HOW TO INVOLVE FACULTY IN EFFECTIVE TEACHING

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The rapid social and economic changes in the world today, triggered by the revolution in communication technologies, is leading to a concept of the "global engineer."[1] Institutional efforts have already begun that will induce and accelerate change in engineering education toward this goal.[2-6] A good example is the ABET EC 2000 criteria in the United States.[3] This concern for a change in higher education also exists in the European Union.[2] The key concern is how engineering schools and departments can obtain and maintain the proactive involvement of faculty in such a change.

The purpose of the paper is to analyze the key factors in achieving involvement and active participation of faculty in the conception and implementation of new and effective teaching strategies. We will analyze the impact that a benchmark in cooperative learning implemented at the introductory level in the chemistry program at Tarragona had on faculty involvement fifteen years ago. We will then go on to identify factors responsible for the decline of the professors' interest in effective teaching when the new five-year ChE undergraduate program was introduced in 1993 and will describe the teaching strategies presently underway to recover the holistic approach to ChE education. These specific and open-ended learning experiences managed by professors and students working together in close collaboration include, at the first year of undergraduate education, development of design projects directed by fourth-year students.

EXAMPLE OF FACULTY INVOLVEMENT

Chemical engineering studies were introduced at Tarragona in 1977 as an Industrial (ICh) option in the five-year chemistry program. Students accessed this ICh option after three years of compulsory education in science and mathematics. Chemical engineering was introduced in the third-year course "Fundamentals of Chemical Engineering." The ICh option included a total of five yearly courses in ChE—one in the fourth year and four in the fifth year—together with three yearly courses in advanced chemistry. The "Fundamentals of Chemical Engineering" course was attended by all students enrolled in the chemistry program. The syllabus included two parts: macroscopic mass and energy balances, and transport phenomena and fluid mechanics.

Chemistry students decided whether to choose the ICh option based on their success in the introductory third-year chemical engineering course. In the early eighties, the number of students enrolled in the ICh option showed a systematic tendency to decrease, and enrollment reached a mini-

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mum of four students from a total of forty candidates in 1983. This situation could have ultimately led to the elimination of the ICh option. The faculty then decided to focus attention on the undergraduate program and to adopt a holistic and professional approach to education. It is worth noting that none of the nine faculty members involved in this decision was yet a full professor in 1983 and that seven of these positions were temporary Assistant Professorships, heavily dependent on teaching needs. Thus, the motivation to change learning strategies and course development was high.

> ***The purpose of [this] paper is to analyze the key factors in achieving involvement and active participation of faculty in the conception and implementation of new and effective teaching strategies.***

The first faculty decision was to abandon traditional lecturing so that different learning and teaching styles[7-10] could be implemented in the third-year course. In particular, the strategies and actions that were field tested had the following characteristics:

- *Cooperative learning[11] was introduced because students learn more by doing things than by simply hearing or seeing.[9]*
- *Professors were free to experiment and evaluate different learning strategies, with colleagues and students providing direct feedback.*
- *Contents and the corresponding classwork were structured as a set of activities carried out cooperatively by students[12,13] during three hour-long sessions.*
- *Students decided the objectives of each class session within the framework of the syllabus of the course. In other words, they decided what to do next and how to do it.*
- *Students developed a final design project during the second semester of the course.*
- *A strategy of continuous evaluation, including self-assessment, was introduced in some activities to enhance students' involvement in the class sessions.*

Implementation of the above characteristics into the "Fundamentals of Chemical Engineering" course favored the adoption of metacognitive learning strategies.[14-17] For example, students had to comprehend the demands of a given task and to respond to them during development of the different classroom activities. Students were responsible for their own learning and learned how to learn, *i.e,* they recognized and controlled the learning opportunities and became aware of their own learning activities. This experience also helped them to develop other competencies such as creative thinking, work interdependence with personal accountability, individual responsibility, self-esteem, communication skills, and sharing the values of the organization. Students also developed the desire to learn continuously and to grow professionally in a multidisciplinary environment, not only in technical and scientific areas but also socially and in humanities.

