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# Embedding Fluid Power into Fluid Mechanics and Thermodynamics Courses through Problem-Based Learning and Entrepreneurially Minded Learning Modules

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# Embedding Fluid Power into Fluid Mechanics and Thermodynamics Courses through Problem-Based Learning and Entrepreneurially Minded Learning Modules


## Abstract

This paper presents problem-based learning and entrepreneurially minded learning modules focused on fluid power applications in undergraduate Fluid Mechanics and Thermodynamics courses. This effort focuses on creating awareness and engaging students in the area of fluid power, and challenging them to apply the concepts and theories in class to analyze and design real-world fluid power systems. Therefore, the course modules target both technical and entrepreneurial mindset objectives. Assessment methods and results are detailed and discussed in the paper. Preliminary results indicate positive student learning in the area of fluid power and student practice of entrepreneurial skills.


## Introduction

At Lawrence Technological University (Lawrence Tech), faculty are engaged in a multiyear process to incorporate active and collaborative learning (ACL), problem-based learning (PBL), and entrepreneurially minded learning (EML) into the engineering curriculum [1, 2, 3]. Active learning requires students to actively discuss issues or work problems in the classroom, rather than listening passively to a lecture. If students informally assist one another in this process, the technique is deemed collaborative learning [4]. A related approach, problem-based learning, introduces engaging real-world problems for students to solve, usually as part of a group [5]. A new twist on problem-based learning is the inclusion of student skills associated with an entrepreneurial mindset, such as integrating information from many sources to gain insight, conveying engineering solutions in economic terms, and identifying unexpected opportunities. The resulting entrepreneurially minded learning activities emphasize “discovery, opportunity identification, and value creation with attention given to effectual thinking over causal (predictive) thinking” [3]. At Lawrence Tech approximately 75% of the engineering curriculum, including mathematics and general education, is being modified to include ACL, PBL, and EML. These courses span the curriculum and range from multidisciplinary Introduction to Engineering [6, 7] to junior level technical courses [8, 9] to graduate level mechatronic design [10, 11].

As a member school in the Kern Entrepreneurial Engineering Network (KEEN), Lawrence Tech defines the entrepreneurial mindset in terms of the KEEN framework. The KEEN framework begins with the “three Cs”: Curiosity, Connections, and Creating Value [12]. Each of the three Cs is supported by example student behaviors. For instance, Curiosity is demonstrated by “explore a contrarian view of accepted solutions” and Creating Value is demonstrated by “identify unexpected opportunities to create extraordinary value”. The framework continues from the three Cs to Engineering Thought and Action, Collaboration, Communication, and Character. As with the three Cs, each concept is supported by example student behaviors. As noted by reference [3], “many of the example behaviors and complementary skills are well-represented in common student-centered learning modules". Therefore, modifications to enhance EML should focus on a subset of the example student behaviors that are less prevalent in PBLs.

In the undergraduate Mechanical Engineering curriculum, pneumatics and hydraulics (i.e., fluid power) often receive little to no coverage. In collaboration with the National Fluid Power Association (NFPA), Lawrence Tech faculty seek to improve undergraduate Mechanical Engineering education in the area of fluid power by leveraging effective ACL, PBL, and EML strategies. This work targets both student awareness of fluid power applications and technical skills related to pneumatics and hydraulics. Two core undergraduate mechanical engineering courses were modified to enhance fluid power content: Thermodynamics and Fluid Mechanics. Based on existing course content, Thermodynamics modifications focused on pneumatics while Fluid Mechanics modifications focused on hydraulics.

Starting in Fall 2016, the authors developed the fluid-power based modules and piloted them in two sections of Fluid Mechanics and two sections of Thermodynamics classes. Modules include a mix of low-effort in-class ACL activities, in-class demonstrations, individual homework assignments, and larger-scale PBL design projects. Preliminary direct and indirect assessment was performed after Fall 2016. Direct assessment via rubrics, to be reported in future work, will be used to assess students' technical skills as demonstrated in design reports and oral presentations. Indirect assessment via student surveys was used to assess students' awareness of and attitudes towards the fluid power industry, as well as growth in the entrepreneurial mindset [9]. Based on assessment results, the piloted modules will be improved and implemented again in Spring 2017.

