46	4.83	0.35	0.820
	ACE	45	4.84	0.41	
specific application of physical concepts	Traditional	54	4.69	0.39	0.122
	ACE	54	4.52	0.68	
mathematical procedures	Traditional	54	4.28	0.68	0.071
	ACE	53	4.05	0.62	
logical progression	Traditional	54	4.29	0.59	0.221
	ACE	54	4.14	0.66	

### *Communication skills*

For the pilot research study, the E&M course was selected to investigate the communication skills that are promoted in the ACE classroom. That course was selected because it focuses on conceptual aspects through collaborative activities.

A group of students was video recorded and analyzed during the full class session, yielding 85 minutes of video. The video was analyzed, and it was found that the most common roles that



students took on were: leader (coordinator), secretary (pointer) and skeptic (devil's advocate). Regarding communication skills, this study began with an adaptation of the work reported by Knapp and Daly<sup>16</sup> in which communication skills are called: expression, altercentrism, interaction management, and composure.

These four skills were observed in an academic context. All of the students participated at some point, starting discussions, expressing doubts, or contributing to solving the problem. Each of them naturally served at various times as activity leaders, skeptics or secretaries.

Throughout the session the students exhibit a personal interest in explaining or clarifying doubts. On their own initiative, students use graphs and share mnemonics rules attempting to explain their views. The skills that are observed most are interaction management, altercentrism and expression. With regard to expression, during the 85 minutes of class, only 6-7 minutes of social conversation were observed, with an average duration of less than two minutes. This occurred most often when the instructor spoke for more than 5 minutes without any opportunity for student comments or questions to break the monotony. The fact that student social conversation is held to a minimum, together with the fact that students are able to work autonomously and collaborate on various activities, represent the most significant contribution to the learning process in an ACE classroom.

### *Opinion Survey*

At the end of the semester we introduced a survey about the student experience in the ACE classroom. The survey was translated from the study by Gaffney, Gaffney, and Beichner<sup>17</sup>. This survey aims to provide feedback to the teacher on the attitudes of students in a classroom with features similar to SCALE-UP. Details of the study may be consulted elsewhere<sup>18</sup>.

The questionnaire contains six Likert-type questions. The questions consist of the sentences presented in Table 2 and the student had to choose from among seven options, ranging from completely disagree (1) to completely agree (7).

Table 2

*Survey questions on the experience in ACE.*

Question	Statement
1	The ACE classroom environment is a useful style of teaching and learning
2	I would have learned better in a more traditional setting than the ACE classroom
3	The ACE classroom environment is inappropriate for college classes
4	The style of this course helped me learn (physics/math)
5	Courses from other departments should use the ACE classroom environment
6	The ACE classroom is not for me

The online questionnaire was taken during the student's free time for three of the four subjects in ACE: Introduction to Mathematics, Differential Equations and Electricity and Magnetism. Extra points were offered to students to encourage them to complete the survey. The results are presented in Table 3.

Table 3

*Descriptive statistical analysis of the results of the opinion survey.*

Question	Mean	Standard Deviation	Mode
1	4.9	2.0	7
2	4.3	2.1	7
3	3.0	1.9	1
4	4.4	2.0	4
5	4.9	1.9	7
6	3.5	2.2	1

Students in general agree that the classroom environment is useful (question 1) and that teaching and learning courses from other departments should be taught in this type of classroom (question 5).

The results also indicate that there is some disagreement as to whether the classroom is inappropriate for university courses (question 3) and that the room is not for them (question 6). These results also indicate the positive outcomes of the ACE implementation, and more so when compared with questions 1 and 5, which have a reverse ranking. That is, the most positive outcome of questions 1 and 5 was that the student had answered 7 and the most positive result of questions 3 and 6 was that the student had answered 1. This indicates that the students were paying attention to the survey.

However, there are results that are not so positive, such as questions 4 and 2, which point to the student's lack of conviction about the advantages that this type of environment offers to their learning. This indicates the difficulties that students had in adjusting to the ACE classroom strategies.

### **Conclusion**

With the support of the University President and a project sponsored by Hewlett-Packard, the construction of the ACE classroom was one of the educational innovation projects carried out on campus. This room aims to become a classroom model that is at the forefront of educational technology. In this section we will mention the most relevant findings in the implementation of ACE.

Earlier versions of the ACE room in different places, mainly in the U.S., have shown that the strategies of teaching / learning that were implemented were very successful, both for learning and for acceptance by students. For this reason, some of the objectives of ACE were to improve student skills in the areas of learning, communications skills, technology skills, attitudes and problem-solving skills.

The classroom features the latest technology in the field of education. As mentioned in the text, the instructors who teach in the ACE classroom have the opportunity to use different technologies that favor learning. Laptops and Tablet PCs create a dynamic environment in the classroom that otherwise could not be achieved. The preliminary study shows that students do

make use of technology when it is needed. Furthermore, in well-designed activities, the student uses technology to find information relevant to the issues presented in the activity.

The student learning in an ACE classroom is not adversely affected by the experience; in fact, in one preliminary study (not discussed in this paper), Electricity and Magnetism students in the ACE classroom display better conceptual learning than students in traditional classrooms. However, in another preliminary study (included in this paper), over all dimensions of problem solving the two groups had no statistical difference except for algebraic procedures, with a slight advantage for students who did not take classes in ACE. This indicates that in the ACE course the professor does not emphasize mathematical procedures to solve problems.

Communication between students was a positive revelation of the ACE classroom. Students showed that small group communication is rich with discussion among its members, and serves to maintain the students' focus on the class when doing a collaborative activity. Among the communications dynamics that were presented, it was found that small groups occasionally communicated with the two other small groups at their table, thereby creating a learning community of nine people. This dynamic occurred when one of the teams had a question and could not find help from an instructor, or when an instructor came to answer questions. We conclude that the dynamics of small groups and large help the activity to proceed more efficiently.

The classroom in its first implementations had an adequate level of acceptance by students. This conclusion can be drawn from the opinion poll given at the end of the semester. Acceptance by the students is important because they communicate with students who are taking courses in traditional classrooms, and their comments contribute to the expectations of those students who will take courses in the ACE classroom in the future. We believe that the experience in subsequent academic years will give us an opportunity to increase students' acceptance.

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