ChemECar Experiments in a Chemical Engineering Freshman Seminar

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Abstract

This paper describes experiments with a ChemECar used in a new chemical engineering freshman seminar at Vanderbilt University. The 1 credit hour course is designed to introduce freshman to the field and profession of chemical engineering by using examples from cutting-edge research. The goal is to expose students to chemical engineering in their first semester providing them an earlier chance to catch the excitement of chemical engineering and helping them make better-informed decisions regarding their educational plans. One 4 week module of the course was based on examining and experimenting with a fuel cell car to be used in the AIChE ChemECar contest. Each class period student teams were presented with an open-ended question such as how does the car work, how fast does it go, how much weight can it carry, what "mileage" does it get, etc. Teams designed simple experiments using basic measurement tools and items available in the classroom. Experimental results from all teams were compiled and used to try and answer the question of the day. At the beginning of the next class, the results and proposed explanations were examined in detail and the theory behind the experiments was discussed. Throughout the module concepts such as experimental error, uncertainty, data analysis, and technical writing were introduced and reinforced. The impact of the seminar, and the ChemECar module in particular, on student attitudes and understanding of chemical engineering will be presented.

Introduction

Chemical engineering students at many universities receive little if any exposure to chemical engineering as freshmen, taking primarily large lecture courses in math, physics, chemistry, and general engineering. Often students do not begin to see the big picture of the chemical engineering profession until the senior capstone design course. Consequently, students form impressions of chemical engineering, make decisions on which major to pursue, and set expectations for the college learning environment early in their college career based almost entirely on non-engineering courses and professors.

Many engineering programs across the country have modified their freshman curricula to address these challenges. A variety of approaches has been used including general engineering courses, design-based courses[1, 2], orientation courses[3-5], and seminars[6, 7]. The Vanderbilt University School of Engineering has recently introduced a variety of freshman seminar electives for the purpose of providing students greater access to engineering faculty, helping them make more informed career choices, and developing diverse learning and problem-solving skills[8]. These seminars are one-semester hour courses, taught entirely by full-time professors, with a limited student enrollment (typically 10-15 students). In recent years, over half of the freshman engineering students have elected to participate in a freshman seminar. Faculty involvement is voluntary and professors are free to teach on anything within their area of expertise. Seminar topics are wide-ranging as evidenced by some of last year's offerings: Hi-Fidelity Sound Reproduction, The Second Law of Thermodynamics, Laser Vision Correction, Fundamentals of Engineering Ethics, and Frontiers in Chemical Engineering.

Frontiers in Chemical Engineering Freshman Seminar

For the past five years I have helped teach the "Frontiers in Chemical Engineering" seminar as part of the Vanderbilt freshman engineering seminar program[9]. Different professors spend three to four weeks teaching a unit that is focused on their research area. The class meets for 75 minutes once a week for a total of 15 weeks. The course is designed so that different research units can rotate or be replaced from year to year depending on faculty availability and interest. During the past five years, we used examples from the modern chemical engineering topics of biopharmaceutical production, semiconductor fabrication, atmospheric particle formation, molecular self-assembly, and hydrogen fuel cells to introduce the profession and principles of chemical engineering. The seminar has enrolled between 9 and 15 students each year, with a total of 32 intending to major in chemical engineering, and 23 from other majors who were considering or were otherwise interested in chemical engineering.

In designing the course, we identified the objectives listed below.

- Explain what a chemical engineer does
- Introduce students to chemical engineering principles.
- Provide students with an introduction to non-traditional chemical engineering topics.
- Excite freshman about engineering and chemical engineering
- Provide an opportunity for freshman chemical engineers to get to know each other and the chemical engineering faculty

Within the individual research units, each objective is targeted. The goal is for students to see several different fields within chemical engineering, to see different applications of the same principles, and to interact with different faculty members.

