Case-based and problem-based learning (PBL) are undergoing a renaissance in professional education, including engineering and technology education (Wilkerson & Gijselaers, 1996; ASEE PRISM, 1996). Case-based and problem-based learning are not new, however. Case based learning has been used in law and business for over 25 years (Barnes, Christensen & Hansen, 1994) and considerably longer in medicine (Cabot, 1906). PBL had its beginnings in 1969 in the MD program at McMaster University in Hamilton, Ontario, Canada. McMaster graduated it’s first PBL class in 1972. At about the same time the College of Human Medicine at Michigan State University implemented a problem-based curriculum (Jones, Bieber, Echt, Scheifley & Ways, 1984) as did several other institutions. Problem-based learning was included under “reforms and innovations” in Sinclair Goodlad’s 1984 Education for the Professions (Neufeld & Chong, 1984). Case-based and problem-based learning are rapidly being adopted in professional programs – medicine, law, business, engineering, and technology. Harvard University, for example, has extensive descriptions of its use of case-based and problem-based learning in business and medicine (Moore, 1997; Tosteson, et.al., 1994; Christensen, 1981).

Several recent large-scale projects, such as SEATEC (and it’s predecessor, TEFATE) are focused on implementing case-based/problem-based learning in higher education. Several web sites focus on PBL, including, Southern Illinois School of Medicine (http://edaff.siemed.edu/PBLI/pblisiu.htm), McMaster University Chemical Engineering (http://chemeng.mcmaster.ca/pbl/pbl.htm), Illinois Math and Science Academy (http://www.imsa.edu/team/cpbl/cpbl.html), the University of Delaware
Important Features of a Case Study

The most important features are the case or problem itself, the procedure the instructor uses, and the attitudes and the relationships that exist in the class.

The most important features of the problem or case are (1) a context-based, relevant and relatively realistic scenario; (2) a challenging but not too frustrating problem, task, or situation; (3) a somewhat open-ended problem or situation that requires careful formulation and listing of assumptions; (4) a problem or situation that motivates students to explore, investigate, and study; (5) a problem or situation that encourages or requires interaction among students, between students and faculty, between students and outside resources; and (6) a problem that requires addressing the integration of broader aspects, including technical, economic, social, ethical, and environmental.

Characteristics of good problems according to Duch & Allen (1996, http://www.udel.edu/pbl/cte/spr96-phys.html) include:

- An effective problem must first engage students' interest, and motivate them to probe for deeper understanding of the concepts being introduced. It should relate the subject to the real world, so that students have a stake in solving the problem.
- Good problems require students to make decisions or judgements based on facts, information, logic and/or rationalization. Students should be required to justify all decisions and reasoning based on the principles being learned. Problems should require students to define what assumptions are needed (and why), what information is relevant, and/or what steps or procedures are required in order to solve them.
- Cooperation from all members of the student group should be necessary in order to effectively work through a good problem. The length and complexity of the problem or case must be controlled so that students realize that a "divide and conquer" effort will not be an effective problem-solving strategy. For example, a problem that consists of a series of straight-forward "end of chapter" questions will be divided by the group and assigned to individuals and then reassembled for the assignment submission. In this case, students end up learning less not more.
- The initial questions in the problem should have one or more of the following characteristics so that all students in the groups are initially drawn into a discussion of the topic:
  - open-ended, not limited to one correct answer
  - connected to previously learned knowledge
  - controversial issues that will elicit diverse opinions

This strategy keeps the students functioning as a group, drawing on each other's
knowledge and ideas, rather than encouraging them to work individually at the outset of the problem.

- The content objectives of the course should be incorporated into the problems, connecting previous knowledge to new concepts, and connecting new knowledge to concepts in other courses and/or disciplines.
- An effective problem must first engage students’ interests.

