AC 2007-1748: HANDS-ON INTRODUCTION TO CHEMICAL AND BIOLOGICAL ENGINEERING

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Hands-On Introduction to Chemical and Biological Engineering

Abstract

Montana State University has revised our freshman seminar course by modeling it after Rowan University's exemplary Freshman Engineering Clinic which utilizes a hands-on laboratory approach to introduce freshman students to engineering.

In the first half of the course, innovative laboratory modules developed by faculty at MSU and Rowan were adapted and implemented. These laboratories utilize common activities (such as brewing coffee, taking blood pressure, and delivery of medication) and cutting edge research (such as magnetic resonance imaging and microbial fuel cells) to teach fundamental engineering principles, techniques for experimental measurement, data representation and analysis, and group problem solving and communication skills. Many of these laboratories are designed to build upon the student's current base of knowledge and experience. A unique aspect of these lab units is that many concepts are taught in an inductive learning format. Students are asked to predict experimental outcomes, perform the experiments, plot and analyze the data, and compare results to their predictions. All this occurs prior to exposing the student to the underlying theory, predictive calculations, and industrial applications.

In the second half of the course, student groups are asked to design their own experiment, run the experiment, analyze and interpret the data, and present their experimental design and results to peers and instructors. In this experiment, students must apply their learning from the first half of the semester to an experiment of their own choosing.

In this paper, we will briefly discuss the structure of the course and present assessment data from Fall 2004 and Fall 2005 course offerings. The assessment data include a pre- and post-course assessment exam, pre and post-course skills survey, student assessment of learning in the labs, and focus group interviews as well as the standard end-of-course instructor evaluation and course outcomes survey.

Introduction

In a manner similar to Rowan University's Freshman Engineering Clinic I, students were introduced during their first semester in the program to fundamental engineering concepts using a hands-on laboratory approach. Innovative laboratory modules were designed and/or adapted from published materials. These laboratories utilize common activities (such as brewing coffee, taking blood pressure, and delivery of medication) to teach fundamental engineering principles, techniques for experimental measurement, data representation and analysis, and group problem solving skills [1,2,3]. Many of these laboratories are designed to build upon the student's current base of knowledge and experience. Through hands-on laboratories and follow-up seminars, the students were also introduced to the breadth of traditional and non-traditional careers available to graduates in chemical engineering. A unique aspect of this laboratory based course is that most concepts are taught in an inductive learning format. Students were asked to predict experimental outcomes, perform the experiments, plot and analyze the data, and compare results to their predictions before being exposed to the underlying theory and predictive calculations. By incorporating the concepts within innovative/hands-on activities, it is expected that the students will personalize the learning, thereby leading to improved mastery, retention, and transferability. The course change was initiated fall semester of 2003 by incorporating selected laboratory modules into the existing one credit seminar-based course. In fall 2004, the course was expanded to two credits with the addition of several more laboratory units. The resulting course was formatted as a one credit seminar which meets one hour per week and a one credit laboratory which meets two hours per week.

The revised freshman seminar course that we developed is based on the findings of research on learners and learning as presented in How People Learn: Brain, Mind, Experience, and School, a National Research Council publication. The three key findings of research on learners and learning outlined in the NRC publication are[4]:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside of the classroom.
2. To develop competence in an area of inquiry, students must:
    a. have a deep foundation of factual knowledge,
    b. understand facts and ideas in a conceptual framework, and
    c. organize knowledge in ways that facilitate retrieval and application.
3. A metacognitive approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

The format for the course is as follows. Lab/recitation sections meet for two hours each week on Wednesday or Thursday and the seminar section meets for one hour each week on Friday. Lab sections have been limited to 9 students in order to provide more intimate contact between the instructor(s) and the students. Lab groups are limited to 3 students as we have found that in groups with 4 or more students, one or more students may not fully participate in the exercise. Prior to the lab session, each group must meet to discuss the lab and assign team responsibilities which consist of a team leader, data recorder, and worker. At the beginning of most experiments, the group will be asked to predict a particular outcome of the experiment and explain their prediction. The group then performs the experiment, plots and/or analyzes the data, and compares the outcome to their initial prediction. Computers are available in the lab for "on the spot" data entry and analysis. If the outcome differs from their prediction, they will then be asked to postulate why the outcome differs and formulate a new explanation. Only after the students spend some time working with data and attempting to explain trends do we expose them to the underlying theory. After discussing the theory, we often ask the groups to make predictive calculations based on the theoretical relationships and compare the predictions to the data obtained in the experiment. This format of inductive teaching is fully supported by educational research as described in How Students Learn: "A critical feature of effective teaching is that it elicits from students their preexisting understanding of the subject matter to be taught and provides opportunities to build on –

