A Hands-On Course For Five Hundred Students:
Introduction To Engineering I At Puc-Rio

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Abstract

This paper is a report on the teaching experiment conducted in the Introduction to Engineering I course at PUC-Rio's Technical-Scientific Center (CTC) during the two terms of 1997. The idea was to test and develop hands-on teaching methodology — more precisely, concurrent teaching methodology as set forth in [1], including principles of entrepreneurship development, following the educational policy recommended by the NSF (U.S.) and the REENGE program (Brazil) and applied at PUC-Rio's CTC. What makes this experiment original in comparison with other project courses is the number of students involved, as well as the strategies resorted to in order to use a hands-on approach on a large scale.

The paper begins with a consideration of the problem to be faced: the number and type of students who enter the University, the teachers working on this course, and the equipment available. Then the organizational strategy is described, including the division of the students in groups of 60, each under the responsibility of a specific Department. Each Department interpreted the meaning of "hands-on" in its own way and developed its own strategy for working with a large number of students. These different strategies are analyzed and compared. The paper ends with the results of an evaluation that took into account the formal results, students' opinions (surveyed by means of questionnaires), and the opinions of teachers and outside observers.

The final result was positive, and the University officially adopted the new course. Older students requested the creation of a special course using the same methodology, so that their training might also profit from it.

Key Words*: Engineering Education, Hands-On Course, Freshman Year*

Acknowledgments*: Thanks are due to the large number of teachers who acted as supervisors for the courses Introduction to Engineering I and II in 1996 and 1997 at PUC-Rio's CTC. It is their work that the present paper describes.*

Why Introduction to Engineering?

This paper reports the experience of PUC-Rio's Technical-Scientific Center (CTC) in organizing an introductory engineering course for freshmen. Part of the results of the experiment were previously reported in [2]. The students, fresh arrivals from secondary school, have only a vague and stereotyped notion of engineering and its different areas, and are more aware of the engineer's social position than of the actual work of an engineer.

This course was created basically as an attempt to reduce the drop-out rate, which was as high as 63 percent of all students who had passed the college-entrance examinations. A high drop-out rate is to be expected, since applicants taking the PUC-Rio entrance exams also try for UFRJ and UERJ (two large public universities in Rio de Janeiro) and make up their minds as to where they will study only after they take the three examinations (by which time they have already registered at PUC-Rio). Nevertheless, this figure was considered excessively high.

Would-be engineering students who decided to drop out were surveyed, and the main reasons for their decision were:

1. lack of previous knowledge about engineering as a career[1];
2. the abstract and dry nature of the Basic Cycle ("When does engineering really begin?");
3. discouragement caused by successive failures.

Few mentioned the tuition fees, even though PUC-Rio is the only private institution among the major

[1] Even after they had entered the university they still knew little about engineering.

universities in the Rio de Janeiro area.

Careful examination of drop-out data showed that most students gave up after the first two terms, in two major waves: there were those who left after a short while (for reasons 1 and 2) in the first term, and those who did so after failing the introductory courses repeatedly. Also, incoming students at the CTC have been getting weaker ever year, both because of the decay of secondary-school education brought about by the dramatic surge in the number of students and because of the rather paradoxical decrease in the number of applicants for engineering courses. This has occurred because the current opinion among high-school students is that engineering courses are the hardest (they involve math and physics, the two most unpopular subjects among students) and that engineering graduates are finding it difficult to get jobs.

It was decided to tackle the problem on several fronts. Thus a reform program for the engineering course was developed (REENGE/PUC-Rio, see [2]) involving such initiatives as the introduction of new teaching techniques (hands-on teaching and multimedia, for instance), changes in the curriculum, contacts with high schools, and the creation of a special introductory engineering course for freshmen that would help them through the basic science courses, which necessarily predominate during the two-year Basic Cycle. It should be noted that the weaker freshmen are, the greater their need for basic science courses, and the more formidable the difficulties they tend to face in these courses.

The new course was named Introduction to Engineering, and it was introduced on an experimental basis in 1996 as an optional, though recommended, freshman course.

Difficulties with the Faculty

The initial idea of the Basic Cycle Coordination was to adopt a hands-on teaching strategy, posing problems for students to solve that would make them feel like engineers and give them a good sense of the function and the fascination of engineering.