The role of the instructor is crucial to the success of case-based and problem-based learning. A learning environment must be maintained where the students take more responsibility for their own learning and the learning of others. Ideally, the faculty member serves as a facilitator or coach. One approach to creating a conducive environment is formal cooperative learning. A typical format for problem-based cooperative learning is shown in Figure 1. The format illustrates the professor's role in a formal cooperative learning lesson and shows how the five essential elements – positive interdependence, individual accountability, face-to-face promotive interaction, teamwork skills, and group processing -- of a well-structured cooperative lesson are incorporated (Johnson, Johnson & Smith, 1991, 1998; Smith, 1995, 1996).

Cooperative problem-solving groups typically consist of two to four members. Group membership is randomly selected and typically changes with each assignment. Problem-solving group work follows a format such as:

1. Groups formulate and solve problems. Each group places its formulation and solution on an overhead transparency or on paper.
2. Randomly selected students present their group's model and solution.
3. Discussion of formulation and solution. All members of the class are expected to discuss and question all models.
4. Each group prepares and submits a project report, and processes its effectiveness as a group.

Formal cooperative learning groups may last from one class period to several weeks to complete specific tasks and assignments--such as decision making or problem solving, writing a report, conducting a survey or experiment, preparing for an exam, or answering questions or homework problems. Any course requirement may be reformulated to be cooperative. In formal cooperative groups the professor should (Johnson, Johnson & Smith, 1998):

1. **Specify the objectives for the lesson.**
2. Make a number of instructional decisions, including the size of groups, the method of assigning students to groups, how long the groups stay together, the roles the students will be assigned, the materials needed to conduct the lesson, and the way the room will be arranged.

3. Explain the task, and the positive interdependence and individual and group accountability.

4. Monitor students' learning and intervene within the groups to provide task assistance or to increase students' teamwork skills.

5. Evaluate students' learning and help students process how well their group functioned. Students' learning is carefully assessed and their performances are evaluated. The professor provides time and a structure for members of each learning group to process how effectively they have been working together. A criteria-referenced evaluation procedure must be used, that is, grading must NOT be curved (Smith, 1998).

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### Problem-Based Cooperative Learning Format

| TASK: | Solve the problem, Accomplish the task |
| INDIVIDUAL: | Estimate answer. Note strategy. |
| COOPERATIVE: | One set of answers from the group, strive for agreement, make sure everyone is able to explain the strategies used to solve each problem. |
| EXPECTED CRITERIA FOR SUCCESS: | Everyone must be able to explain the strategies used to solve each problem. |
| EVALUATION: | Best answer within available resources or constraints. |
| INDIVIDUAL ACCOUNTABILITY: | One member from any group may be randomly chosen to explain (a) the answer and (b) how to solve each problem. |
| EXPECTED BEHAVIORS: | Active participating, checking, encouraging, and elaborating by all members. |
| INTERGROUP COOPERATION: | Whenever it is helpful, check procedures, answers, and strategies with another group. |

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**Figure 1.** Typical Formal Cooperative Learning Format

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### Why are these features important?

Case-based and problem-based learning is very important because it helps students develop skills and confidence for formulating problems they've never seen before. The Problem-Based Learning web site at Southern Illinois University lists the intent of PBL to produce students who will:

- Engage a challenge (problem, complex task, situation) with initiative and enthusiasm
- Reason effectively, accurately and creatively from an integrated, flexible, usable knowledge base
- Monitor and assess their own adequacy to achieve a desirable outcome given a challenge
- Address their own perceived inadequacies in knowledge and skills efficiently and effectively
- Collaborate effectively as a member of a team working to achieve a common goal
The intellectual activity of building models to solve problems—an explicit activity of constructing or creating the qualitative or quantitative relationships—helps students understand, explain, predict, synthesize and deliver (Smith and Starfield, 1993; Starfield, Smith, and Bleloch, 1994). Problem-based learning is a terrific format for helping students learn how to do engineering design. Design is routinely listed as essential for engineering and technology students. ABET defines engineering design as “the process of devising a system, component or process to meet a desired need.” A 1986 NSF Workshop Committee described the importance more emphatically: “Design in a major sense is the essence of engineering; it begins with the identification of a need and ends with a product or system in the hands of a user. It is primarily concerned with synthesis rather than the analysis that is central to engineering science. Design, above all else, distinguishes engineering from science” (Hancock, 1986).