The decision to adopt a student-centered educational model,[17] together with cooperation from students in this educational effort, had a remarkable impact on the student body as a whole. The percentage of students choosing the ICh option reached, and even surpassed, the levels before the enrollment crisis, finding a stable plateau around 75%. Another relevant effect was an increase in the performance of students while at the university and after graduation. Our graduates became the preferred choice of employers at the chemical and petrochemical sites located near Tarragona, and today, many of them occupy positions of responsibility in various world-class companies.

The third-year course also induced professors to experiment with different teaching strategies. Teaching the course jointly with more experienced professors became the training policy until 1993 when the new five-year undergraduate chemical engineering program was implemented. During the ten-year period from 1983 to 1993, seven professors out of the eleven that constituted the faculty participated in the initiative, and two-thirds of those actively involved in the initiative exported the model of cooperative learning to other courses taught in the last two years of the ICh option. Therefore, the prospects for continuous improvement of ChE education in Tarragona were excellent just before the new program started in 1993.

BACK TO TRADITIONAL EDUCATION

The New ChE Program • The new ChE Program generated high social expectations in Catalonia in 1993. This, together with the favorable evaluation of our ICh graduates by industry, conveyed a perception among faculty that everything related to academia would improve continuously, by itself, as a result of the previous momentum. The following factors were considered particularly relevant for the initial success of our new undergraduate offer and academic organization:

- *The design and deployment of a ChE undergraduate program attractive to students, employees, and the administration. The new studies were modeled after the most successful programs in North America and Europe, with input from world-class chemical companies and a reliance on our previous educational experiences.*
- *The segregation of a Department of Mechanical Engineering from the original Chemical Engineering Department, and the creation of a School of Chemical Engineering (ETSEQ) to provide the necessary visibility for the unique engineering educational project. A*

quality program was simultaneously launched to continuously improve the organization.

- *The hiring of young professors educated abroad and interested in excellence in research, undergraduate education, and transfer of technology to industry. The ChE department at Tarragona was the first in Spain to hire citizens from other European countries as professors.*
- *Transformation of the graduate school to offer an international doctoral program in chemical engineering.*
- *The assignment of the first-year engineering science courses to the most experienced professors, with the purpose of reproducing throughout the academic organization of the ETSEQ, the student-centered approach to ChE education achieved in the old ICh option.*

The design of the new program started in 1987, five years before the Spanish government established chemical engineering as a separate undergraduate program and degree. A semester organization was adopted, with 55% of credits corresponding to regular classroom hours and the remaining 45% to laboratories, modeling and computer simulations, research and development projects, or internships in industry. The main characteristics are summarized in Table 1. Students learn physics, chemistry, mathematics, and engineering science during a first two-year cycle of undergraduate education and apply this fundamental knowledge to real problems, with emphasis on process downscaling. The objective of the third year is process upscaling because it is the core of engineering practice and technology development. The last two years bridge fundamental education with professional practice. This academic organization allows the adoption of Bloom's taxonomy of educational objectives.[18] Students advance from comprehension to analysis and synthesis of the essential scientific and engineering concepts in a smooth and continuous manner within each year of study and over the five years of the program.

The start of the new program in the fall of 1993 significantly increased the teaching load in chemical and mechanical engineering, and new faculty positions were opened to citizens of the European Union. Since that time, all new faculty positions have been advertised in international engineering journals. This new employment policy was later complemented with a continuing-education program aimed at all faculty. It consisted of seminars, courses, and workshops conducted by specialists from North America and Europe on topics such as learning strategies, cooperative learning, communication skills, project management, and quality in education. Most of these on-the-job training activities are also open to staff and to graduate students. Courses in Spanish and the Catalan language are also offered by the university to help new faculty.