ChemECar Module

Last year, one 3 week module of the course was based on examining and experimenting with a fuel cell car to be used in the AIChE ChemECar contest[10]. The 8" car is powered by a reversible PEM fuel cell that generates electricity to run an electric motor by converting hydrogen and oxygen to water. When operated in reverse, a battery or solar panel provides electricity and the fuel cell separates water into hydrogen and oxygen that are stored for later use. At the beginning of the module, the class was divided into teams of 3 or 4. Students were allowed to select their own groups, but since this occurred in the second week of the semester the freshmen did not know each other yet, making the selection process fairly random.

Each class period the student teams were presented with one or two open-ended questions to answer including:

- How does the car work?
- How fast does it go?
- How fast does it go now (on different surfaces, inclines, etc.)?
- What else can we study (design your own experiment)?
- What "mileage" does it get?

In the first class period we looked at the question of how does the car work. Before presenting any background information, we took the car outside, connected the electric motor, and watched it run in the sunlight for a minute or two. Some of the students quickly guessed that the solar panel was powering the car, but they were unaware that it was also generating hydrogen and oxygen. After a minute or two, we brought the car back inside and saw that it continued to run, albeit more slowly, even without sunlight. The students' first guess was that the hallway lights were driving the motor, but even after covering up the solar panel it continued to run.

At this point we returned to the classroom and I had each group of students examine the car more closely. Each team then came to the board and drew one part of the car and explained what they thought its function was. The composite picture did not say much for the artistic abilities of the class, but helped the students visually break the car into its component pieces. The first few parts were easy to identify (wheels, so the car can roll; solar panel, to convert sunlight to electricity; axles to connect the wheels; wires, to allow electricity to flow). More difficult were the electric motor and water, hydrogen, and oxygen compartments.

The fuel cell itself, however, remained a mysterious rectangle with tubes and wires that somehow provided electric power. After telling them it was a fuel cell that generated electricity by combining hydrogen and oxygen to make water it was still just a mysterious rectangular box. Engineering freshman at Vanderbilt are required to have laptop computers, so they spent a few minutes finding a good internet source about fuel cells. As a homework assignment they were asked to write a half page description of how fuel cells work and come prepared to share their findings with the class.

This exercise followed a challenge-based learning-cycle approach[11]. First, the car was demonstrated briefly and a question was posed - how does the car work. Students generated an initial answer (solar power) which was partially, but not entirely, correct. Next they conducted additional research, running the car inside, then without the solar panel, then examining the car in detail. At each step they continued to revise their conclusions based on what they observed and in response to the ideas presented by other groups. Then, when their curiosity had been aroused and they were motivated to learn, they began reading the technical details of how a fuel cell operates. Finally they had the opportunity to organize all their thoughts and present to the class what they had learned.

The next question the student teams were given was "how fast does the car go?" Again, a challenge-based learning framework was used. After some brainstorming about possible methods to measure velocity (i.e., a radar gun was neither available nor likely to be accurate enough to measure the slow moving car) a tape measure and stopwatch were produced. Students then selected a hallway as the best location for their "time trials." Teams took turns measuring either the time required to travel a given distance or the distance traveled in a given time. Teams used slightly differently approaches for taking the time and distance measurements. Data was recorded in a laptop computer as the measurements were taken.

As each team finished taking their measurements, they returned to the classroom and began analyzing their data. As homework for the next class period, they were asked to calculate the car's velocity, make a plot of velocity vs. distance, and describe in detail all significant features of the plot. Shown below in Figure 1 is a plot of all the student data, followed by a summary in Table 1 of the reported velocities and conclusions from the four student teams.

