

A HOLISTIC APPROACH TO ChE EDUCATION

Part 1. Professional and Issue-Oriented Approach^[1]

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Most chemical engineering education is delivered in a conventional three-mode structure of lectures, supervised problem-solving sessions, and predefined experimental work in the laboratory. In some cases these activities are combined in an integrated approach, strengthened by a variety of classroom organizations, and complemented with extracurricular activities by faculty concerned about ways to increase students' perceptions of the importance of effective human interactions in the engineering profession.^[1] This approach has been generally accepted because it produces engineers who are knowledgeable about existing technology. Employers have overcome any lack of necessary skills and/or professional orientation of new employees through additional on-the-job training. It has been estimated that it takes two years after schooling for a graduate to become a fully effective engineer.^[2]

Past concerns of the chemical industry about the need to change undergraduate engineering education^[3] have increased recently because organizational behavior is affected by the rapidly occurring technological changes. Also, industries must implement these changes while at the same time remaining competitive in a global market strongly influenced by societal issues.

There has been ample documentation^[2,4,5] that even well-trained graduating engineers sometimes lack the skill and experience to apply their knowledge in a way that contributes to the solving of an actual problem, whether it be on an individual basis or in a group situation. One possible explanation is the fact that traditional engineering education is an *artificial process*—the students are passive, listening subjects who memorize individual facts and technical procedures taught in separate courses; they are seldom encour-

aged to ask questions or analyze available evidence.

Students first learn the basic sciences and mathematics that are necessary for understanding engineering principles and processes. Then, if they want to become chemical engineers they study, for example, various principles and operations used to change raw materials into useful products. In this context, a chemical engineer can be considered an expert in the calculations, design, construction, and operation of equipment or installations where matter undergoes a change of state, energy, or composition. Understanding topics such as thermodynamics and kinetics, the physico-chemical properties of matter, heat transfer and fluid flow, etc., is essential to their success.

In our traditional artificial approach, each of these topics is studied as a separate discipline, taught by professors who are experts in their field. The implied assumption is that if a student understands the various individual subject principles

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... concerns about the real-world problems in engineering education suggest the possibility of taking a more professional and issue-oriented holistic or integrated approach to engineering education. This does not mean simply incorporating a project or a research period into the standard course . . . , but rather signifies a total reorganization of the approach to instruction and assessment.

and processes, he or she will be able to apply them to real-world problems—the essence of engineering. Feedback from the real world where these engineers go to practice their craft, however, indicates that initially they are not very efficient in synthesizing what they have learned into an integrated approach to solving a problem.

Also, our synthetic approach to engineering education focuses on the role of the individual student as learner and practitioner since each individual is evaluated separately and the goal is to do better on an individual basis. Rhinehart substantiates these points of view.^[6,7] This individual focus is quite different from the actual practice of engineering today where group efforts are common and an individual with expertise in a specific field contributes to the solving of an interdisciplinary problem.

The need to modify the traditional lecture approach has become more apparent in recent years. We increasingly expect today's engineer to deal effectively with the environmental and other public policy issues that are an integral part of modern engineering activity. This, in turn, demands a capacity to synthesize one's thinking since the engineer must go beyond the science and at least be cognizant of the public policy issues involved in his or her work. These concerns about the real-world problems in engineering education suggest the possibility of taking a more *professional and issue-oriented holistic or integrated approach* to some or all of engineering education. This does not mean simply incorporating a project or a research period into the standard course as suggested by many (see, for example, Miller and Petrich^[8]), but rather signifies a total reorganization of the approach to instruction and assessment.

The chemical engineering faculty of the former University of Barcelona in Tarragona, Catalunya, Spain, decided in 1985 to fully implement a holistic approach in an introductory chemical engineering major taught in the college of chemistry. One reason for accepting the challenge of changing educational methodologies at that time was a diminishing interest of the students enrolled in the College of Chemistry toward chemical engineering.