The teachers selected for the new course (one per CTC Department) were against the use of hands-on methodology. The idea was to show each of the engineering areas covered by the CTC to every student: each engineering Department was to advertise itself to all students. Assuming 500 freshmen — the usual number — this meant that each Department would have to deal with 500 engineering projects in the first term every year, to be conducted in four months, by students who had just finished high school! And each student would have seven projects to carry out in such a short period, precisely at a time when freshmen are getting to know the university and its resources, as well as facing new problems. In addition, the teachers, all of them with Ph.D.'s and plenty of academic experience, professionals who had conducted very complex projects, had no experience in supervising simple, interesting, and viable engineering problems.

It was then decided to create a conventional course in which, after a general presentation of the CTC given by the CTC Dean, the students attended expositions of each Department, where they were told what engineering was, what were the different areas associated with each Department, and so on. Each Department presented three lectures, relying mostly on blackboards or transparencies, with occasional visits to laboratories.

This traditional strategy was used throughout 1996, and proved a complete failure. First, students complained, the different teachers who lectured all said very much the same thing: the essence of engineering is the same, whatever the specific area. Second, the presentations told them nothing, for the vocabulary used was unfamiliar to students and the examples given were unrelated to their experience and interests. Third, a list of descriptions and names is terribly boring (not just from the viewpoint of the students, incidentally). Consequently, as soon as they realized that the course was optional they stopped coming to the lectures, and soon the number of students fell dramatically. Halfway through the term the classrooms were nearly empty.

These criticisms were duly heeded at the end of 1996, and it was decided that a different strategy would be adopted the following year. After a number of discussions, it became clear that to present all areas to all students was an impossibility. Instead, each Department was to supervise projects involving 70 students, with the suggestion that students be grouped in 12 to 14 teams of five each. These 12 teams would all tackle the same engineering problem, competing with each other. The top two teams in each Department would present their projects at the end of the term, in a major event followed by an official ceremony for the presentation of the prizes. It was suggested that hands-on methodology be strictly followed, along the lines set forth in [1].

One problem remained: teachers found it difficult to supervise freshman projects. In fact, to many of them it seemed an impossible task; the best they could think of was simulated projects. It was decided that each Department would choose its own methodology. This resulted in a large number of different approaches, so that the various results could later be compared with each other.

Description of Strategies Used and Results Achieved

The distribution of students among Departments and in teams was done at random, so that students were not allowed to choose teammates or opt for the particular branch of engineering they intended to specialize in. They were told that one does not select one's teammates in a real-life situation in the work market, and that we were interested in showing them what they did not know rather than what they thought they knew. Each student was given an E-mail address, and discussion groups were organized on the Internet for each Department. An ombudsman address was created; students began to use it only towards the end of the term, although anonymity and protection was ensured by the University. More often they resorted to a specific auxiliary coordination created at the CTC's Basic Cycle Coordination, for they preferred person-to-person interaction. The most common problem had to do with the first contact between teachers and students: mostly, students found it difficult to be weaned from the dependence on the traditional schoolteacher figure that told them everything they were supposed to do. The Coordination was invaluable to help cushion the initial culture shock.

Civil Engineering

The Civil Engineering Department proposed that each team build a bridge over a 50-centimeter span that could support a standard charge (a miniature truck) and conform to technical norms (4-milimiter maximal middle point displacement under the maximal load). Once built, the bridges would be submitted to a failure load test. The winner of the contest was to be the team that built the bridge with the maximum failure load-bridge weight quotient. Each team would be supervised by a different Structures teacher.

The bridges were built, each according to a different principle, in accordance with the supervisor's interests — bamboo bridges, metal lattice bridges, wooden lattice bridges, and so forth, all of them conforming to technical norms. The presentation of the finished bridges and the exhibition of videos of the tests were grandiose spectacles. The students were then able to explain in approximate terms how the bridges worked, thanks to the explanations given by their supervisors.

This teaching strategy made it possible for students to understand the practice and the scope of civil engineering, and gave them an overall view of the problem of building structures, its foundations and methods. In addition, it established a concrete relation between civil engineering and the physics courses being taken by freshmen at the time, and showed them the importance of learning more. The students were very much enthusiastic about the project, and there were few dropouts.

