Problem-Based Freshman Engineering Course

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Problem-based learning (PBL) is undergoing a renaissance in professional education, including engineering education (Wilkerson & Gijselaers, 1996; ASEE PRISM, 1996). PBL is not a new idea; it 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 (Jones, Bieber, Echt, Scheifley & Ways, 1984). Problem-based learning was included under "reforms and innovations" in Sinclair Goodlad's 1984 *Education for the Profession* (Neufeld & Chong, 1984).

We have been teaching a problem-based course— How to Model It, CE/GeoE 3700— since the mid-seventies for first year students in the Institute of Technology at the University of Minnesota. The course has always incorporated computer-based modeling technology (programming, spreadsheets and equations solvers) and recently a World Wide Web site that support the course. The course evolved to make extensive use of problem-based cooperative learning. The goal of the course is to develop students' skill, knowledge, and confidence for thinking both quantitatively and qualitatively. The course focuses on problem formulation and representation; and on building, interpreting, explaining, presenting and evaluating mathematical and computer models.

Problem-Based Cooperative Learning

Problem-based learning results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process (Barrows & Tamblyn, 1980). The process of problem-based learning in engineering was described in detail by Woods (1994) and ASEE PRISM (1996)..

Problem-based learning is very suitable for engineering (as it is for medicine, where it is currently used) because it helps students develop skills and confidence for formulating problems they've never seen before. 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, etc. (Smith and Starfield, 1993; Starfield, Smith, and Bleloch, 1994). The process of building models together in face-to-face interpersonal interaction results in learning that is difficult to achieve in any other way.

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 of a well-structured cooperative lesson are incorporated (Johnson, Johnson & Smith, 1991; 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 will place its formulation and solution on an overhead transparency or on paper.
2. Randomly selected students will present their group's model and solution.
3. Discussion of formulation and solution. All members of the class will be expected to discuss and question all models.
4. Each group will prepare and submit a project report, and process 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:

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.

Problem-Based Cooperative Learning Format

TASK: (Solve the problems)

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.

Figure 1. Typical Formal Cooperative Learning Format

Problem-Based Cooperative Learning and Engineering Design

Problem-based learning is a terrific format for helping students learn how to do engineering design. Design is routinely listed as essential for engineering 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 which 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 (Eugene Ferguson, 1992).

Ethnographic research on engineering design conducted at the Stanford Center for Design Research indicates that design is a more social process that we once thought. Larry Leifer claims that "engineering is a social process that identifies a need, defines a problem, and specifies a plan that enables other to manufacture the solutions."

The implications of Leifer and Ferguson's work for the teaching of design is 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).

References

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

Barrows, H.S. & Tamblyn, R. 1980. *Problem-Based Learning*. New York: Springer.

Brown, J.S. and Duguid, P. 1991. Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organizational Science, 2* (1), 40-56.

Ferguson, Eugene S. 1992. *Engineering and the Mind's Eye*. Cambridge, MA: MIT Press.

Goodlad, Sinclair. 1984. *Education for the professions*. Guidford, Surrey: Society for Research into Higher Education

Johnson, D.W., Johnson, R.T., and Smith, K.A. 1991. Cooperative learning: Increasing college faculty instructional productivity. Washington, DC: *ASHE-ERIC Reports on Higher Education.*

Jones, J.W., Bieber, L.L., Echt, R., Scheifley, V., & Ways, P.O. 1984. A problem-based curriculum— Ten years of experience. In H.G. Schmidt & M.L. DeVolder (eds). Tutorials in problem-based learning. Assen/Maastricht, the Netherlands: Van Gorcum.

Neufeld, Victor & Chong, John P. 1984. Problem-based professional education in medicine. In Sinclair Goodlad, (Ed.), *Education for the professions*. Guidford, Surrey: Society for Research into Higher Education.

Schön, Donald. 1987. *Educating the Reflective Practioner*. San Francisco: Jossey-Bass.

Smith, K.A. 1996. Cooperative learning: Making "groupwork" work. In C. Bonwell & T. Sutherlund, Eds., Active learning: Lessons from practice and emerging issues. New Directions for Teaching and Learning 67, 71-82. San Francisco: Jossey-Bass.

Smith, K.A. 1996. Cooperative learning: Making "groupwork" work. In C. Bonwell & T. Sutherlund, Eds., Active learning: Lessons from practice and emerging issues. *New Directions for Teaching and Learning*. San Francisco: Jossey-Bass.

Smith, K.A. 1995. Cooperative learning: Effective teamwork for engineering classrooms. *IEEE Education Society/ASEE Electrical Engineering Division Newsletter*. March, 1-6.

Smith, K.A., & Starfield, A.M. Building models to solve problems. In J.H. Clarke & A.W. Biddle, (Eds.), *Teaching critical thinking: Reports from across the curriculum*. Englewood Cliffs, NJ: Prentice-Hall, 1993, 254-263.

Starfield, Anthony M., Smith, Karl A., and Bleloch, Andrew L. 1994. *How to model it: Problem solving for the computer age*. Edina, MN: Burgess International Group, Inc.

Wilkerson, LuAnn & Gijselaers, Wim H. (Eds.). 1996. Bringing problem-based learning to higher education: Theory and practice. New Directions for Teaching and Learning 68, San Francisco: Jossey-Bass.

Woods, Donald R. 1994. *Problem-based learning: How to gain the most from PBL*. Waterdown, Ontario: Donald R. Woods.