The introductory course was organized around a theme, such as the preliminary design of a chemical plant. Students focused their attention on several issues of engineering and societal interest that could be analyzed while learning the basic principles of chemical processes, unit operations, and transport phenomena. A cooperative goal structure was adopted as the basic instructional method for the course since cooperation is most effectively used for learning con-

ceptual and theoretical skills, for open-ended problem solving, for reasoning assignments, and for problems involving technology and society,^[9,10] A description of the basic elements of cooperative learning may be found elsewhere.^[11-15]

The specific methodological objectives were to

- ❖ *Incorporate practicing-engineer skills and public-policy issues into the first course where basic chemical engineering principles are taught*
- ❖ *Integrate effective project management and relevant behavioral experiences into the classroom via cooperative group learning^[6,11]*
- ❖ *Introduce decision making and work interdependence as the basis for achieving the two previous goals^[9,10]*
- ❖ *Prepare students for a commitment to continuing education throughout their professional life*
- ❖ *Involve chemical engineering faculty, as well as staff from industry, in this educational effort*
- ❖ *Encourage both students and professors to have fun in this challenging and responsible learning environment^[11,16]*

The introductory course was also designed to illustrate the roles of and opportunities for chemical engineers, while at the same time providing a perspective for subsequent classes.^[8] In addition, it considered environmental issues as part of the everyday practice of chemical engineering.^[17,18]

The following sections describe the organization of the course, the procedures we followed, and the opinions of the faculty and industry with respect to the results of the holistic approach adopted. The specific guidelines and evaluation, along with the students' opinions of the course, will be presented in the second installment of this paper to be published in the next issue of *CEE*.

ORGANIZATION

The content of the course and all class work were organized into several activities. The modular structure facilitates an educational approach tailored to the student's needs (which may change every year). It also encourages the participation of these students in deciding their own objectives, *i.e.*, students assume responsibility for their own learning when defining the course activities and deciding their goals. This latter aspect is very important because the course is intended to be a simulation of real workplace situations that most practicing engineers face in industry.

Within this framework, students can learn the process of asking questions—the basic scientific and technological approach for discovery and understanding. Also, learning new concepts and skills when the need arises rather than in a predetermined sequence favors student motivation and the learning process itself. Simulating a real daily workplace environment requires a non-standard schedule for the course. Since the students are no longer passive receptors, weekly class work was usually carried out in two separate sessions of three and two hours, respectively. Thus, all activities were developed during one or several class periods or sessions of five hours, with the following organization and characteristics:

- *Activities began and ended with a session. Students played an active role, either individually or as members of a team or group. A combination of individual and team effort was adopted in some activities to emphasize the need for sharing and collaboration with others when moving from a creative to an applied level. The groups were formed by five students (i.e., twelve groups for a class of sixty) or by four members when enrollment was lower.*
- *The decision about what to do next (i.e., asking a pertinent question and defining the objectives of a new activity) was the result of a decision made by the class during the closing discussion of the current activity. Instructors helped students reach a decision by matching the different class requests with the general conceptual framework of the course. Students were not constrained about the type, duration, and number of activities to carry out, but were encouraged to be specific and realistic in setting their common goals.*
- *The instructors involved in the course, the professors, and the teaching assistants met weekly to plan the development of each new activity as well as to correct time deviations as necessary. Also, the need for complementary seminars and/or lectures was determined and the corresponding time was allocated according to the depth of analysis expected by the instructors for that particular activity.*
- *Students had access to resources outside the classroom to encourage individual or team use of whatever was required to continue asking more and more questions about a given problem or situation. Those resources included the departmental library, computer rooms, other faculty members, industrial staff, and laboratories during pre-scheduled periods each semester. Library access was necessary since no specific textbooks were recommended for this course.*

- *Laboratory work was not a separate entity from the class work. About half of the experimental work was pre-programmed by the instructors and was carried out by all students either in the laboratory or in the field. The other half was used by each group of students to complement their class work, following an integrated approach.^[19] Students were encouraged to experimentally verify published data or to explore new subjects by using innovative research approaches.^[4]*

A detailed description of the guidelines and activities of the introductory chemical engineering course taught at Tarragona will be given in the second installment of this paper. Activities always began with a general question: *i.e.*, Will the chemical plant require external energy supplies? During the development of the activity this initial question would be followed by more specific questions, such as: Which equipment and/or operations will be donors or receptors of energy? Therefore, work aimed at asking further questions was carried out by teams (or in some specific cases by individuals) using available technical information and under the supervision of the group leader. Before the activity and the class session ended, group leaders handed in a report to the professor covering all the work done and the performance of group members.