or challenge – the initial understanding… Numerous research experiments demonstrate the persistence of preexisting understandings among older students even after a new model has been taught that contradicts the naïve understanding… For the scientific understanding to replace the naïve understanding, students must reveal the latter and have the opportunity to see where it falls short[4].” Moreover, active learning techniques, group problem solving, and scientific investigations involving real-world contexts seem to be particularly advantageous for retaining women and minority students in the engineering curriculum[5]

The lab units have been sequenced such that the skills and concepts learned each week form a foundation for concepts developed in subsequent weeks. The order of teaching concepts in this course is modeled after that presented in the text Elementary Principles of Chemical Processes[6]. This is a required text for this course and is also used in the sophomore level material balance course. A schedule for the Fall 2005 course offering is shown in Figure 1.

For the past three years a significant portion of the laboratory has been a student-designed experiment where groups of two to three students design their own experiments, run the experiments, analyze the collected data, run follow-up experiments, and present their results to their peers. The student-designed experiment provided a much needed component to the introductory laboratory: application of learning. The student-designed experiment offers students the opportunity to take what they’ve learned and apply it to an experiment of their choosing. Students had dedicated time with an instructor for experimental plan development. Students were then required to propose their ideas to both instructors and other lab groups prior to experimentation. Each lab group had up to six hours in the laboratory to complete their experiments. Finally, students gave a formal presentation about their experimental design and results. Students design their experiments as they choose, including identifying the experimental parameters and data collection methods.

Figure 1. Course Schedule

Week	Lab Topic	Seminar Topic
8/29 to 9/2	Course Introduction, Blood Pressure Lab, and Problem Solving	Pre-assessment surveys • Bring calculator
9/5 to 9/9	Drug Delivery I • Read Lab Handout • Read F&R Ch 1, 2.1 to 2.3	Significant figures and dimensional homogeneity • Read F&R 2.5a,b and 2.6
9/12 to 9/16	Drug Delivery II • Read Lab Handout • Meet in computer lab (Cob 308)	Linear interpolation and linear curve-fitting of non-linear data • Read F&R 2.7
9/19 to 9/23	Coffee Leaching I • Read Lab Handout	Elementary statistics • Read F&R 2.5c,d
9/26 to 9/30	Coffee Leaching II • Read Lab Handout	Chemical composition • Read F&R 3.1, 3.3
10/3 to 10/7	Fluidized Bed Polymer Coating I • Read Lab Handout • Read F&R 3.2, 3.4,3.5	Industrial Applications of Leaching
10/10 to 10/14	Fluidized Bed Polymer Coating II	Nuclear Submarines
10/17 to 10/21	Biological Fuel Cells	Biological Engineering
10/24 to 10/28	Introduction to term project	Materials and Product Design
10/31 to 11/4	Developing the Experimental Plan	**Exam**
11/7 to 11/11	Presentation of Experimental Plan	No class – Veterans Day
11/14 to 11/18	Student Designed Experiment	MRI Research in Antarctica
11/21 to 11/25	Student Designed Experiment	No class – Thanksgiving
11/28 to 12/2	Student Designed Experiment	PowerPoint Basics
12/5 to 12/9	Student Presentations	Wrap-up and course evaluation

Assessment Methods

We developed an assessment model for the course which included both quantitative and qualitative data collection. For the first two years of the project, students were informed of the research procedures and were asked to sign informed consent forms prior to participating in data collection. Students who participated in the first year of the course were also asked to participate in a focus group one year after their experience. In addition, we triangulated the results with field observations in the lab and by conducting a focus group with senior chemical engineering students who were completing their degree requirements and who had *not* experienced the hands-on introductory course during their first year curriculum.