This work is organized as follows. First, the course modules implemented in Thermodynamics and Fluid Mechanics are described. Next, the direct and indirect assessment tools are introduced. Then the assessment results are presented and discussed. Finally, the work is concluded.

## Description of the Course Modules

### *Activities in Thermodynamics*

The focus for the new thermodynamics modules was to introduce students pneumatics. The thermodynamics course implementing the pneumatics module is typically taken in the junior year, predominantly by mechanical engineering students. However, some civil and architectural engineering students also are enrolled. This course is often the first truly analytical thermodynamics engineering course these students take with the extensive introduction and rigorous development of the abstract concepts of enthalpy and entropy. As a result, there are many new concepts presented to the student in this course. The majority of these students have not had industry experience and typically have not seen advance industrial automation or manufacturing technology that employs pneumatic systems.

With the recognition that many of these junior-year engineering student may be unaware of the wide use of pneumatic systems in manufacturing and are often ignorant of pneumatic technology, there were three goals proposed for the pneumatic modules in this course. First, students are introduced to the basics of pneumatic technology, pneumatic terminology, and pneumatic concepts. Second, students are introduced to, and gain understanding of how pneumatics can be utilized and employed in industry and the basic components of pneumatic systems. Lastly, to address one of the NFPA goals for the funding grant, we want students to realize that there are indeed worthwhile engineering employment opportunities available to them in the pneumatics industry, and that these jobs can provide intellectually satisfying, and financially beneficial life-long employment opportunities.

There is always a challenge in adding more instructional materials to a course already "full" of content. To navigate through the added content the first two goals were addressed outside of class using online resources such as YouTube videos. For the last one students were directed to the NFPA website and reviewing the related employment information it contains. To accomplish these three goals, an assignment was issued to students that comprised the following components.

1. Watch the following three videos. Then answer the questions after each.
   "Introduction to pneumatics" https://www.youtube.com/watch?v=fM11hGJnqtQ
    a. Describe the basic operations you see in this video that are powered by pneumatic systems, or compressed air.
    b. List the advantages to pneumatic systems given in this video.

   "Pneumatic Desktop capping machine with printing function for semi-auto shampoo production line" https://www.youtube.com/watch?v=0zlINr3Vqj4
    c. You may need to watch this video a few times to see what is happening. Describe in detail what is taking place. Why is this operation beneficial?

   "A car that runs on air" https://www.youtube.com/watch?v=uRpxhlX4Ga0
    d. The AirPod car is a vehicle powered by pneumatics (compressed air). Describe the history of using compressed air to provide power to move a vehicle.
    e. What are the advantages to using a compressed air vehicle? Do you think it is practical? Why or why not?
2. Describe the basic components that would be needed in producing, storing and delivering enough high-pressures air to power machines, production lines, or even vehicles.
3. Go online to find references that can supplement and justify your answers. List and describe these references.
4. In chapter 3 of our Thermodynamics textbook we are learning about the nature of gases and the issues they face when compressed to high pressures. Review all of sections 3.11 and 3.12.
    a. Describe the issues that are presented in these sections relating to compressed gases.
    b. How would a thorough understanding of these topics be beneficial in pneumatics engineering applications and systems? Why? Elaborate upon your answer in detail.
5. There is a professional organization devoted to assisting and supporting engineers and manufacturing system designers in using fluid power. This organization is the National Fluid Power Association (NFPA). Their website is located at: http://www.nfpa.com/
    a. Go to their website and review the various sections of their website. Describe what the NFPA sees as their mission.

b. Under the "What is Fluid Power?", they discuss several topics. Briefly describe these various topics.
c. How they define pneumatics?
d. They also give an example of how "a fluid pressure of 1,000 psi can push with 3140 lbs. of force. A pneumatic cylinder using 100 psi air would need a bore of almost 6½ in. (33 sq. in.) to develop the same force." How is this so?
e. Go to the "Education & Careers" section on the website. Under the "Employment" section review the companies listed where career opportunities exist. Pick three companies and describe how they may use pneumatics.

