Structuring Learning Goals To Meet the Goals of Engineering Education

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The growing concern about engineering education in the United States has been the subject of many recent editorials and articles.* They point to the deteriorating quality of engineering and science education, the lack of adequate preparation in mathematics and science on the part of high school graduates, the shortage of engineers, and, especially, the shortage of college teachers of engineering. Unless corrective measures are taken, it may be more difficult in the coming years to achieve the goals of engineering education and to meet the needs of engineering students.

Goals of Engineering Education

The three major goals of engineering education are to promote technological, interpersonal, and social-technical competencies in engineering students. The achievement of *technological competence* requires the mastery and retention of science and engineering facts, principles, theories and analytical skills; the development of synthesis, design, modeling and problem solving skills; and the development of implementation skills for converting knowledge into action.

Interpersonal competence requires the development of the cognitive, affective and behavioral prerequisites for working with others to perform a task.[1] Among the skills required are communication, constructive conflict management, interpersonal problem solving, joint decision making and perspective-taking skills. Interpersonal competence is becoming increasingly important for engineers due to the tremendous technical complexity and the societal constraints of most problems. Engineers must now, more than ever, work with other engineers and scientists, economists, educators, consumer groups, and government regulatory agencies to reach satisfactory and mutually acceptable designs for future technology.

Social-technical competence requires gaining an understanding of the complex interdependencies between technology and society, of the influence of technology on individual and collective behavior and on the natural environment. Essentially, social-technical competence involves perspective-taking on a large scale that encompasses historical, social, psychological, and philosophical viewpoints, as well as an understanding of the basic premises underlying the interaction between society and technology.

Needs of Engineering Graduates

Many studies have been conducted on engineering education since it began at West Point in 1792, and these have been well summarized.[2] The earliest study (by Mann in 1918) called for a return to the basics; each of the subsequent ones emphasized diversity and a broad education,[3] and their general findings have been summarized by Cheit[4] in the following three statements:

1) There is renewed concern that, despite many efforts, engineering education is not yet incorporating what is called the "humanistic-social," "liberal," or "general" parts of the students' education.

2) Engineering education must be more broadly applied, that is, engineers must build bridges between science and the needs of society.

3) Engineers must be made decision makers, since, despite the growing importance of engineering to American life, engineers have not taken a correspondingly important part in the decision-making process.

The recommendations of these studies are similar and recurrent, but the need for change in engineering education remains. Currently, there appears to be a move away from the image of applied science in engineering education.[5] The basis of this apparent change is the growing realization that technological and economic feasibility are not the sole or even the main determinants of what engineers do. Ecological, social, cultural, psychological and political influences are equally important.

The results of the major studies of engineering education tie in closely with the need for developing social-technical competence and interpersonal competence in engineering graduates. Supporting this need, a major study at the University of California, Los Angeles, concluded that every engineering graduate must be capable of communicating with and working with people of other professions to solve the inter-

*See, for example, recent issues of *Engineering Education* (e.g., April 1981) and *Science* (e.g., "Trouble in Science & Engineering Education," by J. Walsh, vol. 200, no. 4470, 1980.)

disciplinary problems of society.[6]

Recent assessments have elaborated on the need for innovation and change in the areas of complex problem solving and design;[7-9] interpersonal competence;[10-12] social-technical awareness;[7,8,12-14] experiential learning and clinical experience;[5,15-17] decision-making skills[5,9,18] and autonomy and teamwork.[8] The essence of these assessments is the incorporation of interpersonal competence development and social-technical competence development in engineering education.

Additional support for the importance of interpersonal competence for engineering graduates is derived from studies by Muchansky and Harrisberger. These studies were designed to ascertain the important learning outcomes of engineering education. Muchansky[19] studied the importance of personal characteristics in performing engineering jobs as ranked by recent graduates and their supervisors. The supervisors' mean ranking in declining order was: practical judgment, interpersonal competence, oral communication, managerial skills, precision-care, written communication, understanding problem-solving methods, scientific-technical knowledge, persuasiveness, and creativity-originality. The students' rankings were similar except that they ranked persuasiveness slightly higher and precision-care slightly lower. Muchansky's analysis of these performance ratings[20] revealed that interpersonal relations ability accounted for 32.2 percent of the variance, technical ability accounted for 25.3 percent, and 42.5 percent of the variance was unaccounted for. Harrisberger[21,22] obtained a ranking of the importance of various learning outcomes during a study of experiential education at five engineering schools. These rankings were completed by students, faculty, administrators and, in some cases, alumni. The average of all rankings for all institutions in declining order was: problem-solving skills, engineering judgment, communicative skills, engineering fundamentals, planning skills, technical skills, interpersonal awareness, professional ethics, organizational skills, self-confidence building, creative expression, leadership skills, and computational skills.