Data Collection. Students completed a pre-test of chemical engineering knowledge and a pre-test survey of attitudes and self-reported skills in the first week of the course. The same test of knowledge was administered as a post-test and final exam during a regular class period just prior to the beginning of the student-designed labs. The post-test of attitudes and self-reported skills included the pre-test items and some additional items measuring student engagement in the various lab exercises and was administered in the final class meeting. These instruments were designed specifically to assess the objectives of this course. As a final assessment of the course, we compared the student evaluations for the new course with those of the previous iteration of the introductory course without the hands-on lab component.

In addition to completing the knowledge, skills and attitudes assessment measures, students in the first two cohort years were also asked to participate in a focus group during the last class period. We also conducted two one-year follow-up focus groups with the first cohort of students and a focus group with seniors who had not taken a hands-on introductory course near the end of fall semester of the second year. All focus groups were conducted by the third author in the role of independent evaluator or her designated assistants so that students could be assured that their honest discussion of the course would not affect their grades. All focus group interviews (13 groups total) were transcribed verbatim by a paid transcriptionist and were analyzed and coded for themes. Pre-test and post-test data were analyzed using paired t-tests.

Student absenteeism on the days we collected assessment data resulted in a few missing cases. The pre-test sample size for the chemical engineering knowledge test for year one was n= 36 and for the knowledge post test was n=34 resulting in a 94% response rate. The sample size for the pre-test of attitudes and skills for year one was n=35 and the post-test for that cohort was n=31 (response rate = 88.6%). For the second year cohort, knowledge pre-test and post-test were both n=37 (100% response rate) and the attitudes pre-test and post-test sample sizes were n=37 and n=34 respectively (91.9% response rate). The combined cohorts therefore had a pre- and post-test knowledge response rate of 97.3% (N=71 and N=73) and a pre- and post-test attitudes response rate of 90.3% (N=72 and N=65). In addition, in analyzing particular items, there was some item non-response, so the final N for each analysis varied from N=72 to N=62.

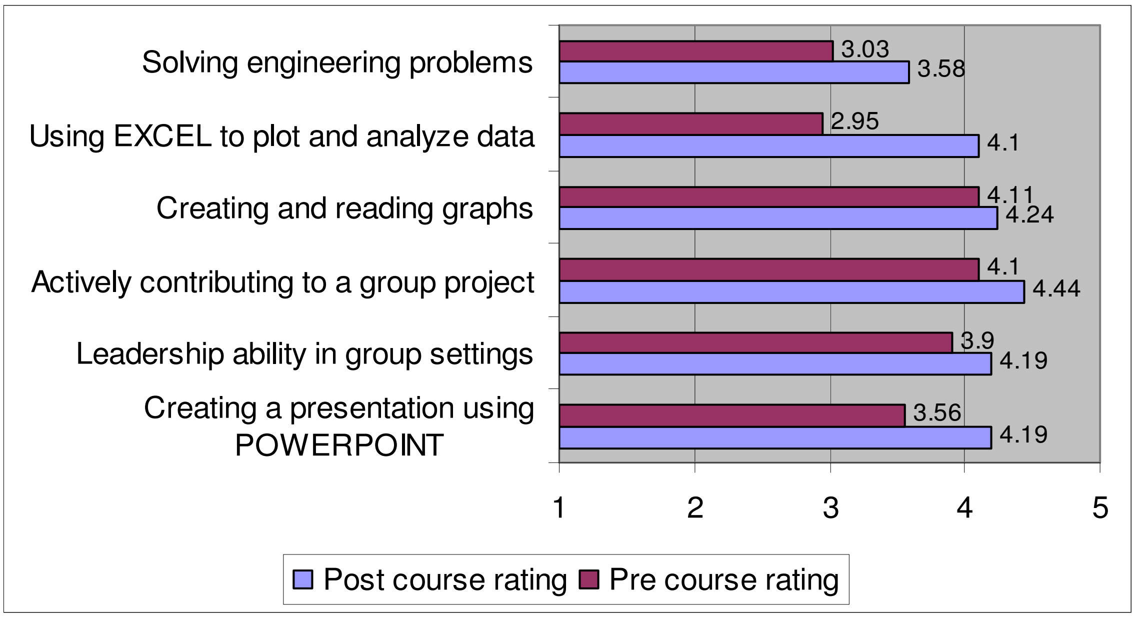
Assessment Results

As might be expected students scored significantly higher on the post-test of engineering knowledge than they did on the pre-test. The mean score on the pre-test was 42.3 (n=71, sd = 13.5) and on the post-test, the mean score was 84.1 (N=71, sd =12.8). We tested the difference between these means with a paired t-test which was significant well below the .05 alpha level (t = 23.08, df=70, p=.000). Students in the course made significant gains in learning the required course material. An interesting and unexpected outcome from our assessment strategy was that students commented frequently on the knowledge gained in the course based on the pre-test. One student commented, "I was surprised how much I learned and not even realizing it. At the beginning of the year, we took that pre-test and I failed it. We had to take it again at the end of the year and I aced it. I didn't realize I had gone over all of that."