A second analytical computational assignment is being developed to help expand a student's knowledge of pressurized air and transitioning from ideal gas operational ranges to non-ideal gas pressure ranges and how those two ranges can impact pneumatic performance.

*Activity in Fluid Mechanics*

Fluid Mechanics is a junior-level course and two sections were taught in Fall 2016. During the final four weeks of the course, students were tasked to work in a self-selected team of three (with some teams of two) to design a fountain with hydraulically controlled nozzles. Each team was required to submit one technical report describing their detailed design. The project assignment (i.e., PBL/EML) is given below:

**Fountain from Youth**
**(a.k.a. Bellagio's Little Cousin)**

Three and half years ago, your rich uncle, Mortimer, purchased a large tract of land in the Upper Peninsula of Michigan. He did not become wealthy by purchasing worthless things, yet the land he bought has no valuable minerals, nor any profit from lumber. Instead, it has a magnificent wilderness resort lodge, which had been abandoned years ago and had fallen into a dilapidated state. The lodge is known as the Overlook Hotel. (No, not *that* Overlook Hotel from *The Shining*; that place makes people go crazy and is located in the mountains of Colorado.) After Uncle Mortimer restored the Overlook, his guests come to enjoy forest hiking, mountain biking, and a variety of other outdoor pursuits. Some just come to enjoy the peace and quiet at the hotel. Since the Overlook is located on a rocky hillside 300 vertical feet above the lake (which is what the hotel "overlooks") and 2200 ground feet from the lake's edge, he installed a chair lift for downhill skiing to draw customers during the brutally cold winter months. He has also installed a surface called "Snowflex" so that skiers can enjoy the slopes in both summer and winter. Yet with all that, there is one more element that Uncle Mort feels would really enhance his hotel: a mesmerizing fountain display. He has seen the fabulous Bellagio Fountains, and enjoys the interesting fountain in the McNamara Terminal of the Detroit Metropolitan Airport. He wants something that will be appropriate for his wilderness resort.

After learning of your vast new knowledge of fluid mechanics, he has asked you to design a fountain. As a member of the National Fluid Power Association, he requires that one or more of the nozzles is controlled by a hydraulic system which will allow the nozzle(s) to move the water jet(s) in some sort of pattern. The water jet(s) from the movable nozzle(s) must be high enough pressure to allow for a sufficient water height. He wants this fountain to be an attraction for his customers. You will need to consider a water delivery system, filter(s), a piping system, hydraulic system, and other components for this fountain.

Preliminary Reply Investigation: some (not all) considerations during the first week:

- What major components are needed for a fountain and a hydraulically controlled device?
- What should be the overall footprint size of the fountain?
- What intriguing display features should the fountain exhibit, and how many nozzles does that require?
- What items have a significant cost for operation?

Some considerations:

- Ensure that the fountain has sufficient water flow and pressure.
- Be careful with pipe selection (sizing) and material, ensuring that the water is fairly equally distributed throughout the area based on the display options. Carefully consider the layout of the water system so as not to overcomplicate the problem.
- Be cautious that the components and design are not too costly. You should keep track of approximate expenses for components, and keep notes of how you kept costs down. Uncle Mort will want to know. You do <u>not</u> need to consider installation costs, unless your design plan is especially unique. (Consult your customer to determine if installation costs are required for your plan.)
- Include operational expenses for Uncle Mortimer. In other words, choose your water delivery system wisely. What will it cost per year to run the water operation?
- You are designing the fluid system and hydraulic system only, <u>not</u> the solid structure of the pool, pipe/pump support, etc. On the other hand, you must consider forces from the nozzles (as per the hydraulic system requirements). You will also have to consider placement of the various components and, of course, sizes.
- Be careful with all fluid components sizing (pipes, pumps, etc.). Do not drastically oversize or undersize your pump(s).
- Valves….
- The hillside continues above the lodge another 400 vertical feet to the summit in 600 ground feet.

