Involving High School Students in an Engineering Fluid Mechanics Course Project

David O. Lignell, Matthew J. Memmott, April A. Andersen
Brigham Young University/Brigham Young University/Mountain View High School

Abstract

The Chemical Engineering Department at Brigham Young University teaches a junior level Fluid Mechanics course. This course is required of all undergraduates and typically has an enrollment of 100 students. The course includes a class project in which groups of around five students work independently for several weeks. Groups identify a problem in fluid mechanics; write a 1-2 page proposal, which is reviewed for safety, cost, feasibility, and appropriateness; gather and analyze data; then give oral presentations of the project to other students in the class. Students really enjoy the projects. They are open-ended, allow students to solidify concepts learned in class, and allow for creativity and problem solving. Examples of projects have included creating parallel pipe networks and measuring fluid flow, fitting coefficients, and friction factors; and making a water bottle rocket and modeling the pressurized nozzle flow and resulting height predictions. Students are given detailed project instructions and a list of questions to inspire ideas. Examples of such questions include "how do tall trees get water to the leaves at the top; how does a boomerang work; and why do curve balls curve?" Over the past several years, we have included high school students taking AP Physics in these groups. This outreach was part of an NSF outreach program. Project groups consist of two high school students paired with three BYU students. BYU students are given a unique opportunity to mentor younger students, and solidify their own understanding as they teach others. The High School students visit campus, interact with students and faculty, and learn more about engineering. We discuss logistics issues related to BYU student training, legal requirements, and safe group interactions. Examples of successful projects are given, along with lessons learned from the interactions.

Keywords

Engineering Project, High School Outreach

Introduction

Science, technology, engineering, and mathematics (STEM) are ever more important areas of education in an era of unprecedented technological advances. The is especially true when considering the needs of an expanding global population with increased claim on high standards of living, necessitating abundant energy to deliver clean water, adequate food, and safe living environments.

The U.S. Department of Labor Bureau of Labor Statistics[1] report that STEM jobs represent only 6.2% of U.S. employment, but 93 of 100 STEM jobs have wages above the national average. In addition, they report that STEM occupations grew by 10.5% from 2009-2015, compared to 5.2%

in non-STEM occupations. The National Science Foundation[2] has long emphasized STEM educational outreach, and competitive NSF proposals often have significant outreach programs that are part of the required Broader Impacts of a project[3].

One of the difficulties of introducing new students to STEM careers is a simple lack of knowledge of the wide range of options available as students begin university studies. The high school background of most STEM-bound students is limited to single fundamental math and science courses: math, physics, chemistry, biology, sometimes an engineering/technology related course. At the university, in just engineering, students can choose from half a dozen majors, including Chemical, Mechanical, Civil, Electrical, Environmental, Biological, and Materials Engineering. Each of these majors will include dozens of courses on separate topics. (It is no wonder that so many students change majors at least once.)

Engineering departments work very hard to teach students to become engineers. Besides teaching raw technical abilities, graduates are expected to become creative problem solvers, effective leaders, ethical and safety-minded, and, notably, good at working on teams. One very effective way of teaching these skills is through team-based class projects.

This paper describes one such engineering class project, and new efforts to include high school students on the teams. The project was part of a junior level Fluid Mechanics course project taught in the Chemical Engineering Department at Brigham Young University. The project was supported by a National Science Foundation research grant. This project was one of two outreach efforts that were part of the required Broader Impacts portion of the project. (The NSF grant was on computer simulations of soot formation in turbulent nonpremixed flames, which involves significant fluid mechanics concepts.)

In the following sections, we provide a detailed description of the project, our efforts to connect with and select high school students, logistical issues, and lessons learned. This effort has been a success and we have continued the high school and college collaboration on the project beyond the original requirements. Navigation of significant issues to the development of this project required special attention, and we hope that this paper will aid others who would like to do similar work involving high school students in college programs.