Students also self-reported their knowledge of the field of chemical and biological engineering and their knowledge of professional practices in chemical and biological engineering on the pre- and post-course assessments. On both items, students rated themselves as having gained knowledge of chemical engineering (t_{field} = 4.85, df=63, p=.000, ($t_{profession}$ = 5.66, df=63, p=.000).

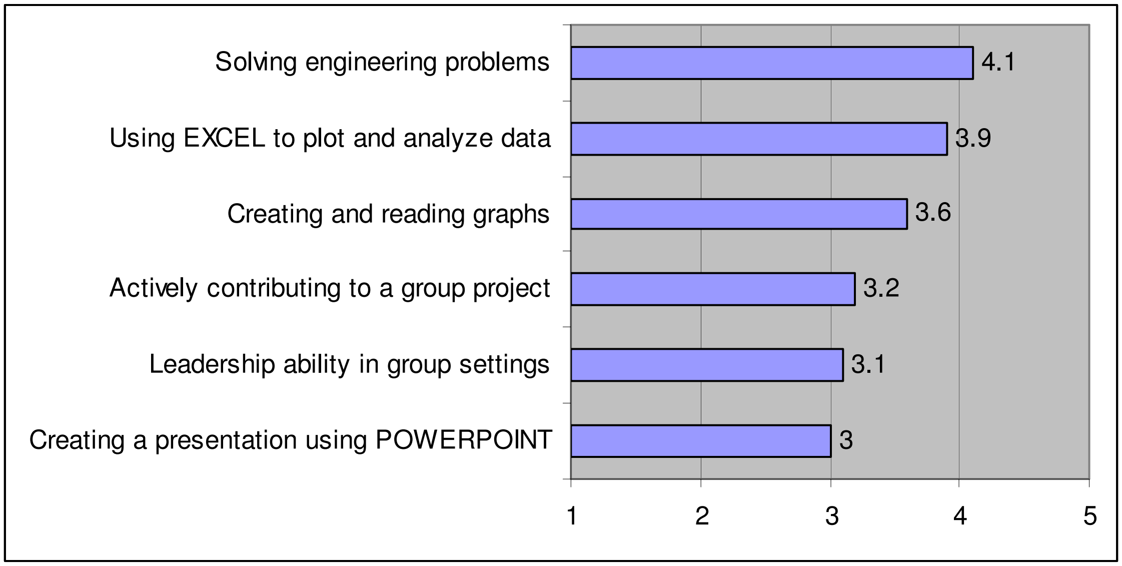
On the six skill items (EXCEL, PowerPoint, engineering problem-solving, group participation, leadership, graphing) students rated themselves significantly higher on their post-test skill assessments in all areas except creating and reading graphs. Figure 2 shows the students' pre- and post-course mean skill assessments

Figure 2. Student Assessment: Pre and post-course rating of skills
Rating scale: 1 = Not skilled 3 = Some skill 5 = Very skilled