One-third of the leaders then gave short oral presentations (five minutes each), in a rotary fashion, reporting the results and conclusions reached by their teams. This was followed by a closing discussion that allowed us to reach common conclusions and to propose the next activity. With this information the instructors outlined the worksheet for the next activity, specifying its main goal, the procedures, and the rules (see, for example, Goldstein^[13]). This was handed to each student or group leader at the beginning of the next session when the new activity started.

PROCEDURES

Individual and Teamwork

The main objective of organizing the classroom into groups was to create a learning opportunity where professional and behavioral values could come into play. It is well known that teamwork facilitates learning the skills necessary for dealing with real engineering situations.^[10] This type of organization smooths the future integration of a junior engineer into a corporate culture. In addition, issue-oriented engineering education (*e.g.*, education related to societal issues), is best performed when students assume responsibility for learning and participate in decision making so that they can become a part of role-taking and role-playing under a variety of circumstances.

The transmission of old knowledge to students in the traditional approach to education does not favor creative thinking,^[11,15] self-reliance, or cooperation. For example,

creativity is fostered by openness to experience and questioning.^[20] Individuals who are open to experience can deal with open questions, (*i.e.*, those with conflicting information and ambiguity) with independent thought. Creativity is also fostered by the ability to play (experiment). This explains why new trends in engineering education point toward introducing research in undergraduate engineering education.^[4]

In the present introductory course, the groups were organized so that each had a leader responsible for the work involved and for the presentation of results. All members of each group occupied this position through rotation. During the stage of gathering evidence, the group leader was allowed to assign work to each member or to let each choose the role he or she wanted to take and play, depending on the activity to be carried out and on their preferences and abilities. In any event, all students were supposed to carry out a part of the group's work, to be aware, to understand the work done by the group or by any individual member, and to participate in the process of using all the evidence. When, for any reason, work was not finished during the assigned class sessions, it was completed as homework. This allowed all groups or individuals to proceed at their own optimal learning pace.

This type of organization encourages

- *Implementation of student-centered discussions*^[15]
- *Building a sense of culture and organization*
- *Self-motivation through involvement*
- *Setting up effective communication*^[12] *while establishing and sharing goals, procedures, and rules*
- *Developing ways of seeking, gathering, assessing, and sharing information.*

Also, students made choices, participated in decision making with a creative and critical attitude, and learned how to identify and generate alternatives to a given situation. They experienced the process of continuous learning, which is of more lasting value than specific content in a rapidly changing society.

Once the class had decided on an activity at the end of a class session, the instructors handed in, at the beginning of the next session, a worksheet with the leading question(s), a set of procedures and rules, and a tentative schedule. Then, under the responsible coordination of the group leaders, each team of four to five students:

- *Brainstormed to explore different possibilities, to get ideas and to gain insight about the activity in order to set up appropriate goals.*
- *Identified actions to be undertaken so that tasks and roles could be defined and assigned to group members. Students were encouraged not to repeat*

the same type of task and role in each activity so that they could explore their own abilities.

- *Planned the activity. The importance of work interdependence, collaborative information gathering, and processing to achieve a goal was stressed.*^[10,11,14]
- *Used the information and evidence to attain the objectives of the activity. This step usually required individual efforts by group members working together in the classroom and learning within the team of peers through continuous questioning of each others' results. The instructors and invited lecturers circulated throughout the classroom to discuss issues with each group of students when the need arose, as suggested by Blanks.^[16] The rule in this step is never to ask a question of the professor before the group has thoroughly discussed it.*
- *Prepared the group report and the corresponding oral presentation. The group leader reported to the professor the different roles taken and played by each team member, related any incidents of importance, and gave an evaluation of the work done by the group under his or her coordination.*

A group member evaluation procedure similar to that suggested by Rhinehart^[6] was adopted. The weight of all classroom and laboratory activities, including projects, was 70% of the final grade. The other 30% reflected the ability to solve unknown problems during three open-book tests per semester. A more detailed account of the student grading will also be included in the second part of this paper.

The Role of the Instructors

In a cooperative learning environment the professor creates opportunities or situations where technical skills (or values) and experience come into play (*i.e.*, the professor is mainly a resource^[13,14]). In the educational sense, the professor is a facilitator of learning because he or she sets up learning situations that help students identify what they want and need. In this course the instructors also helped students use all available information as well as any available external resource^[15] so that they could develop technical skills with a creative and critical attitude.^[20] Visits to industry and discussions with technical staff there were common. The professor was no longer an infallible expert who "knows everything" but instead, was merely a person who may not know everything the students wanted to learn or needed to know during the course.