Project Description

The BYU Chemical Engineering Department teaches a required three credit hour junior-level course in Fluid Mechanics—ChEn 374[4]. This course covers a range of technical topics, such as

- Fluid properties and pressure statics
- Mass, momentum, and mechanical energy balances
- Laminar and turbulent pipe flow, including relations between elevation, flow rate, pressure drop, pipe length and diameter, and pipe roughness. Series and parallel pipe networks are covered
- Pump and turbine design
- Drag laws and boundary layers
- Compressible flows including choked flow and converging/diverging nozzles
- Non-Newtonian fluids

- Differential balances and computational fluid mechanics (CFD).

The class is fairly technical, but there are many practical applications that help students develop a conceptual understanding to match the mathematical description of the processes involved. The course is organized in a standard fashion consisting of three one-hour lectures per week, with required reading from a textbook and homework assignments associated with each lecture.

The course includes a class project that has be used and passed on to several faculty over the years. The idea for involving high school students in a fluids class project came from Dr. Larry Baxter, a faculty member in Chemical Engineering at BYU. He involved students in a class project similar to the one presented here from 2001-2005. The project is normally performed in the second half of the class, and students are given 5-6 weeks to complete the project. The timing of the project allows students to practice the techniques they have learned in the first half of the class. This class project has been held during fall semesters. The fluids class was not taught in winter semesters until this past winter 2017. That class is taught by a new faculty member, and has only around twenty students so that the number of groups available for HS student participation would be much smaller. It is likely that the HS students would have a better experience if the project were held during the winter semester since they would have more physics training. The projects are performed in teams of four-to-six students. The projects are completely open-ended and students come up with the project topics themselves. The **goals of the project** are to

1. help students connect fluid mechanic principles with observations and hands-on experience;
2. enhance teamwork and communications skills;
3. develop problem solving skills on open-ended problems;
4. be fun.

Students are given a detailed write-up of the project tasks, and given autonomy in completing and recording each part of the project. The projects consist of the following four parts:

1. A **written proposa**l to the professor.
2. **Experimental work**, data collection, and analysis.
3. **Oral repor**t given to the class in the form of a PowerPoint presentation.
4. **Leadership feedback**.

The **proposal** is a 1-2 page "memo to your boss," and assumes the boss is technically trained, but may not be familiar with the project. The proposal includes:

1. An objective statement (what problem is being solved).
2. Methods used, including equipment to be assembled (diagram); measurements to be taken; information to be gathered from the literature or online; and detailed safety precautions (this is emphasized).
3. Analysis, such as mathematical relationships.
4. Resources required, including the number of person-hours and a timeline. Students normally spend 10-12 hours each on the project. Equipment and supplies are also listed. Past projects have included limited budget of up to $20 per group for supplies such as card board, buckets, PVC fittings, and tape. Students are pretty good at scrounging equipment on the cheap, and sometimes getting donations from the local hardware store.

5. The team structure and roles of the group, such as team leader, presentation coordinator, proposal coordinator, materials specialist. The leader role can be rotated.

The proposal is reviewed by the professor and must be approved before students can begin. A separate class project approval form was required that detailed the project and listed safety guidelines. This was to be approved by the department safety officer.

Experimental work is done on campus. Depending on the nature of the project, this might be done in a lab facility, a common area, or outside. The projects are reviewed for safety so that hazardous chemicals, or high pressure are precluded. Our favorite two fluids are air and water. Examples of projects are given later.

The **oral report** is a ten minute presentation given to the class, with several groups reporting in 2-3 class periods at the end of the semester. This is a PowerPoint (or other software) presentation. Most students have had previous instructions and practice in giving both technical and business presentations through our ChEn 391 Career Skills course, but basic instructions and best practices are provided to both the BYU and high school students. All group members stand together for the presentation and each student normally discusses a couple slides. Students in the audience have a grade sheet that they evaluate their peers with. This includes items such as presentation quality, creativity of the project, accuracy of the analysis, and whether they learned something new.

For the **leadership feedback** students provide each member of their group with a written statement describing at least two strengths that the member has, as well as two aspects of teamwork or leadership where the member could improve. In the project instructions, students are given a list of leadership qualities that a BYU Chemical Engineer should work to develop. These include (among others):

- Is reliable and can be counted on to accomplish tasks in a manner that exceeds expectations.
- Takes initiative rather than waiting for assignments.
- Demonstrates a good attitude on life and is pleasant to work with.
- Is culturally sensitive and works effectively with people from diverse backgrounds.
- Gives honest feedback to others and helps them succeed in their responsibilities.
- Takes time to evaluate personal performance as a team member and improves when needed.

