The Use of Active Learning in Design of Engineering Experiments

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This paper discusses the issues and experiences in developing an active learning atmosphere during a Design of Engineering Experiments course. The course covered three main topics: introduction to statistics, design of experiments, and statistical process control. Twelve undergraduate students at the sophomore and junior levels participated in the course. The course was taught at the University of Minnesota Duluth. A highly motivated classroom environment was achieved by using a combination of the following techniques: real life examples, classroom projects (individual and group), brainstorming, computer-guided sessions, and a special-interest course project. The special-interest project used hobbies of the students to enlarge their enthusiasm for the course; for instance, one of the students worked on a project to use fractional factorial design to improve her performance in her hammer throw competition; another student used the same technique to improve her performance when playing tennis. Examples of the case-studies developed for the course, classroom, and take-home projects will be presented and discussed, including their impact on the students. Some of the special interest projects developed by the students will be shown and discussed.

Introduction

The idea of creating an enthusiastic learning atmosphere in the classroom is the dream of any teacher. Of course, that is a dream that depends upon many factors: the enthusiasm of the professor, the motivation of the students, the number of students in the class, and the difficulty of the content covered in the course. Nevertheless, there are some general strategies and tips that can be used to create a keen atmosphere for learning in the classroom. These strategies form part of what is called "active learning." Traditionally, it is expected that students will be involved in active learning by listening to the lectures and doing some projects out of the classroom that will make them use the concepts learned in class. This conventional way of learning is driven by the constraint in the time of the lecture period and by the fact that the student should demonstrate his/her interests for learning.

However, the research literature suggests[1] "that students must do more than just listen. They must read, write, discuss, or be engaged in solving problems. Most important to be actively involved, students must engage in such higher-order thinking tasks as analysis, synthesis, and evaluation. Within this context, it is proposed that strategies promoting active learning be defined as instructional activities involving students in doing things and thinking about what they are doing."

Basically, it is suggested that the lecture time be divided so that the students can do all these activities (read, write, discuss, and be engage in solving problems) in the classroom. The instructor serves as a mentor, and the students learn by doing small projects in the classroom. Additionally, classroom activities must be complemented with longer assignments out of the classroom.

Research[2] has shown that involvement of students in the educational process through active learning makes students recognize and accept their responsibility for lifelong learning and continued education, which is consistent with ABET 2000 accreditation criteria.[3]

Seeler *et al.*[2] have suggested ways to modify the lecture in order to achieve an active learning atmosphere in the School of Veterinary Medicine which have demonstrated excellent results for their students. The objective of this paper is to discuss some of the applications of their suggestions along with other tips to achieve active learning in a Design of Engineering Experiments Class for Chemical Engineers. Some examples of student cases studies will be presented.

Course Description and Scenario

The Design of Engineering Experiments course was taught by Dr. Botte at the University of Minnesota Duluth in spring 2001. It was Dr. Botte's first course taught. The description of the course according to the UMD course catalog is "CHE 2011. Design of Engineering Experiments: Basic theories of experimental design, data analysis, and statistical process control, emphasizing their application to chemical engineering practice."[4] The freshman introduction to calculus courses (limits, derivatives, integrals, vectors, partial derivatives, etc) are prerequisites of the course. Twelve undergraduate students at the sophomore and junior levels participated in the course. The course was taught twice a week with a lecture time of 75 minutes each session, over fifteen weeks (semester format).

Structure and Course Content

The first step to implement active learning requires a critical evaluation of the course, its structure, and content. The structure and content should be consistent with the educational objectives of the institution, the relationships of the course with others in the curriculum, and the instructor's expectations of the course.[2] The instructor must recognize what is important that students learn from the course (instructor's expectations), which must be related to the application of the course material to the future job of the student. For doing this, is extremely important to use the industrial experience of the instructor and/or to discuss the ideas with the Industrial Advisory Board of the Department. Keeping all this information in mind, the objective of the course was to teach the most basic principles and techniques of experimentation, data analysis, and statistical process control with a minimum of statistical formality abstraction. Special emphasis was placed on experimentation for quality improvement. Table I presents a summary of the major content covered in the course.

Table I. Major Content Covered in the Design of Engineering Experiments Course

Topic	Details
Basic Statistics	1. Description of variation (e.g. histograms, standard deviation, etc) 2. Probability distributions (e.g., Poisson, normal probability distribution, etc)
Design of Engineering Experiments (DOE)	1. Meaning of Quality and quality philosophies 2. Full factorial design (two level experiments) 3. Fractional factorial design (two level experiments) 4. Evaluating variability 5. Blocks effects 6. Process Optimization with DOE
Statistical Process Control	1. Methods and Philosophies of control charts 2. Control Charts for variables 3. Control Charts for attributes 4. Process Capability

Active Learning Implementation

Concepts were taught using a combination of the following techniques: short case studies (classroom and/or take home projects), real life examples, brainstorming, computed guided sessions, and a special interest course project. The introduction of new concepts was made through a short lecture follow by a practice. The use of all of these techniques is described next.