Lessons To Be Learned • The above undergraduate ChE program features the most widespread methods of learning activities applied in chemical engineering education, with project-oriented capstone courses, short stays in university research laboratories, and industrial placement. Nevertheless, the first evaluation carried out in 1995, two years after the start of the new program, showed student retention of only 60%, lower than expected. In addition, most teaching had reverted to lecturing.

The return to traditional lecturing by both new faculty and the professors who had previously experienced cooperative learning was taken very seriously by the heads of the two departments involved because the success of cooperative learning and of any other innovative educational method can be fully attained only when they are applied continuously and systematically in an undergraduate program. We cannot expect to move from the professor-directed and professor-centered model of education toward student-centered instruction[7] just by endowing a few scattered courses with active learning. An undergraduate chemical engineering program should offer individual students the possibility of experiencing their own approaches to learning, to develop engineering and cognitive skills, and thus to become fully accountable for, and have ownership in, all organizational processes that are relevant to corporate life or to commercial organizations.[5,6] Moreover, deficiencies accumulated in such areas during undergraduate education are difficult to address after graduation by continuous on-the-job training, since corporations are reluctant to take unnecessary risks and dedicate resources to nonspecific training programs.

There are several factors that explain the return to traditional education at ETSEQ after the new program was implemented:

- *Faculty lost focus in education due to the extra effort*

TABLE 1
Summary of Contents, Present ChE Program

First and Second Years
Introduction to ChE and Process Downscaling
- Chemical Engineering and Physics (20%)
- Chemistry (9%)
- Mathematics (6%)
- Elective courses in science, mathematics and engineering (2.5%)
- Elective courses in arts and social sciences (2.5%)

Third and Fourth Years
Process Upscaling and Creative Management
- Chemical Engineering (25%)
- Elective courses in science, mathematics, and engineering (10%)
- Elective courses in arts and social sciences (5%)

Fifth Year
Professional Practice and Internship in Industry
- Internship in industry, R&D, and final project (15%)
- Elective courses in science and engineering (2.5%)
- Elective courses in arts and social sciences (2.5%)

required by implementation.

- *The student/faculty ratio increased without augmenting the population of candidates and the standard of selected students. Under these circumstances there is a natural tendency to do whatever is more usual and easier, which in education means lecturing.*
- *The success inherent to implementation of the new program could have contributed to the perception among faculty that there was no further need to procure social recognition and support.*
- *The shift of faculty interests toward research instead of excellence in education, caused by a governmental promotion policy based solely on research productivity.*
- *The tremendous increase in the number of professors in chemical and mechanical engineering, together with the incorporation of professors from other departments to teach mathematics, chemistry, economics, and computer science, made coordinating and sharing experiences more difficult. Also, it was hard to maintain the notion that faculty must act as a team[19] and service the department through education and research, much as we expect our students to work and cooperate efficiently in teams.*
- *The incorporation of young professors with a different organizational culture was perceived as a loss of identity by some faculty, and a natural fear of change appeared in the organization. It should be noted that despite the interest of new faculty in education, they did not receive any training of effective teaching until 1996.*

Nevertheless, consideration and discussion among faculty of all these factors was not sufficient to adopt corrective actions and to substitute a significant percentage of lecturing with other more efficient teaching strategies in 1995. As a consequence, the former holistic approach of ChE education experienced in the ICh option[12,13] was re-examined to identify the key elements that made this previous organization successful and sustainable. Then new elements were considered in view of the situation created by the new program, and finally, corrective actions were taken. The following section presents these analyses and the corrective actions, in addition to the results obtained.