In order to help students develop their projects, a list of around 50 “questions to inspire” are given. A few examples are:

- Why do curve balls curve?
- How does a hovercraft work?
- What is a sonic boom?
- Why does my bath tube form a hole in the water when it drains?
- Do large or small gas jets penetrate further into a surrounding fluid, and why?
- How do airplanes (*really*) fly?
- How do the tallest trees (over 100 m!) get water to the top leaves when a siphon will cavitate above around 10 m?

- How do fish swim so fast?
- How much effect to the dimples on golf balls really have?

Project Examples

Students do all kinds of experiments to quantitatively answer the fluid mechanic questions they pose. A few recent examples are:

- Building a pressure-statics based fluid mechanical speedometer for a car and testing/calibrating it.
- Building a water rocket with a two-liter bottle and compressed with a hand pump: modeling the behavior and predicting the height.
- Measuring (via video camera) the “flow” of people down some of BYU’s crowded halls and walkways.
- Building and operating a hydraulic turbine to power a light bulb and predicting the power output.
- Building a wind tunnel with a fan and cardboard and measuring forces on a sail.
- Measuring minor loss coefficients of pipe fittings using a PVC pipe network.
- Dropping balls through water in the BYU swimming pool to measure fluid viscosity.
- Designing and predicting the behavior of a hovercraft, and then building it and comparing the predictions to actual behavior.

Two representative slides from two oral presentations are shown in Fig. 1. The left image half of the image shows two slides from a project with Coke and Mentos. The students formulated a physical model of the pressurized system with a hole in the bottle cap to predict the height of the water column. The students created three trial runs with three cap holes and a control with no cap hole. A correlation between bottle back pressure and height was created. The experiment had several unforeseen problems that the students had to correct, or adjust the goals of the project as they went along. This included the effect of the built-up back pressure which varied with hole size. The second project involved creating a physical model of a dam and measuring the flow patterns when the dam was “broken.” Video was captured of the process, and the framerate used to time the different events. A grid was imposed to measure distances, and the water colored to aid visualization. Water height and reservoir length were varied and velocity was measured in dimensionless form as the Froude number (a ratio of momentum and gravitational forces).

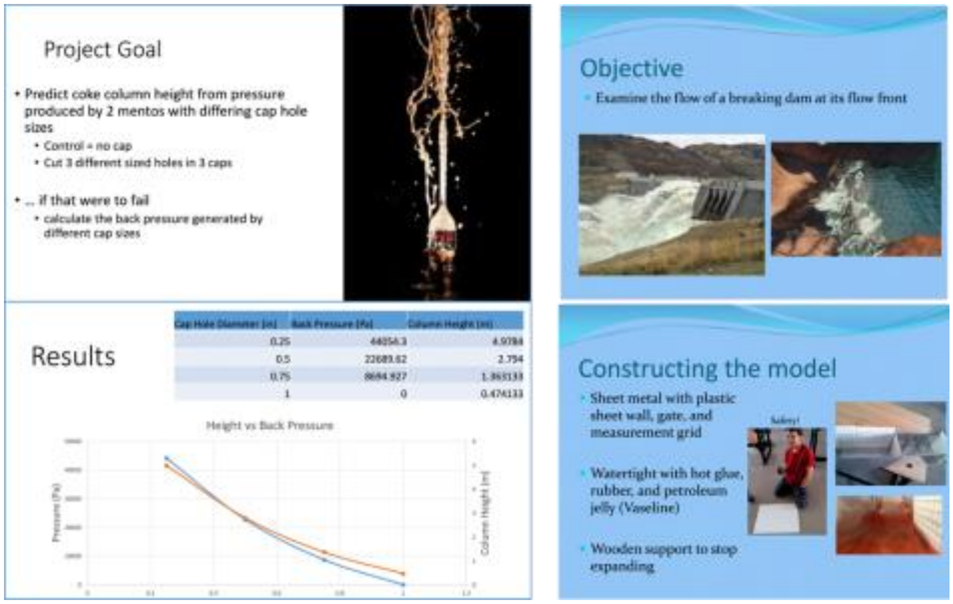

Figure 1. Examples slides from two presentations. Left: project predicting and measuring the height of a water column from Mentos and Coke. Right: project examining the flow structure of a breaking dam.