In the process of completing this PBL/EML, students must gather information from their customer, Uncle Mort, role-played by the course instructor. The students will not only solve the technical problem, but must communicate their solution in economic terms. Finally the students should be looking for unexpected opportunities that will enhance the value for their customer. A few of these opportunities are “hidden” within the problem statement. For example, the extended hillside above the lodge can be used for a water tank and additional water pressure, decreasing pump size at the lake. In addition, because of the low power needed for hydraulic control, water can be used for the hydraulic fluid instead of more expensive (and complex) hydraulic fluid. More information on unexpected opportunities and their use in EML modules can be found in reference [3].

**Assessment Method**

It must be specifically noted here that for the thermodynamics module, the authors have not incorporated any examples of student responses to the various questions asked in the first thermodynamics pneumatics assignment because none of the eighteen students in this class agreed to allow their answers from their work to be shown as evidence in this paper.

The final versions (as was done for the first version of the first assignment) of the thermodynamics modules will be evaluated using a fully-developed answer sheet for comparing the student's responses to the desired and expected answers to the assignment, as is typically employed in standard engineering courses. The second assignment (still being developed) will contain a higher analytic computational emphasis and be specifically based on pre-determined educational knowledge outcomes and computational understanding that is considered fundamental for basic application skills in the pneumatics industry. Assessment of all questions asked in this second assignment will also employ a grading rubric. This grading rubric will also be specifically based on the pre-determined educational knowledge outcomes and computational understanding that were considered fundamental for basic application skills in the pneumatics industry. Once this grading rubric is developed then it will be used by the individual reviewing (grading) the second assignment to compare the student’s responses to the rubric to assure answer compliance. Lastly, one informal class discussion (approximately fifteen minutes long) with the students about these assignments and information gained by the students from these assignments will be held with each class. Such direct, but “soft”, feedback will be noted by the course instructor, and may also be used to potentially sharpen the focus of future assignments, and to possibly help clarify for students any aspects of the materials covered.

In order to evaluate the students’ outcome of the PBL/EML activity in Fluid Mechanics, a survey was distributed to students to acquire their perceptions and experience about their design process. The students were asked to answer the question “This project improved my technical skills in:”

i. Identifying the components and functions of a pipe system.
ii. Identifying the components and functions of a hydraulic system.
iii. Making reasonable simplifying assumptions.
iv. Analyzing the function of various flow components (pumps, valves, etc.)
v. Identifying and determining major and minor losses in a flow system.
vi. Predicting pressure and pipe size for series piping systems.
vii. Determining the required pumping power according to flow requirements.
viii. Choosing an actual pump that meets the flow requirements.
ix. Designing a real-world fluid mechanics system.
x. Reporting the solution to a customer.

Answers were provided as scales from 1 to 5:

1. Strongly disagree
2. Disagree
3. No opinion
4. Agree
5. Strongly agree

Besides evaluating the students on technical skills, they were also assessed for entrepreneurial mindset learning. The students were given the following statements and were asked to provide their perception in the same scales 1 to 5:

a. My project design satisfied the customer's needs and goals.
b. I consider the results of my project successful.
c. I found my work on the project to be satisfying.
d. The real-world application of the project motivated me to do my best work.
e. The open-ended nature of the project motivated me to do my best work.

The students were asked to answer questions in regards to example behaviors of the entrepreneurial mindset - directly addressing the student outcomes from Kern Entrepreneurial Engineering Network (KEEN) - in the format of "During the course of this project, to what extent did you:"

f. Explore a contrarian view of accepted (i.e., typical) solutions.
g. Identify an unexpected opportunity for your design.
h. Create extraordinary value for a customer or stakeholder.
i. Integrate information from many sources to gain insight.
j. Assess and manage risk.
k. Persist through failure.
l. Apply creative thinking to ambiguous problems.
m. Apply systems thinking to complex problems.
n. Evaluate economic drivers.
o. Examine a customer's or stakeholder's needs.
p. Understand the motivations and perspectives of others.
q. Convey engineering solutions in economic terms.
r. Substantiate claims with data and facts.