In addition to the already heavily emphasized technological competency, engineers need to be trained to be interpersonally competent and social-technically aware. Mastery of the three competency areas—technical, interpersonal, and social-technical—constitutes the requisites of a well-educated professional engineer. This is clearly stated by Grinter:

> He must be not only a competent professional engineer, but also an informed and participating citizen, and a person whose living expresses high cultural values and moral standards. Thus, the competent engineer needs understanding and appreciation in the humanities and in the social sciences as much as in his own field of engineering. He needs to be able to deal with the economic, social, and human factors of his professional problems. His facility with, and understanding of, ideas in the fields of humanities and social sciences not only provide an essential contribution to his professional engineering work, but also contribute to his success as a citizen and the enrichment and meaning of his life as an individual.[3] (p. 35)

Instructional Methods

The goal of engineering education is to develop skilled, professional engineers. This requires building students' mastery of the three competencies. Clearly, a single course or a series of courses cannot achieve this goal. Considering the alleged shortage of engineering educators, engineering training programs must either curtail enrollments or find ways to teach more to students with fewer faculty. Given the demand for engineers, the latter seems the preferred approach. There is a pressing need, therefore, for instructional methods that simultaneously promote, in any engineering course, technological, interpersonal, and social-technical competencies. While engineering students are mastering technological skills they need to be interacting with each other in ways that also promote interpersonal and social-technical competencies. This may be accomplished through the systematic use of instructional goal structures.

Instructional Goal Structures

There are three alternative ways of structuring learning goals in engineering courses:[23-25] cooperative, competitive, and individualistic. A *cooperative* goal structure exists when there is a positive correlation among students' goal attainments; that is, when students perceive that they can obtain their goal if and only if the other students with whom they are cooperatively linked attain their goals. An example of a cooperative goal structure would be students working together on a circuit design problem in electrical engineering. The instructor would assign students to small learning groups, set a group goal of arriving at one answer that all members can explain, and specify a criterion-referenced evaluation procedure. All members would be expected to participate and master the information and procedures needed to solve the assigned problems.

A *competitive* goal structure exists when there is a negative correlation among students' goal attainments; that is, when students perceive that they can obtain their goal only if the other students with whom they are linked fail to obtain their goals. An example of a competitive goal structure would be an instructor giving a chemistry examination and assigning the goal of each student trying to outperform the other students on the test, with the instructor using a norm-referenced evaluation procedure and rewarding the students who scored the highest on the examination.

An *individualistic* goal structure exists when there is no correlation among students' goal attainments; that is, when students perceive that obtaining their goal is unrelated to the goal achievement of other students. An example would be assigning a series of problems in engineering mechanics, setting a goal of preset criteria of excellence, using a criterion-referenced evaluation sys-

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tem, and rewarding each student who achieved up to the criteria.

There is considerable research comparing the relative impact of the three structures on instructional outcomes. This research will be reviewed below. The competitive and individualistic goal structures have been extensively used and researched in engineering education, while the cooperative goal structure has been under-used and ignored. There are appropriate conditions under which each goal structure should be used, and engineering educators will want to make a rational and informed choice as to which to use in any given instructional situation. Cooperation should not be ignored in making such choices.

Research on Instructional Goal Structures

Dubin and Taveggia[26] state that the instructional method makes no difference in students' performance on factual examinations. Re-analysis of these results has shown, however, that discussion methods resulted in greater retention and high-level thinking skills, and more positive attitudes and motivation than did lecture methods.[27, 28] Similar advantages have been shown for student-centered discussion over instructor-centered discussion.[27]

Much attention has been given to individualized methods of instruction in engineering education and much support has been presented for this method.[29, 30] Although the individualized methods of instruction may facilitate performance more than do lecture methods, both individualized and lecture methods minimize interaction among students and, as a result, make poor use of the resources of the students.

The research on instructional methods in engineering education has focused on teacher-student interaction (lecture method) and on student-material interaction (individualistic). Little emphasis has been placed on student-student interaction (cooperation). The lecture and individualistic instructional methods affect student-student interaction indirectly since they eliminate it.

