A possible way out of the dilemmas of the science-core requirements in five-year engineering courses

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***Abstract* - Schools that provide the science-core themselves (rather than delegating it to preparatory schools) face a serious motivational problem: having already been admitted to an engineering school, students expect to receive engineering training and are usually disappointed and discouraged by classes that they tend to consider too theoretical and overly scientific. An alternative possibility is explored in this paper, in which some classroom hours in formal disciplines are replaced with tutored workshops on engineering topics that entice the use of relevant scientific content. It is argued that tutored problem-solving assignments motivate the acquisition of disciplinary knowledge while increasing the awareness for needed interactions between disciplines in real-world projects.**

Index Terms – science-core, motivation, tutored workshops, real-world projects..

INTRODUCTION

Some engineering schools require entry-level students to be proficient in mathematics, physics, chemistry, etc., and offer a three-year course in engineering. Typically students acquire the required science-core knowledge in preparatory schools, where they find motivation in the perspective of being admitted to a prestigious engineering school.

On the other hand, schools that do provide the science-core themselves — typically as part of a five-year undergraduate curriculum —, face a serious motivational problem: having already been admitted to an engineering school, students expect to receive engineering training and are usually disappointed and discouraged by classes that they tend to consider too theoretical and overly scientific.

Some schools try to mitigate this problem by means of an "Introduction to Engineering" course in the first year, as well as courses on applied sciences, and even humanities. Results are questionable, with a significant percentage of abandon and generally mediocre performance, even from students that later prove to be quite motivated and top ranking.

Especially in the case of engineering schools which belong to universities, another frequent discussion relates to the background of the professors who teach the science-core: should they be engineers or rather should future engineers be exposed to differing views of science?

Most of these questions are addressed in this paper and reflect the personal view of the author, after over thirty years teaching Civil Engineering in a leading engineering school in Brazil.

THE NEED FOR A SCIENCE-CORE (OR, DO WE REALLY ACT ACCORDING TO OUR BELIEFS?)

There is little disagreement that all engineering students should be proficient in physics, calculus, linear algebra, chemistry, as well as numerical and graphical modeling, mechanics, materials science, etc., before they can tackle the more specific challenges of the engineering curriculum. Students of five-year course engineering schools are usually expected to fulfill those requirements in the first two years.

Actual results frequently prove to be far from ideal. The degree of success of these first two years varies widely from school to school, but one frequently observed outcome is rather frustrated students who feel they have spent their first two years in an engineering school without learning any engineering. Quite frequently they do not effectively learn the science-core either.

Figure 1 shows a rather dramatic result observed at the "Escola Politécnica" of the University of São Paulo. It shows that a large percentage of the Civil Engineering students carry on without having really cleared their science-core requirements. These results are negatively biased with respect to the student population in the School, because of occasional job market circumstances and peculiarities of the selection procedure for different branches of engineering.

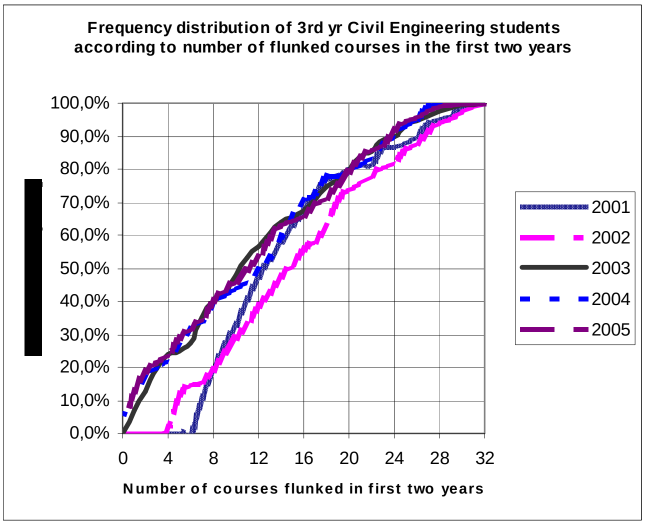

FIGURE 1
DISMAL PERFORMANCE OF STUDENTS IN FIRST TWO YEARS

The obvious question is “why should the School allow students to proceed without having fully completed their science-core?” This tends to be difficult to explain, since it would mean that the School itself admits that the science-core is not that essential after all... In some extreme circumstances, fourth- or fifth-year students would be encountered who had not fully completed their science-core yet. Needless to say, students in that situation did not usually graduate in five years. This question has been addressed in many debates, and some restrictions are being progressively applied to the promotion of students who have not completed all requirements.