The answers were provided in 5 scales:

1. None at all
2. Slightly
3. On some occasions
4. Many times
5. Throughout most of the project

Following the questions above, the students were also asked about their team dynamics:

s. To what extent did you work as a team?

Answers are provided in 5 scales:

1. Almost never
2. Rarely
3. Sometimes
4. Often
5. Almost always

The students were also welcomed to provide commentary statements about their problem-based learning experience. They were asked what they liked or appreciated about the project, what should be changed, and any other additional comments/observations.

## Results and Discussion

*Thermodynamics Course*

The initial review of the first assignment module for the thermodynamics course was quite positive. Eighteen students were in this class, with all students completing the assignment. As was noted above, however, the authors have not incorporated any examples of student responses to the various questions asked in the first thermodynamics pneumatics assignment because none of the eighteen students in this class agreed to allow their answers from their work to be shown as evidence in this paper. The authors can state that, based on the answers provided by the students, it was clear that the overall subject of pneumatics was new to the majority of students in the class. They may, however, have known about air-driven tools, and compressor air systems, but they previously did not associate those systems with pneumatics. As a result, the students were quickly able to relate to technology that they did know about with concepts that they did not understand were part of pneumatics. The authors will work to use the knowledge of air-driven tools as a possible better introduction to the broader field of pneumatics.

An area that was disappointing on this initial assignment was the brevity of answers provided by students, and the lack of expansion and development of their answers. This first assignment needs modification so as to have wording and questions that require more discussion and detail. This will assure more comprehensive answers and responses form the students to the prompting questions in the assignment.

In spite of the moderate shortcomings observed in the work of students for this assignment, there were also real benefits. It was learned during a short class discussion after the assignment was issued that the consensus of the students gained a great deal of introductory knowledge regarding pneumatics. Such short discussions will be held in future classes. Some students expressed surprise that there was an entire industry built around pneumatics, and there were viable career opportunities in that field. In these regards, the initial introductory module in pneumatics is viewed as a success.

*Fluid Mechanics Course*

The survey results assessing the students' perception about technical learning are presented in Table 1. The results are from a total of 12 students. The average number for all the ten questions are above 3.0, indicating that the students perceived that the problem-based learning exercise helped them improve their learning on the technical content. The results are also illustrated in Figure 1. The two items with highest performance are an average of 4.33 in item “i” – Identifying the components and functions of a pipe system and an average of 4.36 in item “iv” - Analyzing the function of various flow components (pumps, valves, etc.). The results also indicate that through this activity the students practiced synthesizing information from different topics learned during the course and applying it to solve a real-world fluid mechanics system (an average of 3.83 in question “ix”).

Table 1. Survey results assessing technical skills in Fluid Mechanics Course

| Question | Mean | Standard Deviation |
|---|---|---|
| i. Identifying the components and functions of a pipe system. | 4.33 | 0.49 |
| ii. Identifying the components and functions of a hydraulic system. | 3.42 | 0.90 |
| iii. Making reasonable simplifying assumptions. | 3.92 | 0.51 |
| iv. Analyzing the function of various flow components (pumps, valves, etc.) | 4.36 | 0.50 |
| v. Identifying and determining major and minor losses in a flow system. | 3.83 | 0.94 |
| vi. Predicting pressure and pipe size for series piping systems. | 4.00 | 0.95 |
| vii. Determining the required pumping power according to flow requirements. | 3.75 | 0.45 |
| viii. Choosing an actual pump that meets the flow requirements. | 3.83 | 0.58 |
| ix. Designing a real-world fluid mechanics system. | 3.83 | 0.72 |
| x. Reporting the solution to a customer. | 3.67 | 0.65 |