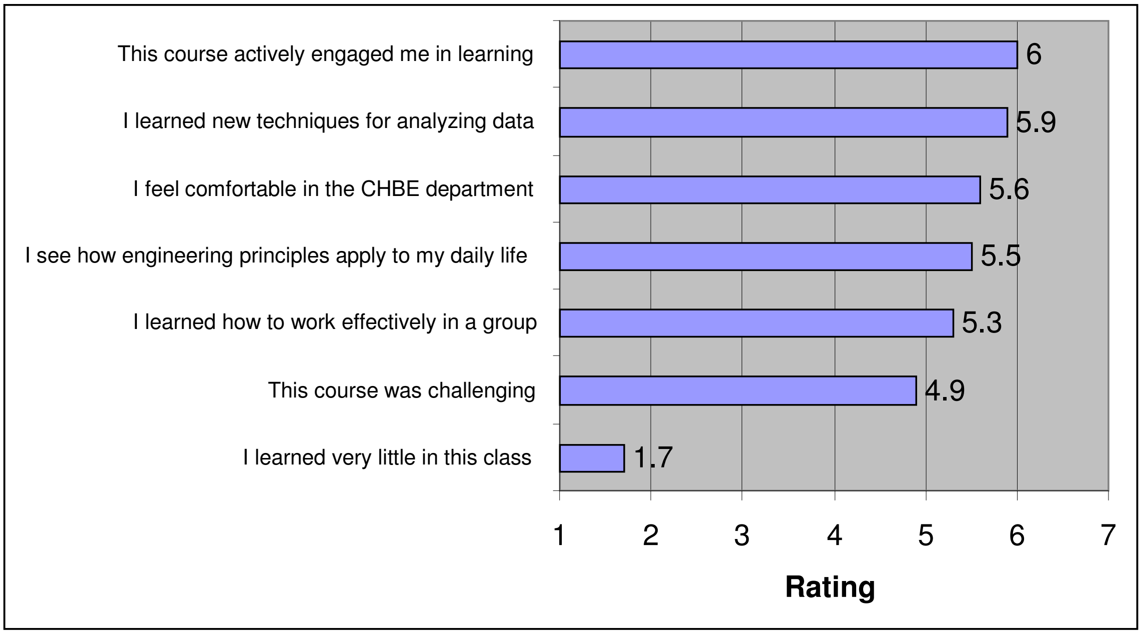
Since students will, at times, over estimate their skill level at the beginning of a learning experience we also asked students directly to estimate the improvement in the six different skill areas on the post-course assessment. As shown in Figure 3, students estimated that their skill in solving engineering problems showed the greatest improvement (X=4.1 on a 1-5 scale). The rated their improvement on creating PowerPoint presentations as the smallest gain. Interestingly, while their skill estimates from pre- to post-course assessment were not significantly different, students rated their improvement in creating and reading graphs in the mid-range of some improvement (X=3.6).

Figure 3. Student Assessment of Improvement in Skill Level
Rating scale:
1 = Did not improve 3 = Some improvement 5 = A great deal of improvement



On the post-course assessment we also asked students to respond to some general attitude items which were created to correspond with overall course re-design objectives. We wanted to see if the course as a whole was having a positive effect on students. As shown in Figure 4, students showed very positive attitudes toward active learning (X=6.0 on 1-7 scale) and learning to analyze data (X=5.9). The students also responded well above neutral to items asking their comfort level in the department, the application of chemical engineering to everyday life and learning to work effectively in groups. In essence, students responded positively to the items corresponding to overall objectives of the course.

Figure 4. Student Assessment: General Impressions
Rating scale: 1 = Disagree strongly 4 = Neutral 7 = Agree strongly