Figure 2. Oral presentation of a group project. Current presenter on the left is a Mountain View High School student.

Figure 2 shows a photograph of one of the group presentations. In this case a high school student is the current presenter, and he is reviewing the design of the experiment.

The open-ended nature of these projects should be emphasized. Practicing engineers deal with open-ended problems every day. An engineer might be given instructions like “that pump isn’t working right, figure it out;” a graduate student’s research topic might be “let’s simulate soot formation using direct numerical simulation,” and that one sentence gets expanded to a twohundred page dissertation. This is in stark contrast to the majority of coursework in a given engineering class, where small, well-defined homework problems are given to demonstrate, practice, and solidify concepts taught in lectures. But each lecture is (often) a new topic so that there is little flexibility to give truly open-ended problems. Such open problems are realistic, but not efficient: they are ill-defined, the time frame is often longer than “the next class period,” they might fail, students are all doing different things with different outcomes and timeframes. But these problems are fantastic for developing creativity, independence, and teamwork. Rather than exercise a given equation through homework, an open-ended problem requires students to formulate a problem (or many sub-problems), and then recall that some equation taught weeks ago might help in a part of the analysis. Or, maybe a given approach is too complex, so they might try a completely different tack. After all, success is related to the problem the students invent, and that problem might have to change. Many of the synthesis aspects of this project are consistent with successful learning techniques as outlined in the book *Make it Stick*[5].

Students almost universally love the projects. They normally account for a modest portion of the overall grade (10%), and are liberally graded. Students get excited about solving creative, interesting problems, and they work hard on them.

High School Student Involvement

We targeted high school students in their junior or senior year who were in an AP Physics class. Most of these students are planning to attend a university and many are interested in STEM fields, though most do not know much about the various options available. This was one of the purposes of the project, to get the students involved in an immersive experience, where they visit the BYU campus several times. Students are introduced to BYU faculty, and work closely with their BYU student counterparts on the project. These interactions allow the high school (HS) students to learn from and be mentored by the BYU students, many of whom were in the same position as the as the HS students a few years prior. They are encouraged to ask questions, not just about the projects but about how to "be" a university student. That is, what kinds of options are available, how and when to apply to the university, how to pick a major, and why the students chose the major they did. The students also learn something about what Chemical Engineers do.

Importantly, the HS students are able to see how the material they are studying in physics applies to a more specialized field, which in turn is used to solve important real-world problems. For example, the principles of Fluid Mechanics are the same as those taught in high school physics. Namely, conservation of mass, momentum, and energy. Concepts such as pressure, are easily communicated: pressure is a force per unit area. Pressure statics is simply a force balance applied to a stationary fluid. Pressure statics can be used to measure forces on submerged objects, such as dams or fluid tanks. It can also be used to measure pressure differences by comparing the height differences of fluid columns in a manometer. These topics are very accessible. Similarly, the Bernoulli equation is an energy balance relating fluid pressure, velocity, and height, with velocity and height representing kinetic and potential energy, both of which are heavily covered in high school AP physics courses. The Bernoulli equation can be applied to a very wide range of fluid phenomena, and is a favorite analysis tool for a range of fluids projects.

While the HS students are certainly not experts in these areas, especially as relates to fluid mechanics, they have enough background that they can be taught a single equation by their BYU counterparts as relates to the fluids project. The HS students are also able to be engaged in discussions of questions of fluid flow as they discuss ideas for a project, as well as the implementation of the measurements, etc. The BYU students will graduate and go to work as engineers in companies where they will likely work on teams. As they advance, they will be in positions of mentoring younger engineers. Hence, these interactions are a useful preparation for their careers.