Even students who have been rather successful in the first two years often give the impression of having retained almost nothing of what they have been taught. This is probably an oversimplification, but the surprising consequence is that many professors in the following years do embrace the notion that the students are not well prepared in the science-core. And they proceed to teach their subject matters with minimum resort to the science fundamentals, refraining from using trivial results in calculus or physics. This has probably to do with the fact that professors relate all too well to the students’ feelings about the first two years: after all, they may have gone themselves through the very same experience, since these problems seem to have been in the root of the engineering teaching and learning process for decades.

The whole picture is aggravated by the rate of abandon during the first two years, which fluctuates between 3% and 4% at “Escola Politécnica”.

If one does believe that education is more than just teaching, there must be a solution for this apparent dilemma.

THE PLOT THICKENS... IS THERE A WAY OUT? (OR, WHO SHOULD TEACH WHAT? AND HOW?)

A few years ago two eminent colleagues, professors of Civil Engineering in most prestigious schools in North America, delivered lectures ([1], [2]) in which the main message was “forward to basics”, meaning that more and more attention should be given to the science-core and applied sciences, since knowledge accumulates and changes at a rate that makes it impractical — if not impossible or even irrelevant — to try to keep students abreast of this ever changing reality. They should rather be taught the basic principles, and be stimulated to develop the ability to grasp fundamental features of a new problem and to identify prospective solutions (resorting to well-learned scientific principles), as well as to acquire life-long learning skills. [3]

Engineering schools must, in fact, facilitate the development of the ability to identify, formulate and solve engineering problems by applying knowledge of mathematics, physics (plus chemistry, biology, etc., depending on the specific problem at hand). ([4],[5])

As previously discussed, professors of technical and applied science courses that appear later in the curriculum tend to fall short of this goal, due to the — real or supposed — perception that students have not achieved a solid understanding of the needed science fundamentals.

Academics from other areas (or disciplines) do not, in general, feel compelled to stimulate the development of these abilities in their classes in engineering schools.

An engineer, when teaching fundamental science disciplines, might arguably be more alert to the need to familiarize students with the challenge of identifying the problems and the possible solutions offered by the basic sciences. He might, however, be incapable of offering the diversity of thought that is so much needed among engineering students.

This is precisely the positive point, especially in universities that have this possibility, of having mathematicians teach calculus to engineering students, physicists teach them physics, etc.. It helps broaden the students’ horizons by increasing their exposure to people with different perspectives of life. In this sense, by the way, encouragement of engineering students to take some courses in humanities should always be welcome (the discussion of the integral formation of the engineer is, however, beyond the scope of this paper).

The proposed solution? Replace some of the hours spent in formal science classes with workshops, tutored by engineers, in which that knowledge is discussed and applied to real-world problems. No need to reach professional-level engineering solutions to those problems: the path — rather than the end-result — is the essence of the process.

PREVIOUS EXPERIMENTS

An experiment has been under way for some years at “Escola Politécnica” of the University of São Paulo, involving the course “Introduction to Engineering”. This is a traditional course intended to give students a general idea of the profession. In the past professors and professionals in the several branches of engineering were invited to deliver lectures, which would supposedly help the students choose one area or another. However, the exposure was not nearly enough to give the students a real appraisal of their activities in each of the different branches of engineering. Moreover, questionnaires circulated among the students [6] have shown that less than about 27% do in fact change their original choices during the first two years in engineering school. To make things worse, while time was not nearly enough for effective presentation of every option in the engineering profession, there was no time left to discuss the general characteristics of the engineering profession itself.