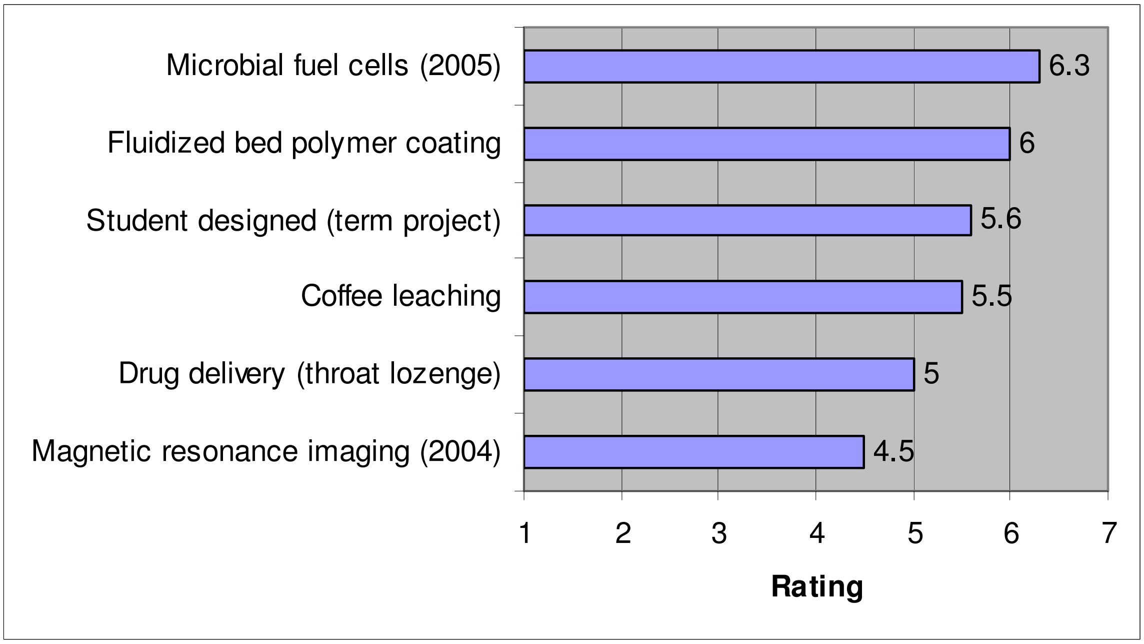


Finally, we were interested in the relative effect of the various lab experiences. Figure 5 presents the student ratings of learning in each of the main laboratory modules. Students reported learning a moderate to an extensive amount of learning in all lab modules but rated the 2005 microbial fuel cell lab and the fluidized polymer bed lab the highest. As one student noted about the microbial fuel cell lab: "Especially with the microbial fuel cell lab. If you are going to major in this business, it is something you could potentially be doing and it gave us a lab session where 'Hey, this is what life might look like in four years.'"

Students rated the student-designed experiment as contributing to their learning, although for this particular lab, students responded on the full range of the scale, with some students rating the lab at a 1 and others at a 7. The average rating was 5.6. In the focus groups, students also disagreed on the value of this lab with one student commenting "[The Student designed labs] took a little bit of extra effort. I think you got more back from it, as well, having put so much of ourselves into it. It combined all those skills we gathered throughout the semester." Other students remarked that the nature of this lab mimicked potential future experiences, both in required senior capstone projects and in real-world work situations. They believed their experiences would be beneficial in preparing them for these future challenges.

Figure 5. Student Assessment of Learning in Labs

Rating scale: 1 = Little to no learning associated with this lab 4 = A moderate amount of learning 7 = Extensive learning associated with this lab



The data in Figure 6 is from the standard "end of course" student evaluation of the instructor. A comparison is made to the former "Freshman Seminar" course that consisted primarily of faculty led seminars about various aspects of chemical and biological engineering. In every category, the newly-designed course was evaluated in a more positive light than the previous, seminar-style course. One student had this observation "I went to a high school with a buddy I played hockey with. He was three years older than I am. He came to MSU and he was in the chemical engineering degree as well. He said he didn't have this class or the class was a lot smaller than it is now. He really regrets not having this opportunity. I think it is a great way to start you into chemical engineering or any degree, no matter what it is. Just kind of ease you into it and give you a background of where we are going and what chemical engineers actually do instead of just throwing it all at you your sophomore year."

Figure 6. End of Course Student Evaluation
The numerical rating system used in this evaluation is:

1 = Excellent
2 = Above Average
3 = Average
4 = Below Average
5 = Poor

Survey Question	**Former Course Rating Fall 2002**	**Current Course Rating Fall 2004**
Organization of the course was:	2.26	1.44
Presentation of the material was:	2.05	1.33
Was the instructor prepared?	1.74	1.03
Was the grading impartial and fair?	1.44	1.21
Was the instructor concerned for the student?	2.32	1.33
The instructor's ability to answer questions was:	1.79	1.21
The instructor's knowledge of the material was:	1.47	1.06
What overall rating do you give the instructor?	1.95	1.09
How useful to learning the material was the homework?	3.1	1.69
Did the course provide a good learning experience for you?	2.21	1.33
The resources (equipment, help) for the class were:	2.41	1.15
How does this course compare to other technical courses?	2.56	1.43
Average Rating for Course	**2.07**	**1.27**

Conclusion

The data presented offers a strong argument that the development and implementation of an introductory laboratory-based freshman course at Montana State University has better prepared students for their education in Chemical Engineering. Students feel actively engaged in the learning, and feel comfortable in the department. Students also felt that their problem solving skills had improved over the course of the semester. Compared to the previous seminar-style course, end-of-course evaluations indicate that students prefer a hands-on introduction to Chemical and Biological Engineering.

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