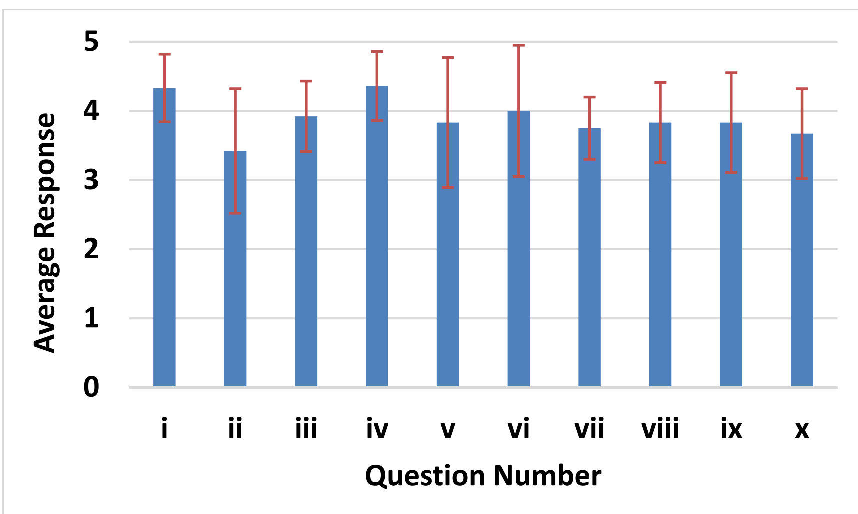


Figure 1. Survey results assessing technical skills in Fluid Mechanics Course

Students' answer to item "ii" - Identifying the components and functions of a hydraulic system - shows the lowest performance among all the ten questions. However, it should be noted that elements of "fluid power" are usually not specifically covered in detail in the classroom of a standard Fluid Mechanics course. The students' score of 3.42 implies that the students were at least exposed to the concepts and application of hydraulic systems during this design exercise. The students also admitted that this project forced them to do a lot of research and reading in this area.

Table 2. Survey results for entrepreneurial mindset in the Fluid Mechanics Course

| Question | Mean | Standard Deviation |
|---|---|---|
| a. My project design satisfied the customer's needs and goals. | 3.67 | 0.78 |
| b. I consider the results of my project successful. | 3.67 | 0.89 |
| c. I found my work on the project to be satisfying. | 3.50 | 0.90 |
| d. The real-world application of the project motivated me to do my best work. | 3.67 | 0.78 |
| e. The open-ended nature of the project motivated me to do my best work. | 3.75 | 0.75 |
| f. Explore a contrarian view of accepted (i.e., typical) solutions. | 3.75 | 0.97 |
| g. Identify an unexpected opportunity for your design. | 3.17 | 0.72 |
| h. Create extraordinary value for a customer or stakeholder. | 3.00 | 0.74 |
| i. Integrate information from many sources to gain insight. | 3.83 | 0.83 |
| j. Assess and manage risk. | 3.17 | 0.72 |
| k. Persist through failure. | 3.50 | 0.90 |
| l. Apply creative thinking to ambiguous problems. | 3.50 | 0.52 |
| m. Apply systems thinking to complex problems. | 3.25 | 0.75 |
| n. Evaluate economic drivers. | 3.42 | 0.67 |
| o. Examine a customer's or stakeholder's needs. | 3.58 | 0.79 |
| p. Understand the motivations and perspectives of others. | 3.50 | 0.80 |
| q. Convey engineering solutions in economic terms. | 3.75 | 0.87 |
| r. Substantiate claims with data and facts. | 3.83 | 0.94 |
| s. To what extent did you work as a team? | 3.83 | 1.19 |