Lectures:

The instructor elected to use the lecture as the primary educational technique. The total lecture time (1 hour and 15 minutes) was divided in to the following sections: 1. warm- up period (2 minutes), 2. review (9 minutes), 3. body of the lecture (30 minutes), 4. classroom practice (25 minutes), and 5. summary (9 minutes).

The *warm-up period* was used to break the ice in the classroom and to make the students interact with the instructor. A quick conversation in general topics such as: TV programs, new movies, favorite sports, etc. were used as examples. Most of the students participated in the conversation and gained confidence with their classmates and the instructor.

The *review time* was used to summarize the key aspects of the previous lecture. Students were asked to help in summarizing the points. They were allowed to quickly review their notes and bring up key points to the classroom. A time for questions about the covered material was permitted.

The *body of the lecture* was used to introduce new concepts. All the lectures were taught using a PowerPoint presentation format, which allowed saving time in the introduction of the concepts. A copy of the presentation was provided to the students as handouts at the beginning of the class. The students were not allowed to take notes while the instructor was speaking and explaining the new concepts. Two to three major concepts were introduced in each lecture session. At the end of each concept, the students were given a time to ask questions, and a classroom practice related to the topic was assigned.

Classroom practices consisted of exercises designed to apply the new concepts introduced during the class. The classroom practices were made in teams; the class was divided into two teams with six members each. Team memberships were constant over the entire semester. The two teams kept competing to finish the exercise first, even though it was not originally planned that way. However, this inherent competition between the teams was favorable for the motivation of the students. The classroom practices substituted for the examples explained and solved completely by the instructor. That is, after introducing a new concept, the instructor did not solve a problem. Instead, the students were challenged to use the concepts to try to solve an exercise by themselves, and the instructor served as a tutor. At the end of the period the solutions of the two teams were discussed, and the whole problem was solved in detailed by the instructor. Once again, the students were not allowed to take notes during this time. Copies of the complete solution of the problem were given to the students.

The *summary* of the lecture was used to emphasize the most important aspects of the lecture. The students were asked to help in providing the key ideas discussed during the lecture. Time for questions was allowed.

Short Case Studies:

Short case studies were used to exercise the concepts explained in class. Some of them were part of the classroom practices explained above which were done by groups and during the class period. Additionally, two take-home case studies were assigned during the semester: 1. the chewing gum exercise, and 2. the helicopter experiment. A description of the cases is given in Table II. Both take-home experiments were done by teams (same members as class teams). A short report from the group as well as a presentation were required in both cases. The speaker for the presentation was selected randomly to assure the participation of each team member in the project. Initially the students complained about this policy, but later they realized that it made a difference in the participation and contribution of the team members to the assignment.

Real life examples and brainstorming:

It really makes a difference in the attitude and interest of the students when the professor uses phrases such as “this is a real industrial problem …I was involved a few years ago…” The students get really interested and willing to learn and listen about the application of the concepts in the industry. For example, when after explaining the use of cause-effect diagrams in the class, Dr. Botte presented briefly the production process of polyvinyl chloride (PVC) and asked the students to work in class in teams (as described in classroom practices) to build a cause-effect diagram for the formation of fish eyes in the resin. The students needed to brainstorm, think, and analyze to propose causes for the problem. Even though it was the first time the students heard about the PVC process, some of the causes discussed by them have been analyzed in the PVC industry.

Computer-guided sessions:

Computer-guided sessions were used to teach how to use design-of-experiments software and Excel to practice some exercises and case studies with computer requirements. A detailed handout with the exercise was provided, for the students to follow step-by-step (encouraging self learning). The instructor acted as a tutor. Once they finished reproducing and learning the method through the handout, they were asked to solve an exercise. Their solutions were discussed at the end of the class period, and the complete solution was presented by the instructor. The complete solution of the problem was provided to the students at the end of the class as a handout.

