

## A LEARNING THEORY-BASED APPROACH TO THE UNDERGRADUATE LABORATORY

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A basic tenet of learning theory is that people learn by doing, not by watching and listening. Engineering laboratory courses are consequently crucial to the learning and retention of engineering principles. The traditional laboratory course has several shortcomings, however, that violate other learning theory principles.

Virtually all cognitive and educational psychologists agree that students learn by discovery, by confronting new problems and challenges, working out how to deal with them, and reflecting on implications of their solutions. In many laboratory courses, students often perform rigidly prescribed experiments mechanically, without having to analyze what they are doing, why they are doing it, or what the results have to do with the theory they may have studied in other courses. A massive body of research on cooperative learning indicates that team projects are most effective if they are structured to assure both positive interdependence and individual accountability. In most laboratory courses, there is little to prevent one or two team members from actually doing most of the work, all team members receiving credit for it, and no one being held individually accountable for any of the material covered.

The chemical engineering laboratory course sequence at North Carolina State University is currently being restructured to conform more closely to principles of effective pedagogy. The following features of the new sequence constitute the principal departures from the traditional instructional model:

1. *The students design and run a small number of experiments to accomplish broadly stated objectives, rather than following prescriptive instructions for a large number of predesigned experiments.* At the beginning of the semester, the students are told that for each experiment they will be given an apparatus description, safety precautions, some preliminary theory, and minimal information about the types of behavior they are to observe and analyze. The groups are required to seek out relevant references, develop a rationale for their experimental design, and work out appropriate data analysis. The teaching assistants are instructed to be circumspect when faced with questioning regarding experimental design, but vigilant regarding potentially unsafe practices.
2. *Hands-on experimentation is augmented with process simulation.* In some experiments computer simulations are used to model the experimental systems and then to explore “what-if” scenarios far more extensively than time would permit in a conventional laboratory.
3. *Structured cooperative learning (Johnson *et al.*, 1991, Felder and Brent, 1994) is used to increase understanding of experimental and analytical procedures and to facilitate*

*development of critical teamwork skills* (leadership, time management, conflict resolution, etc.). Assignments and grading procedures are designed to assure both positive interdependence and individual accountability. Training in teamwork is provided and the teams regularly conduct self-assessments of their performance. (Additional details are provided below.)

4. *Explicit training in technical report writing and technical presentations is provided as part of the laboratory instruction, and presentation quality is heavily weighted in report evaluation.* Reports are graded separately for technical accuracy and quality of presentation (writing, appearance). Staff of the College of Engineering Writing Assistance Center are involved in both training and evaluation. Drafts of all laboratory reports must be submitted to the Center and the feedback must be incorporated into the final reports.

### **Course structure**

The laboratory course sequence is offered in two consecutive semesters. The first course, which is normally taken in the second semester of the junior year, consists of a one-hour lecture and a three-hour laboratory period each week. In the lab the students design, run, and analyze data for four experiments related to fluid dynamics and heat transfer. The lectures deal with laboratory procedures (with an emphasis on safety), statistical data analysis, and written and oral report preparation. The second course—which has no lecture component—involves three experiments related to separation processes and chemical reactions, and the students also design and either simulate or run their own multi-unit experiment. Experiments are carried out in three-week cycles: one week for the teams to learn about the equipment and plan the experiment, one to run the experiment, and one to analyze the data and prepare the report.

Instructional modules for the course sequence deal with the following topics:

- Elementary statistical analysis
- Statistical error analysis
- Statistical design of experiments
- Data acquisition procedures
- Construction of simulation models
- Use of simulation models for process development based on laboratory data
- Preparation of laboratory reports in technical record and memorandum formats
- Preparation and delivery of oral reports
- Descriptions of specific experiments

### **Cooperative Learning Implementation**

The instructional method to be used for the laboratory is based on well established cooperative learning principles of positive interdependence, individual accountability, guided practice in teamwork and communication skills, and periodic self-assessment of team functioning (Johnson, Johnson and Smith, 1991; Felder and Brent, 1994). Students are formed into teams following standard cooperative learning guidelines that include ability heterogeneity (with grades in prerequisite engineering courses used as a measure of ability). For each experiment, team members take the roles of *coordinator*, *analyst/simulator*, *recorder*, and *checker*. These roles rotate from one experiment to another.

Several course policies and procedures assure individual accountability for the complete course content:

- Tests on the experiments and lecture material—including relevant background material from prior courses—are taken by individuals, so that students who do not fully understand the experiments are penalized. The test grades account for 40% of the final course grade.
- All members of a team that earns an average grade of 80 or higher on a test receive a 3-point bonus on their individual test grades.
- Early in the semester, the students submit free-form evaluations of each group member's performance (including their own) and comment on the effectiveness of their group organization and dynamics. They are told that these evaluations are for primarily for self-diagnosis and the instructor will also use them to identify potential problems, but the results will not have any effect on grades.
- More formal group assessments are carried out near the midpoint and the end of the semester, using a scheme developed by Brown (1995). Team members hand in individual assessments of one another's level of effort and teamwork on an 11-point verbal scale ranging from "excellent" to "no-show." They are instructed to consider how consistently and how well their teammates completed assigned tasks, prepared for team meetings, showed up for team meetings, fulfilled their team roles (coordinator, recorder, etc.), and helped other team members. They are also cautioned that the ratings should *not* reflect intelligence or technical competence. The ratings are converted to numbers (100, 87.5, 75, ..., 0). The ratio of an individual's average rating to the overall team rating is multiplied by the average team report grade for that half of the semester to determine the individual grade for the laboratory portion of the course. Irresponsible students will almost invariably get low grades, even if their team project grades are high due to the efforts of their more conscientious teammates.
- In oral team report presentations, individual members are randomly selected to present specified parts of the report. The odds are that students will not be assigned the parts that they did most of the work on, and if they don't understand what their teammates did their grades will suffer. Positive independence is assured by having a student's poor performance in an oral report affect his or her teammates' grades as well.

### **Assessment and evaluation**

The logistics of the laboratory course do not allow for a true controlled experiment, so that a quasi-experimental design is being utilized. The students taking the laboratory courses in the Fall 1997/Spring 1998 semesters went through relatively traditional offerings and constitute a comparison group, and those taking them in the Spring 1998/Fall 1998 semesters constitute the experimental group. Assessment data will include laboratory reports, test scores, responses to attitude surveys, and instructors' observations. Our hypothesis is that the students who experience the new course structure will turn in higher quality reports, demonstrate greater understanding of the experimental methods and data, and view the courses more positively,

despite the fact that they have to do more independent work than the traditional approach requires.

### **Current status of the new course sequence**

In the Fall 1997 semester, the first course was offered in a relatively traditional manner. In the Spring 1998 semester (which is half over as this paper is being written), the first course is being offered according to the new model and the second course is being offered traditionally. Student products and attitude survey responses are being collected and will be subjected to between-group comparisons.

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