The professor operated in the classroom environment according to the values (skills) he or she planned to teach. As a part-time researcher, he or she is knowledgeable about scientific methodologies and values through having applied them in everyday experimental work. A researcher learns by

asking pertinent questions when facing any real-life scientific and/or technological problem. Since this is so, research becomes an integral part of classroom activity and the methodology applied is coherent with the nature of the subject being learned. At times the professor acted as a project manager or supervisor, and at other times as an external consultant when professional values came into play.

The instructors also dispensed knowledge to single groups or to the whole class as a response to student requests, or helped the students learn by structuring situations. A listening-only type of situation was thus avoided and students assumed full responsibility for their own learning. Experts in the specific topic being treated were invited to participate and discuss with the class any additional information required to complete the group activity or project. This also enabled other faculty and professionals working in industry to get to know students in advance, and vice versa, while students in turn had the opportunity to experience various professional approaches to some specific engineering problems.

A general and exhaustive overview of the instructor's role is given by Johnson, *et al.*^[14] It should be noted that in this course, the students assume responsibility for their own learning through defining the activities and their goals, planning materials, assigning roles, and sharing with the instructors the evaluation of the completion of tasks, among other things.

RESULTS

Faculty who taught engineering courses to these students in the following years felt that the students knew "less" contents than before, when the traditional approach to teaching was used, but that they were able to handle new learning situations with greater success. Also, they reported that the attitude of the students was more open and interactive than it had been in previous classes. The students' final performance, based on knowledge, seemed comparable. As a result of the present initiative, teaching of other chemical engineering courses has also been progressively modified to integrate some of the methodologies and procedures mentioned above.

The personnel departments of the most important chemical manufacturers in the area of Tarragona (such as Dow Chemical, Repsol, Hoechst Iberica, BASF, Bayer, ASES, and Shell) have expressed the opinion that under real situations those students who took the holistic-approach course perform best. Also, their integration within a given corporate culture is accomplished smoothly and in a shorter period of time. The Chemical Manufacturers Association of Tarragona has collaborated with the present initiative by offering resources (visits, seminars, etc.) to the classroom. As a result of this partnership and the change in educational approach, the number of chemical engineering students hired from our University during the past five years has been one

of the highest among Spanish engineering schools.

Departmental concern about preparing undergraduate students for the rich world of engineering led to the initiation of new educational experiences. Sustained student enrollment during eight years, faculty and industry involvement in the teaching, and industrial interest in hiring the graduates has proven that a professional and issue-oriented approach to higher education is effective in preparing students for the technical and societal complexities of present and future times. We were also very pleased to find that initiating this course motivated students to elect chemical engineering as a profession and significantly increased enrollment. The number of women enrolled in engineering and graduating with majors in chemical engineering also increased, from 10% to 35%.

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TROUBLESHOOTING IN UNIT OPS

Continued from page 121.

et al.^[19]); developing general troubleshooting charts for a given apparatus (such as those provided with most household appliances, particularly electronics); or instructing the students to develop their own troubleshooting experiments to reinforce what they have learned through application^[16] (and to provide experiments for future classes).

The troubleshooting type of experiment is an excellent method of improving the unit operations laboratory by providing an opportunity for students to develop and apply their problem-solving skills to realistic problems. I have found that this type of experiment adds enjoyment to the laboratory experience for the students and for the instructor.

Perhaps the best advice that I can give to anyone interested in using troubleshooting experiments is to assign meaningful problems—then stay out of the students' way except to provide occasional guidance and encouragement. The challenge of the experiments and the students' interest in applying their skills in realistic situations will ensure a rewarding educational experience.

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NOTATION

- D Impeller diameter (m)
 d_p Particle diameter (m)
 g Acceleration of gravity (m/s^2)
 N_{js} Just-suspended agitation speed (s^{-1})
 S Proportionality constant
 X Solids loading in slurry (solid weight/liquid weight)
 ν Liquid kinematic viscosity (m^2/s)
 ρ_l Liquid density (kg/m^3)
 ρ_s Solid density (kg/m^3)

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