The only external criticism that might be directed at the course is that the project was not fully elaborated by the students. On the other hand, students said that the teachers should have been stricter about requiring that the problem be more clearly specified and that the project be carried out with greater rigor. This shows that students understood what a project means and assumed the attitude expected from them.

Computer Engineering

The problem proposed here was to develop an algorithm for the password game, in which each participant must discover the password encoding the opponent's message on the basis of questions that are to be answered in code. The object of the competition was to find the algorithm that made it possible to discover the opponent's password the fastest, considering the average time obtained in a set of repetitions of the game using different passwords. The game was well known to the students, who constructed algorithms that ensured that the password would be found, even if the number of operations was enormous. They were unable to demonstrate the fact, but they understood it operationally, thinking in terms of disjunction of cases. The supervising teacher tried to get them to devise faster heuristic algorithms, even if there was no assurance that the solution would be found — which is the present trend in research on this problem. But teenagers find it impossible to admit the possibility of an occasional error!

In this particular case, the only equipment necessary was gray matter, but the students thought that their problem was too simple in comparison with those proposed by other Departments, and much more like a game than the actual work of a professional engineer — that is, they thought it was unrelated to the world of technology they have access to in their everyday lives. However, every computerized service uses algorithms of this kind. Students felt the need for a "concrete" problem. The gist of their objective criticisms was that the problem was too simple, or that the explanations were insufficient, or that in the end they had learned nothing at all. It was concluded that the difficulty of the problem (how to devise fast heuristic algorithms) had not been appreciated by the students (which is why they felt they were playing a familiar game) in spite of the teachers' explanations (which is why they were considered confusing or inadequate).

Electrical Engineering

The proposal was to build a digital sensor to measure the volume of liquid in an underground tank. The projects would be evaluated by a committee of teachers on the basis of the actual operation of a prototype to be built for a 20-liter can of paint. A list of obligatory equipment was specified: a digital multimeter, a multiturn potentiometer, and a small electric motor. The material was to be bought by students themselves in the shops specified in a list. The Department's labs would remain open every weekday from

9 to 6 for students working on projects. Three dates were set for presentations of projects, presentations of initial prototypes, and the final contest.

It took the students two months to figure out exactly what they had to do. Two teams began their projects only late in the term, which forced them to work late at night (at times the labs remained open until 2 A.M. for these students, thanks to helpfulness of the teachers and instructors). The teachers and instructors adopted a Socratic approach: they answered questions with further questions, and instead of telling students what to do they criticized what had been done. Suggestions included allusions to the physics involved in the problem — “You remember that $V = RI$ and $P = RI^2$?” — and reminders of the project’s methodology: “Let’s break down the problem into several parts...” An essential characteristic was that teachers and instructions made a point of always displaying enthusiasm over the course and willingness to work, as professionals bent on achieving their goals, an attitude that had a strong influence on students.

By the end of the first half of the term, most teams had already realized that the solution was to use the motor to lower a sensor down to the surface of the liquid, the potentiometer being coupled to the motor’s shaft. The variation in the potentiometer’s resistance is proportional to the height without the liquid, so that it is easy to calculate the volume of the liquid contained in the reservoir. In the mechanical assembly, it was found to be necessary to introduce reduction gears, taken from Walkmans, which provided a natural cue for a discussion of the concept of torque of a motor.

Only one team remembered to calibrate the potentiometer (one of the members had studied at a technical school), and only one team was able to fully automate the process so that the total volume actually appeared on the multimeter display (which requires control of the apparatus’s constants and the use of inverse logic in the measurement of the electric resistance). This particular project was very well done; the team was helped by the grandfather of one of the members. Another group built a liquid-surface sensor that was extremely sophisticated and precise, displaying great creativity. All groups built prototypes, only two of which were not completely functional.

The students’ general comment was that they had felt like real engineers, putting together all their knowledge in order to attack a concrete problem, the solution of which — a functional prototype — was achieved through their own effort. Some of the students even showed up in the lab during vacation because they wanted to “do something”! It was necessary to devise new problems, to integrate them into the laboratory team, and so on.

Thus it was demonstrated that it is possible to apply hands-on methodology to freshmen and at the same time to reach the goals originally set for the course. It is important to note that the proposed problem was multidisciplinary by its very nature, combining electrical and mechanical engineering. This meant that the team was not restricted to a demonstration of the specific area of its Department. Students’ only objective complaint was that the course required a great deal of work.