Figure 1. Velocity data from student teams

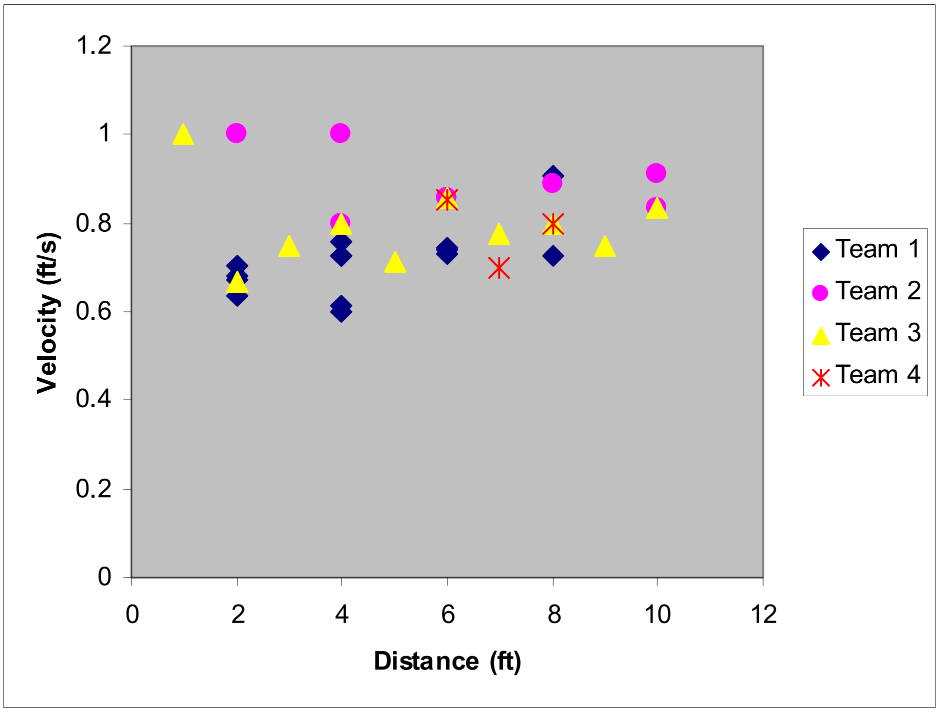


Table 1. Velocities and comments reported by student teams

Team	Reported Velocity (ft/s)	Comments on Acceleration
1	0.724837	velocity constant, then increases
2	0.9034	velocity decreases, then increases
3	0.794921	velocity slowly increases
4	0.78	can't tell from only 3 points

Not surprisingly, the calculated velocities varied from team to team. After writing each velocity on the board, I asked the question which answer is correct? This led to a mini-lecture on uncertainty, measurement errors, and proper use of significant digits. The topic of significant digits was a recurring theme throughout this and other modules. By giving students the opportunity to take measurements and "discover" experimental error on their own they became much more receptive to my lecture, since they had a concrete experience to build from.

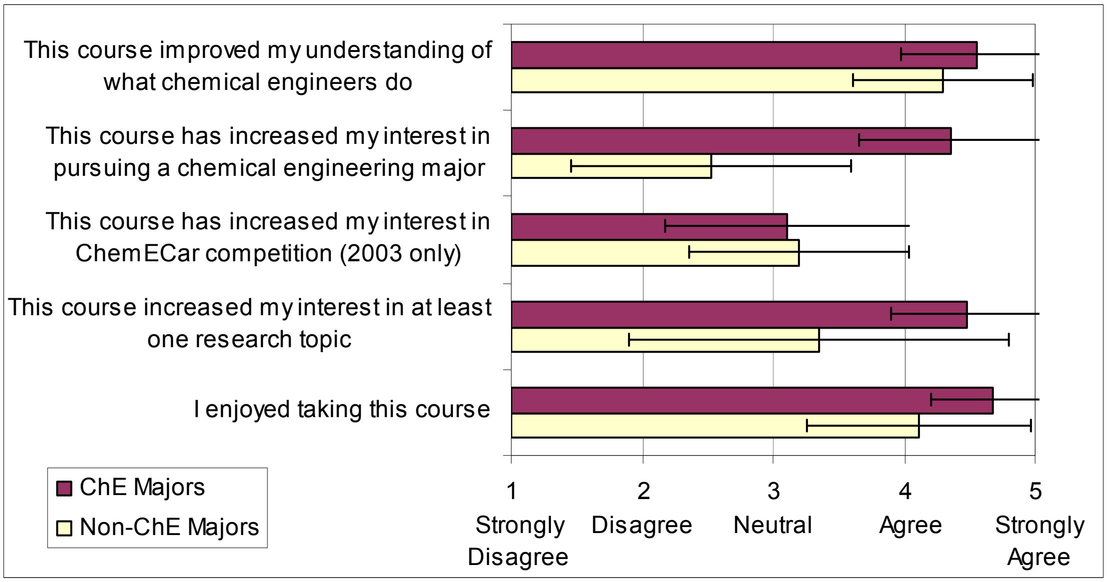
Here again it was interesting to observe the evolution of the students' understanding as they gained additional information and perspectives. After watching the car run several times, the general consensus of the students was that the car started slowly and continued to accelerate for 5-10 seconds. After analysis of the data, this initial conclusion was revised, as they realized the velocity changed little, but most still claimed the car had a some amount of acceleration or deceleration. After looking at other groups data and the discussion of uncertainty they ultimately concluded that the velocity was approximately constant.

