Effectively Engaging Students in an Introductory Chemical Engineering Course

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Abstract
The introductory chemical engineering course at the University of Missouri-Rolla (UMR), Material and Energy Balances, is designed to transform students into higher-thinking problem solvers who can approach complex multi-step problems. Classes are typically comprised of first semester sophomores who have only been exposed to simple, routine calculations, and many find the transition to solving open-ended or multi-step problems extremely challenging. Creativity, problem solving strategy, and interpretation of complex problem statements are best learned through practice. Cooperative learning and teamwork is highly stressed in the UMR engineering curriculum because it has been found that students who work together and are engaged in lecture better understand difficult material and learn how to approach complex problems, particularly in problem-based courses[1-2].

This paper describes the transformation of the UMR Material and Energy Balances course since 2005, along with quantitative and qualitative evidence of increased learning. To engage students during the lecture portion of the course, personal response devices ("clickers") were introduced in 2005. This resulted in increased attendance, in-class participation, and feedback to the instructor and students. In 2006, the 3-hour lab block associated with the course was reorganized into 3 1-hour problem solving sessions. This modification greatly increased students' retention and understanding of the material by efficiently utilizing class time, which resulted in a noticeable improvement in overall course grades.

Collaboration

One of the most important and hardest skills to teach students is collaboration. Many younger students in engineering were at or near the top of their high school and freshman college classes and have learned that they work most effectively by themselves. However, the problem-based courses they encounter in engineering are very different and many students who do not learn to work collaboratively do not successfully complete the engineering curriculum. Many new engineering students are surprised to learn that group work is encouraged, because they have not yet determined where the line between collaboration and copying is drawn. It is absolutely essential that engineering faculty, especially those teaching introductory courses, help instill good collaborative habits in their students and help them distinguish acceptable group behavior (working *together*) from bad ones (*copying*). This can be accomplished through collaborative in-class thought experiments, group homework assignments, and larger semester projects. Most students eventually figure out the benefits of group work, although helping them discover this as early as possible in their career leads to more successful learning overall.

Ultimately, the job of an educator is to prepare students for life outside the university. Since most engineers in the workforce are expected to work effectively in groups comprised of people outside their immediate discipline, the transition from student to employee is much easier if graduates already have the skill set to work with others. In fact, many surveys from industries hiring students have specifically commented that besides technical knowledge, the ability to work in teams is one of the most important attributes engineering graduates can possess.

Course History

In the semesters leading up to Fall 2005, the UMR Material and Energy Balances course was taught twice per year, with the majority of students enrolling in the fall. The spring semester was typically much smaller, with repeat and transfer students comprising most of the enrollment. The course was structured with two standard 50-minute lecture periods and one three-hour laboratory period per week. The laboratory period was reserved for students to work on homework, learn computer programming skills, and complete additional practice problems.

Personal Response Devices

Beginning in Fall 2005, personal response devices ("clickers") were introduced into the course. Clickers are handheld devices that allow students to respond to questions posed by the instructor, typically from a Microsoft PowerPoint presentation format. This relatively new technology has been used at many universities, with mostly positive results[3-6]. Clickers can be used in a wide variety of ways, depending on the instructor's intended outcomes. In this course, clickers were used to monitor attendance, break up the lecture into smaller portions, encourage group discussion, and engage students throughout the entire class period.

By asking three questions spread out over the course of each lecture, students were encouraged to arrive to class on time and to stay the entire hour, and by carefully choosing the focus of each question, the progress of the class could be checked in real-time. The first question of each lecture was taken from that day's reading assignment, with the goal that students came to each class prepared. The second question, in the middle of the lecture, helped to break up the period, but also gave the instructor and students immediate feedback on whether or not the class understood the material up to that point. If it was clear that many students were lost, the concepts could be explained again during the last part of the class. It also gave the instructor the opportunity to ask a relatively short but challenging question, and the students could talk and debate among themselves before answering. The final question of the day was designed to review and summarize the concepts introduced during that lecture.