The type of interdependence teachers structure among students will determine how students interact with each other and with the teacher. These interaction patterns, in turn, will determine the cognitive and affective outcomes of instruction. A great deal of research has been done on the relationship between cooperative, competitive and individualistic goal structures, and the cognitive and affective outcomes of instruction, and it has been summarized.[24, 31-34] A brief summary of the important outcomes for engineering education follows.

Technological competence. Since 1924 there have been over 122 research studies on the effects of goal structures on learning and the retention of information and skills. A recent review[35] of these studies used three meta-analytic procedures. The results indicate that cooperative learning procedures promote considerably greater comprehension, mastery and retention than do competitive and individualistic learning situations. These results hold for all age levels, for all subject areas, and for tasks involving concept attainment, verbal problem-solving, categorizing, spatial problem-solving, retention and memory, motor performance and guessing-judging-predicting. For rote-decoding and correcting tasks, cooperation does not seem to be superior or inferior. The average student in a cooperative situation performs at approximately the eightieth percentile of students in competitive and individualistic situations. When an engineering educator wishes students to master and retain important material, using cooperative instructional procedures is preferred. Greater technological competence by more students may be promoted through the increased use of such procedures.

Interpersonal competence. Besides being competent technologically, engineers need to be competent in all the interpersonal and small-group skills needed to solve problems and plan with people having diverse perspectives. Cooperative learning experiences require students to engage with each other in such interpersonal problem-solving situations, while competitive and individualistic learning situations eliminate it. It is not surprising, therefore, that cooperative learning procedures promote greater interpersonal competence.[32,34,36] Cooperation promotes better communication skills, including those needed to exchange and use technical and non-technical information; more effective conflict skills, including those needed to argue effectively for one's point of view and synthesize the best parts of various positions; effective decision-making and problem-solving skills; relationship-building skills, including those needed to develop achievement-oriented and supportive relationships; and leadership skills, such as facilitating mutual goal accomplishment while maintaining an effective working relationship. When engineering educators wish to increase students' interpersonal competence, a cooperative goal structure is to be preferred.

Social-technical competence requires that engineers be able to take a variety of perspectives towards a project, including technological, environmental, consumer, marketing and manufacturing perspectives. Perspective-taking is therefore a critical ability to develop. Perspective-taking is the ability to understand how a situation appears to another person and what that person is thinking and feeling. The opposite of perspective-taking is egocentrism, the embeddedness in one's own viewpoint to the extent that one is unaware of other points of view and of the limitations of one's perspective.

A series of studies has compared the relative impact of cooperative, competitive and individualistic learning experiences on perspective taking.[32,34,37,38] Cooperation has been found to be more highly related to perspective-taking ability and to promote greater cognitive and affective perspective-taking ability. Competitive and individualistic experiences have been found to promote egocentrism, closed-mindedness, and the rejection of other points of view. These results are all the more important because perspective-taking is a central process underlying the effective presentation of information, comprehension of others' information, the constructive resolution of conflicts, the willingness to disclose personal information, effective group problem solving, cooperativeness, positive attitudes toward others within the same situation, autonomous moral judgment, intellectual and cognitive development, and general social adjustment and psychological health.[32,39-41] When engineering educators wish to increase students' perspective-taking ability and social-technical competence, cooperative learning procedures are to be preferred.

Appropriate Use of All Three Goal Structures

Each of the three goal structures has an important place in the engineering classroom. It is the responsibility of the instructor to orchestrate the class to integrate them effectively. Some guidelines for their use may be helpful.

Competition should be used when it is relatively unimportant whether one wins or loses, when all students see themselves as having a reasonable chance of winning, when the rules and answers are clear and specific, and when students can monitor the progress of their competitors. Drill-review and very simple mechanical and rote tasks seem to be the most appropriate for competition. While occasional competition can add variety and spice to a course, engineering educators will wish to keep in mind that too frequent an inappropriate use of competition can interfere with the development of interpersonal and social-technical competencies.

The *individualistic* goal structure may supplement cooperation through a division of labor in which each student learns material or skills to be used in cooperative, problem-solving activities. When working individualistically, students need adequate individual space and all necessary materials, the directions need to be clear and specific, and the task must be perceived as relevant and worthwhile. The individualistic structure does not involve interpersonal interaction and, as such, does not contribute to the students' developing interpersonal or social-technical competence.