Table II. Take Home Short Case Team Exercises

<table>
<tr><th>Short Case Team Exercise</th><th>Description</th></tr>
<tr><td>Chewing gum exercise</td><td>Design an experiment to evaluate the influence of the following factors: flavor, meal, and gender on the flavor-lasting time of gums. Replicate your experiments once and randomize the trials using the randomizing tables. The factors and the levels are summarized below:
<table>
<tr><th>Factor</th><th>Low Level</th><th>High Level</th></tr>
<tr><td>Flavor</td><td>Fruit Juice</td><td>Double Mint</td></tr>
<tr><td>Gender</td><td>Female</td><td>Male</td></tr>
<tr><td>Meal</td><td>Before</td><td>After</td></tr>
</table>
The response is the flavor lasting-time in minutes. Build a response table, plot effects, two-way interaction tables and plots. What effects are real? Determine the settings that maximize the response and estimate the maximum value of the response. Prepare a team report with your results and a five-minute presentation. The speaker will be chosen randomly in class; therefore, all members of the team should be prepared for presenting and answering questions.</td></tr>
<tr><td>Helicopter experiment</td><td>Product development at “Duluth’s Toys” is developing a cheap distraction toy for use at restaurants to keep children entertained while waiting for service (also while parents are eating). The toy (a paper helicopter) needs to be simple in design, since the children will actually be assembling it using scissors, paper clips, etc. A prototype (basic design) has been developed which satisfies assembly requirements. A study done using the prototype has discovered that the satisfaction of the customers (children) is directly proportional to the flight time (in seconds). The basic design for the prototype is given.
An engineer on the team (chemical engineer from UMD who took ChE-2011) has suggested optimizing the prototype by studying the following factors:
<table>
<tr><th>Factors</th><th>Low Level</th><th>High Level</th></tr>
<tr><td>Paper</td><td>0.04 lbs</td><td>0.26 lbs</td></tr>
<tr><td>Body Fold Width</td><td>1.5”</td><td>2”</td></tr>
<tr><td>Body Design</td><td>No tube</td><td>tube</td></tr>
<tr><td>Wing Width</td><td>1.5”</td><td>2”</td></tr>
<tr><td>Wing Length</td><td>4.75”</td><td>5.75”</td></tr>
<tr><td>Paper Clip</td><td>No</td><td>Yes</td></tr>
<tr><td>Wing Offset</td><td>No</td><td>Yes</td></tr>
</table>
The engineer suggested performing a preliminary study by using 16 runs. He also suggested that is very important to replicate the data two times to reduce the variability of the experiment. Also, the experiments should be performed in random order. What factors affect the response (flight time)? Optimize your design. What would you suggest to improve the design? Prepare a team report with your results and a 10-minute presentation. The speaker will be chosen randomly in class; therefore, all the members of the team should be prepared for presenting and answering questions.</td></tr>
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Special Interest Project:

The special interest project was used as the final project of the course. The students were asked to choose a topic of their interest as their final design-of-experiments project. The objective of the project was to propose, design, carry out, analyze, write a report, and prepare a presentation for an experiment of their choice. The only constraint of the experiment was that it had to have at least 16 total runs. For example, they could run a replicated 2^3, or a single of 2^4, or a fractional factorial in 16 runs, or a fold-over design. Examples of the students' projects are given in Table III.

The projects were presented the last week of class. The results were excellent; the enthusiasm of the students for their projects was really high, which also demonstrated their motivation for the class. Most of the students brought samples of their experiments to the class, e.g., videos of the experiment, equipment used, even food samples in some cases.

Table III. Examples of Special Interests Projects Developed by the Students of the Class

Project title	Objective	Factors
The bouncy ball experiment	Find the conditions for the maximum flight time of the average rubber bouncy ball	Temperature, landing surface, and ball size
Paper airplanes in flight	Maximize the distance a paper airplane can fly	Weight of the paper, style of the airplane, height at which the airplane was launch, the force that the airplane was launched with
The best throw: optimization of throwing technique	Maximize the distance that the hammer travels in the air	Number of spins, number of warm-ups, handle shape
The clay's stress strain test	Find the maximum pressure for the clay to start deforming	Different amounts of cornstarch, water, and baking soda
Is it all about racket size?	Maximize the distance a tennis ball will travel after hitting a tennis racket	Ball age, number of strings in racket, shock absorber
Figure skating: the cutting edge	Maximize the time the skater is in the air during a jump	Jump type, number of revolutions, skater
What's popping	Minimize old maids	Popcorn type, heat settings, pan type

Conclusion

The examples discussed here incorporate active learning into a Design of Engineering Experiments course giving excellent results. Most of the time the students were able to learn by first time, hands-on experience, which increases their motivation for the class. The instructor acted as a mentor. The students were able to read, write, discuss, and be engaged in solving problems both in the classroom and out of it.

References

1. C. C. Bonwell and J. A. Eison, *Active Learning: Creating Excitement in the Classroom*, George Washington University, Washington DC, 1991.

2. D. C. Seeler, G. H. Turnwald, and K. S. Bull, "From Teaching to Learning: Part III. Lectures and Approaches to Active Learning," *J. of Veterinary Medical Education* **21** (1994).
3. ABET-2002, *"2003-2004 Criteria for Accrediting Engineering Programs-Program outcomes and assessment"*, p.1 www.abet.org
4. UMD, *Chemical Engineering Course Catalog*, www.semesters.umn.edu/dulcat/template/courses.cfm

Biographical Information

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