Because the projects only involve on the order of 10-12 hours with 4-5 meetings over a period of several weeks, the extra load is not so high that the HS student involvement is precluded for lack of time. This is especially true if students are given some credit in their class for involvement.

The Fluids course at BYU normally has around 100 students, and not all groups include HS students. This project has been done for the past three years. In the first year, we had 10 HS students in 5 project groups. That has grown to around 30 HS students participating in Fall 2016. The HS students are not required to participate. The project is announced and volunteers are accepted subject to group space limitations. The BYU students are asked to volunteer to have HS students in their groups after being coached on extra requirements involved. Hence, the BYU students are self-selecting and are enthusiastic about the opportunities. BYU students in the Fluids class were given project details both in class, and through written project descriptions. For BYU students in groups with HS students, they were given additional instructions on expected behavior and safety when working with the HS students. Students were required to fill out a Class Project Approval Form (noted above). In addition, BYU students (and faculty) were required to take BYU's online Child Protection Training course, and to read the BYU Child Protection Policy (CPP). This policy includes standards of conduct. BYU is unique in that all students, faculty, and staff are required to abide by a detailed Honor Code that includes dress and grooming standards, moral living, use of clean language, respect for others, and abstaining from drugs, alcohol, and tobacco. The CPP gives standards for protecting minors, including discussions and reporting of abuse, avoiding one-on-one contact, and not transporting minors in vehicles. As such, project groups included at least two BYU students, and at least two HS students. Groups were instructed to stay together and to meet in public areas. We note that every HS student in the Provo area knows about BYU and most want to attend. Parents also understand the culture of BYU as "the most stone cold sober" university in the country[6].

We worked with BYU's Risk Management Office, and gave presentations on the details of the HS student interactions on campus. The BYU Legal Office developed a Liability Waiver form that parents of HS students had to read and sign. The Legal Office insisted on keeping very scary language in the waiver, such as holding BYU harmless from any "personal injury, paralysis or death...which may result from participation in the project." The nature of the projects were very safe and we have not had any safety incidents.

In setting up the high school interaction, we began with short letters of support for the high school administration. This was done as part of the NSF proposal. The letters briefly summarized the project. This was preceded by personal contact with more detailed information on the projects provided (similar to that given previously in this paper). Once a teacher was identified, she announced the project to students once a year and found students who were interested, then provided the waiver form and organized the students to attend a one-hour meeting at BYU, which the teacher attended. She also attended the final group presentations.

For groups with HS student participation, a kickoff meeting was held at the beginning of the projects. This allowed HS students and parents to meet the BYU students and professors, to be given background information on fluid mechanics, an overview of the project, instructions, and turn in forms.

A set of documents that are used in this project are provided in Ref (7). This includes

- representative presentation slides,
- a letter of support,
- the BYU liability waiver,
- the BYU Child Protection Policy,
- the Class Project Approval Form,
- project instructions provided to students.

Results and Lessons Learned

In developing the project for inclusion of High School students, we initially contacted a number of science teachers at local high schools. The goal was to find teachers from one or two schools that would be interested in pursuing this project. There are three high schools close to BYU: Provo, Timpview, and Mountain View. The proximity to BYU was important for facilitating travel of students to the BYU campus. School teachers are very busy, and many of our emails to teachers were ignored. Others felt that they and the students did not have the time or interest to participate. In a few cases, in order to make contact, we contacted the schools to find out when teachers had an open period and made personal visits (with school permission). Surprisingly, one physics teacher did not have confidence in his student's abilities to participate in such a project, stating that they struggled in their coursework. This was quite discouraging since the project interactions were designed with the student preparation in mind. We were fortunate to find Mountain View High School in Orem Utah to be enthusiastic in their support of this project—both the teacher and the administration. The time required of our high school teacher partner is minimal.

One area we would like to improve is having more high school student interactions with BYU faculty. Students are shy and usually interact with faculty at the beginning and end of the project, despite receiving lots of encouragement and offers to meet with faculty.