A SUSTAINABLE AND INNOVATIVE SYSTEM

Key Elements • The above considerations led to the following synthesis of key elements to sustain cooperative learning and faculty involvement:

- *The holistic approach adopted in the old ICh option was a shared learning opportunity for both students and professors, with everyone assuming responsibilities.*
- *Professors experienced different learning strategies and became confident about effective teaching.*
- *Students felt they were a part of the organization and of the decision-making process, with the only limitations being imposed by the syllabus of the course.*
- *Professor and students alike were actively and personally involved in all classroom activities.*

In fact, these factors implied incorporation of the Kolb learning cycle[9] into the professor's training process, in a learning-to-learn hands-on classroom experience. The professors involved in the old ICh option were capable of generating new concepts from observing the students working in teams as they advanced in the series of classroom activities that constituted the course. From this new evidence, both professors and students created additional actions and learning experiences. Thus, the learning cycle advanced naturally in the course and improved the metacognitive skills to learning[14-17] of all involved. Also, a deep approach to learning[9] was favored. The experimental character of the course, blended by the holistic approach to engineering education, and a decision-making process shared by professors and students constituted the core of the above four key elements.

Once the key factors of the previous experience had been identified, the question was how to implement cooperative learning and the holistic approach in the new program. How could lectures and classroom activities scattered over several one-semester courses taught by senior and junior staff from different departments be integrated into one single educational effort? How could we reintroduce the Kolb learning cycle into the classroom so that professors and students become confident in their everyday learning-to-learn experience? How could faculty recover the motivation to act as a team interested in both education and research?

Holistic Approach Within the Academic Organization • Two fundamental actions were taken during the academic years of 1995 through 1998 to reintroduce the holistic approach to student-centered engineering education[12,13] and to recover the sense of teamwork among faculty. One-semester design projects, carried out by teams of first-year students led by junior or senior students, were introduced, and a continuous-improvement quality program was begun. In what follows, only the introduction of the design projects is presented and discussed.

The first-year design project had the following objectives:

- *To redeploy cooperative learning in the organization as a whole.*
- *To enhance students' responsibilities in the decision-making processes.*
- *To include open-ended problems where professors do not have the only solution.*
- *To integrate knowledge; students should be immersed*

in a multidisciplinary and humanistic educational environment.

- *To use faculty as a team; professors should be encouraged to cooperate and innovate.*
- *To enhance junior and/or senior students' role in the educational organization; students should learn to lead a project, to share the culture of the organization, and to perform professional tasks while at the university.*
- *To teach ChE students to think and to work as engineers and to use the highest cognitive levels of Bloom's taxonomy from the beginning of their education.*
- *To use it as a test for evolution toward a new organization of the curriculum in Tarragona; the test should lead to a student-centered, sustainable educational system.*
- *To foster synergetic learning and metacognition where students help other students to learn; junior and/or senior students also learn when coaching first-year students.*

From an organization point of view, execution of the project required severing class hours from the participating courses so the total teaching load per semester was not increased. The scope of the project had to be concrete, but open enough to allow the eventual integration of almost all subjects and to secure the interest of the professors. Three trials were carried out during the second semester of the first year over the period from 1995 to 1998. Table 2 summarizes the academic organization under which these trials were executed.

The first project dealt with the design of a craft oven and integrated only the first-year courses of transport phenomena and fluid mechanics (see Table 3). These projects were directed by third-years students as part of their work in the unit operations laboratory. The second trial integrated the transport phenomena laboratory course with teams of first-years students led by fourth-year students enrolled in project management and management practice courses. The project dealt with the catalytic conversion of the lactose contained in a water effluent from a dairy factory into glucose and galactose. The teams presented their results during two poster sessions at the end of the semester. The third test involved four first-year courses, with the addition of numerical methods, and two fourth-year courses, as shown in Table 2. A total of 145 first-year students, organized into groups of five, were directed by 29 fourth-year students to develop the preliminary design of a low-density polyethylene plant.

The third trial received good evaluations from all. Also, faculty members were asked to participate in the poster presentations to get acquainted with the new project system. As a result, the implementation scheduled for 1998-99 will cover a total of 13 courses and 16 faculty members (see Tables 2 and 3). Three hours per week will correspond to face-to-face teamwork of first- and fourth-year students in the classroom. During the remaining hours assigned to the project, first-year students will work on their own but with access to the professors for consultation.