Design is often presented as a rational, algorithmic process whereby students follow a series of prescribed steps to reach an end product. Recent work on engineering design indicates that it’s not nearly as rational a process as we once naively thought. Ferguson (1992), for example, wrote that

Those who observe the process of engineering design find that it is not a totally formal affair, and that drawings and specifications come into existence as a result of a social process. The various members of a design group can be expected to have divergent views of the most desirable ways to accomplish the design they are working on. As Louis Bucciarelli, an engineering professor who has observed engineering designers at work, points out, informal negotiations, discussions, laughter, gossip, and banter among members of a design group often have a leavening effect on its outcome.

Ethnographic research on engineering design conducted at the Stanford Center for Design Research (http://cdr.stanford.edu/~leifer) indicates that design is a more social process that we once thought. Larry Leifer (1997) claims that “engineering design is a social process that identifies a need, defines a problem, and specifies a plan that enables other to manufacture the solutions.” According to Leifer, engineering design practices include: Negotiating understanding, Conserving ambiguity, Tailoring engineering communications for recipients, and Manipulating mundane representations.
The implications of Leifer and Ferguson’s work for the teaching of design are profound! Essentially it means that we must work in a different way, that we must develop high performance teams of students, and that our role must become one of facilitator rather than one who professes. Donald Schön (1987) described designing and the professor’s role in the process as follows:

Designing, both in its narrower architectural sense and in the broader sense in which all profession practice is designlike, must be learned by doing. However much students may learn about designing from lectures or readings, there is a substantial component of design competence—indeed, the heart of it—that they cannot learn in this way. A designlike practice is learnable but is not teachable by classroom methods. And when students are helped to learn design, the interventions most useful to them are more like coaching than teaching—as in a reflective practicum.

Learning to think like an engineer means learning to do both analysis and synthesis both alone and with a group of team members. Learning that is informal, social, and focused on meaningful problems helps create "insider knowledge.” Gaining insider knowledge— learning to speak, write, and think like members of a profession— is a major part of becoming a member of a community of practice (Brown and Duguid, 1991).

Helping students understand the complexity of trades-offs involved in many engineering and technology decisions is another important aspect of case-based and problem-based learning. A recent statement by Sharon Beder highlighted this point (1998):

Engineering appears to be at a turning point. It is evolving out of the easy certainty of an occupation that simply provides employers and clients with competent technical advice and into a profession that serves the community in a socially and environmentally responsible manner. There is an increasing need for engineers to choose technical solutions that are appropriate to their social context and to give consideration to the long-term effects of their work, if only because the work of engineers can have wide-ranging effects.

Chris Christensen and colleagues make a terrific case for Case-Based Learning in their book Education for judgment: The artistry of discussion leadership. For example, they state:

To teach is to engage students in learning; thus teaching consists of getting students involved in the active construction of knowledge. A teacher requires not only knowledge of subject matter, but knowledge of how students learn and how to transform them into active learners. Good teaching, then, requires a commitment to systematic understanding of learning. . .The aim of
teaching is not only to transmit information, but also to transform students from passive recipients of other people’s knowledge into active constructors of their own and others’ knowledge. The teacher cannot transform without the student’s active participation, of course. Teaching is fundamentally about creating the pedagogical, social, and ethical conditions under which students agree to take charge of their own learning, individually and collectively (p. xiii, xvi).

Finally, the shift to more case-based and problem-based learning is essential because it leads to: (1) Improved learning and retention of the conceptual and procedural material (Springer, Stanne, & Donovan, 1997), (2) Increased retention of students and enhanced motivation to learn (Seymour & Hewitt, 1997), (3) Improved development of broader skills - multidisciplinary systems perspective, teamwork skills (Johnson, Johnson & Smith, 1991, 1998), and (4) The development of students’ problem formulation, modeling, and synthesis skills.

References

ASEE Prism. 1996. Let problems drive the learning in your classroom. ASEE Prism, 6(2), 30-36.