We have not attempted to quantitatively assess the group project or to directly quantify the effect of the outreach component with the high school students. However, both BYU and HS students were positive about the experience. Here are a few samples of BYU student comments:

- “This [regarding character building aspects of the class] mainly came from learning from interactions with my team for the group project. That was an extremely insightful assignment.”

- "I think the problem solving skills I learned from the open-ended problems, and from seeing everyone's project presentations have given me a good model on how to explore different topics."

- "The project also allowed us to apply our skills to a real world problem."

- "The group project was a helpful assignment. I really enjoyed it."

- "I really liked the concept of the group project and how much he allows and trusts us with how we approach a project."

In future efforts, we would like to add a project evaluation form for both the BYU and HS students to better assess their perception of the impacts of the project and to solicit recommendations for improvement.

Conclusions

We developed a class project at Brigham Young University for a junior-level Chemical Engineering Fluid Mechanics course that involved groups of BYU and high school students. The projects were open ended allowing students to use skills learned in class, mentor younger students, and enhance teamwork, creativity, and problem solving skills. Details of the project and logistics of developing the program were presented. This has been going for three years beginning Fall 2014, and we expect to continue the collaboration. The feedback we have received from both BYU and high school students has been positive and very encouraging. High school students are able to be involved in the projects, and interact with faculty and engineering student where they learn more about engineering in general, and a little of the specific area of fluid mechanics. They are able to apply the principles they are learning in their AP Physics class. The project appears to fit the time constraints and contribute to the educational goals of both the BYU course and serve as a fun and instructive extra-curricular activity for the high school students.

There were a number of challenging logistical issues in setting up the collaboration, including finding a high school teacher to participate, and working with BYU to understand policies and develop legal waivers. This sounds obvious in hindsight, but most professors and teachers are not usually aware of institutional requirements. To the authors' understanding, the legal waivers developed, and interactions with Risk Management at BYU were started with this project. We plan to give students a survey at the conclusion of the project to better assess outcomes, compare to expectations, and solicit feedback.

References

1. U.S. Department of Labor Bureau of Labor Statistics (January 2017). *Spotlight on Statistics-Science, technology, engineering, and mathematics (STEM) occupations: past, present, and future*, https://www.bls.gov/spotlight/2017/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future/home.htm.
2. National Science Foundation (accessed June 2017). *National Science Foundation Office of Integrative Activities-Broader Impacts*, https://www.nsf.gov/od/oia/special/broaderimpacts/.
3. National Science Foundation (accessed June 2017). *Proposal and award policies and procedures guide*, https://www.nsf.gov/pubs/policydocs/pappg17_1/nsf17_1.pdf.

4. Memmott, M.J. (September 2014). *ChE 374 Fluid Mechanics*, https://www.et.byu.edu/~mjm82/che374/che374.html.
5. Brown, Peter C., Henry L. Roediger III, and Mark A. McDaniel, *Make it Stick*, Belknap Press: An Imprint of Harvard University Press, 2014.
6. The Princeton Review (accessed Jun 2017). *Stone cold sober schools*, https://www.princetonreview.com/college-rankings?rankings=stone-cold-sober-schools.
7. Lignell, D.O. (June 2017). ChEn 374 class project documents, https://ignite.byu.edu/public/che374_project.

David O. Lignell

Dr. Lignell is an Associate Professor of Chemical Engineering at Brigham Young University. He has taught courses in fluid mechanics, numerical methods, computational tools, career skills, combustion principles, combustion modeling, and probability and statistics. His research interests are simulations of turbulent reacting flows including soot formation, nonpremixed flames, flame extinction and reignition, multiphase flows, and radiative heat transfer.

Matthew J. Memmott

Dr. Memmott is an Assistant Professor of Chemical Engineering at Brigham Young University. He has taught courses in fluid mechanics, introductory nuclear engineering, nuclear reactor design, and career skills. His research interests are in nuclear reactor safety, reactor design, and molten salt reactor design and chemistry.

April A. Andersen

Ms. Andersen is a teacher at Mountain View High School. She holds a B.S. Degree in Physics Teaching with a Minor in Mathematics. She teaches courses in Physics and AP Physics.