Mechanical Engineering

The teacher from the Department of Mechanical Engineering proposed that the students specify and design the structures and pieces of equipment necessary for the survival of a castaway like Robinson Crusoe, on an island with specified resources and with the use of simple tools (salvaged from the shipwreck). The students complained that they it hadn’t been a real hands-on project. The students’ objective criticisms were sharp: the theme was too vague, the project was confused and unfocused.

Metallurgical Engineering

The Department of Metallurgical Engineering and Materials Science asked students to identify all the materials used in some industrial process and to describe their functions. It was suggested that they visit industrial plants. The winning team, for instance, analyzed a copying machine, having visited the Brazilian branch of Xerox, where they were warmly welcomed and given samples and explanations. The students, though they were happy with their discoveries and said that they had caught the spirit of engineering work, complained that they had built nothing with their own hands. Comparing their projects with what had been done in other Departments, they found the proposal superficial and monotonous, for there was no real competition between different teams.

Production Engineering

Students were required to assemble a batch of electric connectors, the winning team to be the one that made its batch fastest, but observing industrial quality standards. Some teams developed machinery to help the process of assembly. The concept of learning curve was exploited. The final contest was recorded on video for future reference. The proposed problem showed clearly the scope of production engineering, but it seemed too simple for most students.

Chemical Engineering

Students were told to perform laboratory tests to compare the efficiency of methods of extracting bergamot oil (from orange rind). The winning team contacted the major Brazilian manufacturers of “natural” perfumes and tested three important methods which were practicable at PUC-Rio's labs. Students worked and discussed chemical engineering with great enthusiasm, but some of them thought that the theme was "not creative enough."

CETUC (Department of Telecommunications)

The students built an amplitude demodulator, supervised by a teacher designated for the task. They were able to reach a concrete result, built but not really designed by them, working in "real" laboratories. But the concepts required for the project were quite distant from students' previous knowledge, which was perhaps inevitable in the case of the subject selected. Students thought that the theme was much too theoretical, and some complained that they had no textbook to fall back on.

Mathematics

The Department of Mathematics decided to participate in the experiment, proposing that the teams assigned to it develop a program that would calculate the zeroes in a real function, on the basis of the Calculus I course and using the graphics programs available in the computer science labs of the Basic Cycle. Industrial finish was required: user-friendly interface, and so on. The winning team presented a program that used Newton's method, without discussing the convergence of the method: they centered on the actual object to be constructed rather than on the abstract methodology. At the moment the issue being discussed is whether or not Mathematics should be included in Introduction to Engineering, since its approach is abstract and its teachers are in direct contact with students in the Calculus I and Linear Algebra I courses.

Evaluation of Results

At the end of the period there was a general presentation of the winning projects of each Department. This proved very important not only to students and their families but also to teachers, both in order to compare their different results and to persuade everyone of the viability and usefulness of hands-on methodology for freshmen. The presentation was a day-long event, given the large number of projects. The expositions were no more than tolerable, which showed freshmen's lack of training in speaking in public, a problem that must be seriously faced by the engineering course.

Certificates and prizes were presented. Curiously enough, the winners said that the prizes were not important: what really counted was having participated and seeing that their work was appreciated. They felt a desire to present their projects before an audience. Some teachers even organized their students' presentations, taking on the role of expositors, but they were publicly criticized by students and had to give way!

Out of the 541 students who originally registered for the course, 402 concluded it (74%). Eighty students (15%) canceled their registration at the University, a much smaller drop-out rate for first-term students than usual (36%). Forty students (7%) failed to finish the course (i.e., they stopped coming to "class"), and 19 (4%) officially dropped the course. However, Introduction to Engineering I remained an optional course, a fact students were aware of.

When the term was over, students were asked to answer a questionnaire about the course, the results of which are to be found in http://www.ctc.puc-rio.br, item REENGE/Introdução à Engenharia, or in the Internal Report of CTC's Basic Cycle on the subject (copies will be sent by the authors of the present article upon request). In addition to the student criticisms already mentioned above, we now present a few selected statistics and most-frequently-expressed opinions:

- 6% of students were very enthusiastic about their work, 58% were enthusiastic, 16% were more or less enthusiastic, 19% were not enthusiastic at all.
- 34% changed their behavior during the project, 66% did not.
- 81% profited from the activity, 3% profited more or less, 16% did not.
- 75% enjoyed the experience, 3% enjoyed it more or less, 22% did not.
- 60% felt an affinity with the area in which they had worked, 3% felt it more or less, 37% did not.
- 70% felt an affinity with the teacher, 3% felt it more or less, 27% did not.
- 62% found it easy to contact the teacher, 38% did not. Only 21% used the Internet for this contact, but 32% used it for other purposes.
- 23% were helped by people outside the University, usually family members.
- 11% changed teams, something that was discouraged but not forbidden.
- 42% were not sure as to what to do at first.