As other questions were posed and answered during this module, these concepts were reinforced. Each time measurements were taken, students plotted the data, described the plots in words, and tried to interpret what the data meant. While their efforts were often characteristic of freshman, this was at least an introduction to concepts of data analysis and interpretation, technical writing, uncertainty and experimental error that will be revisited throughout the engineering curriculum.

Course Assessment

Achievement of course objectives was assessed with anonymous surveys at the beginning and end of the semester. Responses to several questions from the 1999-2003 end of course surveys are shown in Figure 2. Virtually all students, whether chemical engineering majors or non-majors, agreed or strongly agreed that the course improved their understanding of what chemical engineers do, with slightly higher ratings from chemical engineering majors.

Figure 2. Student responses to end of course survey



A larger difference was observed between majors and non-majors on the question about interest in pursuing a chemical engineering major. After taking the course, chemical engineering majors were more interested in continuing to pursue a chemical engineering major, while non-majors tended to become less interested. This suggests that the course has been more effective at confirming students original selection of major, rather than recruiting non-majors into chemical engineering. Written student comments support this view, with chemical engineering majors saying "now I am sure this is what I want to major in," and non-majors saying "I found out that I do not want to be a chemical engineer and that other fields interest me more."

Both sets of students tended to agree or strongly agree that they enjoyed taking the course. That non-majors, despite a demonstrated preference for other engineering majors, enjoyed the course is taken as a sign that the course is providing the desired positive experience for freshman engineering students.

Faculty response to the seminar has also been favorable. We have appreciated the opportunity to get to know our students early in their college careers. As we encounter them in other courses, we find that we have already established a relationship with them, which helps us to connect better with the entire class. Presumably, this experience is reciprocated and students also feel more comfortable interacting with us.

Looking specifically at the ChemECar module, most of the students in the 2003 class remained neutral about participating in the AIChE contest. In future years it may be desirable to involve upperclassmen from the ChemECar team and organize experiments more directly around the competition. Written comments indicate that students enjoyed the hands on aspect of this module, but that it may have been too long. "The ChemECar was interesting, but we may have spent too much time on it." By the third class period, some felt like they were just playing with the car again, and not learning anything new. One improvement I am planning for next year will be to increase the technical content within this module, going into greater detail when presenting uncertainty concepts, and incorporating more chemical engineering principles.

On a positive note, students' use of significant digits seemed to improve. On the first homework assignment, 3 out of 4 teams reported a velocity with at least 4 digits. By the last assignment, all four teams were using an appropriate number, several including an estimated uncertainty, suggesting that they had, at least temporarily, learned this concept.

Overall, the course has been quite successful. Students have learned more about chemical engineering, and by exposure to different research areas, they have gained a clearer view of the wide scope of opportunities available in the profession. Perhaps most importantly, freshman engineering students have had the opportunity to begin their college experience working closely together with other engineering students and with engineering faculty. The experience has proven enjoyable and beneficial for all involved. The format of the course is flexible and should be easily adaptable to other engineering departments.

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