The whole engineering curriculum at “Escola Politécnica” had undergone significant remodeling in 1999, but it was only in 2001 that a new “Introduction to Engineering” syllabus was introduced (1), mainly by the initiative of professors in the Naval and Oceanic Engineering Department, especially Profs. Célio Taniguchi and Hernani Luiz Brinati, whose innovative contribution is hereby acknowledged. The new course is intended to give the students a hands-on experience in engineering problem identification, proposition of alternative solutions, evaluation of costs and consequences of each alternative, and justified

1 http://www.poli.usp.br/Organizacao/Departamentos/GraduacaoDisciplina.asp?discip=PNV2100

choice of one of the solutions. General themes are chosen each year for the project, such as "Residue generation and disposal", "Rational use of energy", "Rational use of water", etc.. Different classes are assigned different tasks, such as rational use of water in hospitals, or in schools, or in private homes. The task is further subdivided within each class and assigned to groups of 4 to 6 students. Each class, organized as a small firm, makes visits to the object of its project, gathers information about real needs and preferences, about possible alternative solutions, and establishes criteria for the choice of the "best" alternative. At the end of the semester, classes that have been assigned the same task compete for the best approach to the problem (not necessarily the best solution).

Results have been quite encouraging. There is usually a short initial period of uneasiness, while students adapt to the idea of having to tackle a real-world problem, despite having just entered engineering school. The fundamentals for the development of a definitive solution are obviously not laid yet, and therefore the support from the professor (or tutor) is most important during this period to help students understand that the process rather than the end-result is what really matters. This idea is assimilated after two to three weeks, and student involvement usually goes in a *crescendo* till the final competition, which tends to mobilize students in a manner not usually seen in other first-year courses. Written and oral presentations of partial and final results help develop communication, planning, control, and teamwork abilities.

Very few students (typically less than 5%) flunk this course. Unfortunately, in many engineering schools (and "Escola Politécnica" is not an exception) such an outcome sometimes contributes to a negative rather than positive evaluation of the course. This outcome must, nevertheless, be analyzed in conjunction with the very low observed absenteeism, combined with an average performance well above that observed in other first-year courses and low dispersion, both intra-class and inter-classes. There is strong evidence that the course attains its objectives and partly fulfills one of the students' expectations as they enter an engineering school. The author believes that a similar approach might effectively address other expectations, and most of the aforementioned dilemmas.

THE ENTRY-LEVEL PROJECT(S)

Many engineering schools require a project or manuscript (either individual or group work) during the last year before graduation (typically the fifth year). It is believed that a similar project could be undertaken within the first two years to familiarize the students with engineered solutions derived from knowledge acquired in the science-core and applied sciences.

Main objectives of the project:

- place the scientific knowledge in proper engineering perspective and exercise its application for the solution of real-world problems;
- motivate young engineering students by stimulating them to investigate engineered solutions to real-world problems;
- help students identify the interrelationships and common ground among different branches of engineering;
- foster social, political and environmental awareness, as well as the ability to work in teams.

General themes can be, for example, energy, housing, transportation and logistics, telecommunications, water resources and sanitation, or any other general issue that appears to be relevant to the formation of an engineer at any particular time and place.

Within each of these general themes, specific projects will be assigned to classes and groups, much in the same way adopted for "Introduction to Engineering". Students will be graded on the basis of their class projects, group participation, and personal portfolio.

Each student will be required to prepare a personal portfolio accounting for his participation and contributions to the project. Each project will be graded according to written and oral presentations before a jury composed of the faculty involved in the course and invited professionals familiar with the theme and the project. The very same project will be assigned to two or three classes, so that the final presentations will in fact be a competition between "firms" that have possibly adopted different approaches.

In keeping in line with the original idea of the course, grading should value the effectiveness of the learning process (demonstrated ability to make use of the science-core and applied science fundamentals, and understanding of the interrelationships between different branches of engineering) over the final engineering solution itself.

Given this requisite, it is probably better to start this discipline with a course in the second semester and, depending on the scope of the project, extend it through courses in one or two subsequent semesters, progressively gaining insight into the problem.