Reorganization of Laboratory Sessions

In Spring 2006, the laboratory sessions were reorganized so one hour of problem-solving time was scheduled after each hour of lecture, in addition to an extra hour of lab at the beginning of each week. During these lab sessions, the students were given a semi-challenging problem that they had to finish by the end of that session. This approach achieved three main goals. First, students found that it was necessary to work in groups to solve the problems during the allotted time. This helped to build the mindset that collaborative work is necessary, and in fact can be very beneficial. Second, the students spent more time on task by reviewing new material, which helped to solidify the concepts taught in lecture the hour before. Finally, posing a moderately

challenging problem helped them to build problem-solving skills, which was one of the crucial objectives of this course.

Results and Discussion

Data for four semesters of Material and Energy Balances are shown in Table 1. It can be seen that the addition of clickers to the course in Fall 2005 resulted in a slight increase in the overall class average relative to the Spring 2004 semester. Although the spring semester courses were comprised of mostly repeat and transfer students and the fall semesters were mostly first-semester sophomores, the past history of the course shows very little difference (± 2%) in the overall raw class average between the fall and spring semesters when the same lecture and laboratory formats were followed. During the Spring 2006 semester, both clickers and the reorganized laboratory schedule were implemented, resulting in a 9.6% increase in the overall class average from the Spring 2004 semester, where roughly the same number of students were enrolled. The 5.8% increase in the class average from the Spring 2006 to Fall 2006 semesters could be due to more refined laboratory questions and the larger number of students with which to partner.

In addition, there was a significant difference in student learning and retention; with the old 3-hour lab setup, the class average during the Fall 2005 semester was a 70.9% with only one student (out of 50) obtaining higher than 90%. After adopting the new one-hour format, the class average during the Fall 2006 semester was 82.4% with 16 out of 49 students obtaining higher than 90%, even with what was considered to be more challenging exam and homework problems.

Table 1. Summary of Results

Semester	# of Students	Clickers	Lab Format	Raw Class Average
Spring 2004	16	No	3-hour	67.0%
Fall 2005	50	Yes	3-hour	70.9%
Spring 2006	18	Yes	1-hour	76.6%
Fall 2006	49	Yes	1-hour	82.4%

In addition to quantitative data, student feedback provided much qualitative data with which to assess the effect of the course modifications. For example, students experiencing the 3-hour block of labs were very resistant to the format, because they felt they were just doing extra homework problems, and it was observed that the last hour was usually reserved for the slower students to finish up the assignments. With the new 1-hour format, all students were busy for three hours, and each lab session was very focused on one problem that was specific to that week's lecture. For the first time, the course began to receive extremely positive feedback about the labs, with many students saying the lab sessions helped to solidify their understanding of the concepts:

- "…I also like the course schedule. It is much more convenient to have three one-hour labs instead of a three-hour lab on one day."
- "I like the time schedule of the class, meaning I like doing the labs right after lecture. It is a good way to immediately practice what we learned that day in lecture."

- "I really enjoy doing the labs in class. I actually look forward to lab days because it is nice to problem solve in class where we can get help if we need it."
- "I like how you incorporate labs at the end of lectures to practice the material that was just covered. It gets us thinking in the right manner on how to solve the problems."
- "I like most everything about the course. I do enjoy that we have to do so many labs. As non-exciting as they are, it helps to get all of the practice we need."
- "Labs and lecture are great. The labs are very helpful and kind of fun to work on them in groups."

Conclusions

The significant improvement in class performance, combined with the change in student attitudes (based on feedback), seem to indicate that the format changes implemented in this course have had a positive effect overall. It was difficult to assess the effect of clickers alone because data was available for only one semester (Fall 2005). However, based on course history from Fall 2001 to Spring 2005, the raw class average remained relatively constant without the addition of clickers, while a 3.9% increase in the Fall 2005 semester indicates a slight improvement in student performance with the use of this technology. The reorganization of the laboratory structure seems to have led to a significant change in material retention and student attitudes, with an 11.5% increase in the raw class average over the course of two semesters. Both modifications will remain in place for upcoming semesters, and additional data will be analyzed to determine whether these trends continue.

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