Cooperation may be used most effectively for learning conceptual and theoretical skills, reasoning assignments, resolving technically complex projects, open-ended problem solving, and dealing with problems involving technology and society. The cooperative structure involves a group goal and teamwork. Its use helps to develop cognitive and interpersonal skills, and social-technical awareness. The emphasis is simultaneously on productivity and interpersonal collaboration.

The advantages of cooperative learning methods have been pointed out by an engineering educator[42] and by educators in other professional fields.[43-45] Roe and Glassman make clear distinctions between discussion groups and cooperative learning groups. Cooperative learning is much more than being physically close to other students, discussing material with each other, or helping or sharing materials, although each of these is important. The essence of cooperative learning is assigning a group goal, such as producing a single report and achieving as high a group average on a test as possible. The entire cooperative learning group is rewarded on the basis of the quality or quantity of their product according to a fixed set of standards.

Establishing a Cooperative Structure

The instructor establishes a group goal and a criterion-referenced evaluation system, and rewards members on the basis of their group performance. Teaching a cooperative lesson, however, involves more than just setting up a cooperative goal structure. Here is a summary of the teacher's role in cooperation:

1) As far as possible, specify the instructional objectives.

2) Select the group size most appropriate for the lesson. The optimum size of a cooperative group will vary according to the resources needed to complete the lesson or project (the larger the group, the greater the resources available), the cooperative skills of group members (the less skillful the group members, the smaller the group should be), and the nature of the task.

3) Assign students to groups. You will usually want to maximize the heterogeneity of the groups. Random assignment usually ensures a good mixture of males and females, highly verbal and passive students, leaders and followers, and enthusiastic and reluctant learners. Sometimes, however, you may want to let students choose whom they want to work with; sometimes you may want to group students according to their interests.

4) Arrange the classroom. Cluster groups of students so that they will not interfere with one another. Within the groups, all students should be able to see the relevant materials, talk with one another, and exchange materials and ideas. Usually a circle is best and long tables should be avoided.

5) Explain the task of the cooperative goal structure. The task may be laboratory exercises, drill and review, concept attainment, a design problem or any other area. The goal structure is communicated by telling students that there is a group goal and a criterion-referenced evaluation system, and that all group members will be rewarded on the basis of the quality of their group's work.

6) Provide the appropriate materials. When students are first learning to cooperate, or when some students are having problems in contributing to the group work, you may want to arrange the materials like a jigsaw puzzle and give each group member one piece. One group, for example, could be writing a report on alternative energy resources, with each member responsible for material on the different types; in order for the report to be completed, each has to contribute material to the report.

7) Observe interactions between students. Asking students to cooperate does not mean they will do so. Much of your time may be spent observing the groups to see what problems they are having.

8) Intervene as a consultant to help the group solve its problems and help members learn the interpersonal skills necessary for cooperating.

9) Evaluate the group products, using a criterion-referenced evaluation system.

Conclusions

Engineering education needs to emphasize technological, interpersonal, and social-technical competencies. Given the demand for engineers and the lack of engineering educators, instructional strategies are needed that promote simultaneously the development of all three types of competencies. While competitive and individualistic instructional strategies have dominated engineering education, it is the cooperative goal structure that seems to be the most effective in facilitating students' development. Cooperative learning procedures may be used effectively in any engineering course without adding new curriculum materials. Rather than adding new courses on interpersonal and social-technical competencies, engineering programs may teach existing courses primarily using cooperative learning procedures and thereby promote all three types of competencies simultaneously, without additional course requirements and without adding to existing curricula.

The cooperative goal structure allows larger, more complicated and often more interesting problems to be tackled by students without their feeling overwhelmed; allows students to serve as resources for each other, hence taking some of the pressure off instructors and teaching assistants; and allows more effort to be expended on sharing ideas and producing good products, and less on beating other students on some performance measure.

Current technical and social-technical problems are much too complicated for a person working in isolation to formulate and solve. Input is needed from many different people, with differing viewpoints, to achieve a satisfactory solution. Professional engineers generally do not compete with their colleagues to obtain solutions to problems facing their organization. The successful engineer must cooperate with his or her colleagues and coordinate activities so that each person involved is contributing skills and resources.

Knowledge and skills are of no use if a student cannot apply them in cooperative interaction with other people. It does no good to train an engineer who does not have the competencies needed to apply knowledge and technical skills in cooperative relationships on the job, in the family and community, and with friends. The most logical way to emphasize cooperative competencies as learning outcomes is to structure the majority of academic learning situations cooperatively.

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