TABLE 2
Summary of Student-Directed Design Projects

	First Trial	Second Trial	Third Trial	Implementation
topic	Craft oven	Lactose Recovery Plant	Polyethylene Reactor	Industrial Waste Treatment Plant
class hours/week	1	2	4	6
% of project in first year	20	40	50	50
coach	3rd-yr student	4th-yr student	4th-yr student	4th-yr student
subjects involved in first year	2	3	4	8
subjects involved in fourth year	1*	2	2	5
professors involved	3	5	8	16
teams	21	23	29	35
students/team	5-6	5-6	5	4

* *Third-year subject*

TABLE 3
First- and Fourth-Year Subjects in Current Program (Hours/Week)

First year - First semester	First year - Second semester	Fourth year - First semester	Fourth year - Second semester
Algebra - 3	**Statistics -3**	**Process Manufact. & Control Lab - 8**	**Chemical Process Design - 4**
Calculus - 6	**Transport Phenomena - 4 (2+2*)**	**Electives - 8**	**Economy & Industrial Organization - 4**
Physics - 6 (4+2*)	**Fluid Mechanics - 4 (2+2*)**	**Project Management - 4 (2+2*)**	**Project Management Practice II - 4 (1+3†)***
Chem. Eng. Funds. - 4 (2+2*)	**Transport Phenomena Lab - 7 (6+1*)**	**Project Management Practice I - 4(1+3†)***	**Environmental Technology - 4 (2+2*)**
Physical Chemistry - 4 (3+1*)	**Numerical Methods - 3 (2+1*)**	**Convective Heat/Mass Transfer - 4 (2+2*)**	**Electives - 12**
Inorganic Chemistry - 4 (3+1*)	**Analytical Chemistry - 4**		

* *hours/week assigned to design project*
† *hours/week of face-to-face teamwork*

The progression experienced in the degree of professors' involvement has encouraged ETSEQ to test the same organization in the second year of undergraduate education. This trial will be carried out with the participation of 7 subjects and 6 professors. The second-year preliminary design project will emphasize process downscaling and will be organized around the two-semester chemical engineering laboratory.

A direct benefit from the experience is that we have reproduced, on a larger scale, the model of education that was successful in the old ICh option. Professors become sponsors of cooperative learning and perform as consultants, and their curiosity is enhanced because they are faced with real and interesting problems. As a consequence, we are involving professors to a higher degree than before, and students are learning what chemical engineering is all about from the first year of their undergraduate education. From an educational point of view, the project experience is a good example of learning synergism; first- and fourth-year students cooperate in their own instruction and are learning together. First-year students (with the help of fourth-year students) act as team leaders and coaches, apply knowledge to a real problem, develop their competency and skill, and learn how to learn and how to cooperate with peers. Fourth-year students integrate into the academic organization by assuming specific responsibilities and by acting as project managers. They reinforce their own learning-to-learn strategies when confronted with a teaching responsibility beyond simple tutoring experiences. The opportunity to re-examine fundamental subjects or topics, to define strategies to help first-year students overcome their learning difficulties, and to manage a real project until completion are also invaluable professional assets related to team management and organizational behavior.

CONCLUDING REMARKS

Altogether, our experience indicates that professors have a natural tendency to teach by lecturing since that is how they were taught. The yearly design projects compel professors, otherwise isolated in teaching their courses, to cooperate with other faculty and with students. This new holistic approach represents a benchmark where professors can continuously experience effective teaching and innovation in education. The strategies have also contributed to their personal and professional development.

The current study shows the benefits of incorporating student-centered learning into classroom instruction, the difficulties of doing so, and the ease of reverting to more traditional and less effective approaches when emphasis on effective teaching is relaxed. Also, it is shown that the holistic approach, with first-year students working in projects led by junior or senior students, can be easily extended to full-scale curriculum improvement throughout an academic organization. The outburst of creativity and participation that was attained fifteen years ago at Tarragona has been revived.

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