SOME SPECIFIC REQUIREMENTS

As far as creating specific projects it should be kept in mind that engineering students have, in general, a natural curiosity for engineering projects and are increasingly aware of their relationship with people, nature and its resources. Projects should therefore foster this awareness, a concern that is frequently missing from engineering curricula. Helping them learn to cope with uncertainties and the tradeoffs implied in their decisions is also essential.

Projects should never be restricted to specific branches of engineering, just as they usually are not in practice. On the contrary, they should be devised so as to foster as much transversal interaction as possible, so that interrelationships rather than just peculiarities are the preferred means to help students envisage the different professional options before them.

In the project for a new transportation system, for example, the students should be stimulated to tackle all sorts of problems, from the logistics and the financial aspects of the project to the mode of transportation, its mechanical and energy characteristics, the interaction with the city and the environment, the infra-structure works needed, etc.. The project should be well anchored in time and space, so that the students feel related to it (such as the new transportation system between the downtown area of the city where the school is located and the local airport). At the same time, a systemic view of the enterprise — and the ensuing investigation on its relationship with production chains — should be stimulated to help the future engineer place his work in proper societal perspective.

No excessive emphasis on the actual engineering solution (or solutions) can be given, since first- or second-year students still lack specific technical background. They should, nevertheless, be encouraged to search (both bibliographically and personally) for the essential information so as not to be led astray to non-realistic — or even non-viable — solutions. To this end, part of the faculty in all branches of engineering must be involved — necessarily by persuasion rather than imposition — in the effort, by setting aside a few hours (one to two) per week to act as consultants to the different groups working on entry-level projects. This should also give the students a flavor of the richness of the interaction with professionals specialized in different areas, as well as the ensuing real-world difficulties.

It is obvious that the groups need tutors. As a matter of fact, no formal lectures are planned for this course. Students are required to attend three 50-minute tutorials per week. In order not to increase the credit requirements of the engineering course, these three sessions per week must be taken from the regular first- and second-year courses, the idea being that examples and applications of the subject matters of those courses will be dealt with in the tutorials.

Instructors for these tutorials should be engineers, so as to provide guidance about the areas of engineering involved in the project at hand, to help select the appropriate references and "consultants", and to help students recognize, in the development of their projects, situations in which scientific concepts can be used to their advantage. Applications of integrals, derivatives, single- and multi-variable functions, matrix and vector operations, differential equations, conservation principles, etc. spring to mind in any engineering project, so that all the instructors have to do is draw the students' attention to them and make suggestions as to how to proceed to derive the results needed for the project.

The course will not probably be restricted to applications of the science-core in strict terms: opportunities will certainly develop for students to be encouraged to exercise *all* skills acquired, including those typically developed in second-year courses (such as applied probability and statistics, engineering mechanics and structural engineering, materials science, thermodynamics, simulation, modeling, and computer science).

On this day and age, when students are increasingly more conversant with computers than their tutors, one can even dream of computer simulation games aimed at testing the students' knowledge, skills and abilities acquired in the project.

PERCEIVED DIFFICULTIES

While the proposal seems promising, especially given the success of similar experiences, it is not without its own serious difficulties.

The main one is, as usual, a question of motivation of people. It must be recognized that, while the proposal addresses the motivational problem of students, it does, at the same time, create the need for motivating professors and tutors to act in an orchestrated way to achieve the objectives.

The question of the interaction between the engineer-professor and the scientist-professor is of paramount importance. One of them will have to teach the fundamentals in a rather traditional way, while the other will have to be perfectly informed as to the level at which those fundamentals are being taught, so as to be able to take full advantage of this knowledge while guiding the students in their projects.

Achieving this integration is by no means a trivial task. Nevertheless, it is a challenge probably worth undertaking.

ADDITIONAL ADVANTAGES

In addition to all other points mentioned, this approach to education in basic sciences for engineering students has the advantage of easing the adaptation of five-year engineering schools to the Bologna declaration.

It cannot be denied that there are some concerns, in different parts of the world, about the formation of a bachelor in engineering in three years, particularly if the first two years are entirely devoted to the science-core. A course that offers a hands-on opportunity for problem solving in engineering might be extremely useful under the circumstances.

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