The average grade students gave to the new course, on a scale of 0 to 10, was 9.65; 78% of the students gave it a 10.

The most common positive comments, appearing in almost every Department, were:

- It stimulates competition and team work; working in a team is very interesting; interaction between team members was possible because we had a common goal.
- I learned a lot; I learned how to make a project.
- It was a positive experience because I had contact with practical work.
- This was my first contact with the profession.
- It encourages creativity.

- I learned how to study on my own (i.e., without a teacher).
- I realized I can use my intelligence to build things.
- I learned how to go for it.
- It was hard work, but thrilling.
- It was rewarding without being dull.

A few students said they had found their true vocation, which in some cases implied changing the opinions they held at the time they entered the University. A number of students criticized the random selection of areas and teams: each student, they felt, should select his or her own area, or else each student should be exposed to each area. These were precisely the positions defended by teachers at first, as has been shown above, arguing from a different perspective. Unfortunately, such a program would be unworkable in a single term, considering that there were 500 students.

Perhaps the major indicator of success of the course was the enthusiasm of the teachers and University authorities. The course and hands-on methodology were officially adopted, the experimental phase having been successfully concluded. Teachers said they were convinced of the method's usefulness, and spoke of the experiments at the Departments of Civil Engineering and Electrical Engineering as exemplary. The directors of these Departments expressed the opinion that it was necessary to allocate more resources for the new activity, and University authorities agreed.

Some methodological decisions were taken:

1. The search for themes that are specific to each area in engineering is counterproductive; it is easier and more effective to adopt multidisciplinary themes that involve the branch in question.
2. Freshmen find it difficult to deal with abstractions, which is why they are more interested in concrete, real hands-on projects. Abstraction should take place throughout the process and only as necessary, rather than in the form of a priori considerations for the definition of the problem.
3. The attitude of teachers and instructors is very important; above all, they must be dedicated and accessible. Freshmen complain about the attitude of college professors in comparison with that of high-school teachers, which is only natural, and expect teachers to help them cope with this cultural change. Here the specific coordination and the ombudsman are useful.
4. An attitude of seriousness towards work should be required from freshmen. They themselves expect this.
5. Students should be helped in the audio-visual expositions. They need hints, criticism, and dry runs.

[1] The students themselves requested this. They will be used as monitors.

Conclusion

The experiment was a success, both for the results achieved with the students and for the general consensus as to the viability, usefulness, and importance of the use of the hands-on approach, in its most concrete sense, with freshmen. Essential ingredients of this success were the fact that so many different strategies were tested simultaneously and the careful evaluation described above.

University statistics indicate that there was a significant decrease in student drop-out rates in 1997 and early in 1998. Part of this result may be attributable to Introduction to Engineering I. Also, teachers of basic science courses made a considerable effort to make the contents and methods of their courses more palatable to freshmen.

In the second term of 1997, when the number of freshmen was small (only students who had previously dropped the course), Introduction to Engineering I was the responsibility of Prof. Mauro S. da Silva of the Department of Electrical Engineering. The activity was to design and assemble an electric model airplane that would actually fly. And fly it did, if not very well. The project excited huge enthusiasm, and Varig, Brazil's major airline, was interested in using it as part of a promotional scheme.

In the first term of 1998 the experiment was extended to advanced students who had not had the chance of taking the hands-on course as freshmen,[2] and interaction with high schools was attempted. Each of the high schools that tend to send a number of new students to PUC-Rio was invited to choose 5 students to take the course, making up a team, together with the freshmen. The initial enthusiasm of schools and their students was enormous. At the time this is being written, the experiment is only beginning, and the University is well aware of the risk it is taking: it might turn out to be good publicity or quite the opposite. The answer will be known only in 1999.

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