The data shown in Table 2 are the student feedback about entrepreneurial mindset learning to the PBL/EML activity implemented in Fluid Mechanics. The results are also presented as a bar graph in Figure 2. As shown in the Figure, the design project allowed students to gain various practice of entrepreneurial skills. The activity particularly addressed the student outcomes of "integrate information from many sources to gain insight" and "substantiate claims with data and facts" (average feedback of 3.83 to survey questions "i" and "r"). It is also clear that this highly collaborative activity facilitates team work and forces students to work together (average feedback of 3.83 to survey question "s"). The students did not feel that they created extraordinary value (item “h”). There is likely two explanations for this. First “extraordinary” is a strong term. This is the first experience students have had design an entire fountain; they certainly would feel they could design a better one with more experience and/or with more expert guidance. Second, the students feel time pressure at the end of the semester with multiple deadlines looming from all of their coursework. The students likely felt that they could have produced a better fountain if they could have devoted full-time to its development.

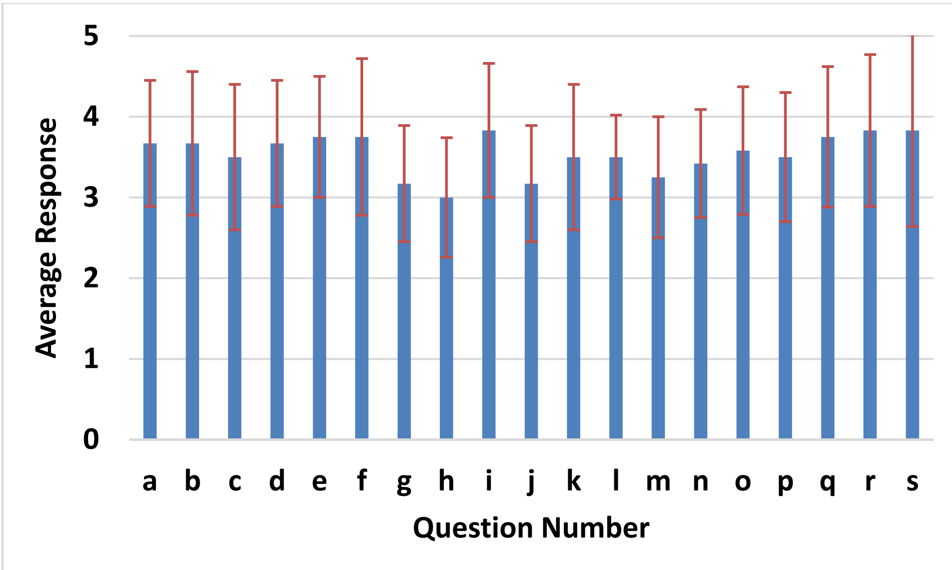


Figure 2. Survey results for entrepreneurial mindset in the Fluid Mechanics Course

On the survey many students wrote comments about their learning experience through this PBL exercise. Most of them mentioned that they liked applying what they are learning from class to real-world problem solving, and they appreciated the open-ended nature of the problems, which are directly addressing survey questions “d” and “e”. Several student comments are listed as examples:

- “It was realistic and I could apply what we're learning directly to the problem. It relied on using a lot of references from the book directly instead of relying on outside sources… for what I was struggling to work with. My partner was very good at helping me understand.”
- “This project made us think critically about what will happen to water flow under certain conditions. For example, pressure loss, flow rates through different size pipes.”
- “It is not limited in textbook so that the question is more open and combined with real life applications.”
- “If a hydraulic system is required, we should spend some class time discussing how one works and how to find the losses within one of those.”
- “We were able to be creative. The project was open to how we wanted to design the system.”
- “I liked how it incorporated many aspects of the fluid mechanics curriculum. It used many chapters to come up with an end result that could be related to the real world.”

The instructor has some concern that the students are not comfortable implementing the hydraulic system to the fountain nozzles. While an example hydraulics problem is solved in class, it is very early in the academic term, nearly two months before the project is assigned. In the future, the instructor will remind the students of the example, and perhaps even briefly describe the components necessary in a hydraulic power system.

The work is ongoing to improve and complete the modules and assessment methods. More assessment will be performed in future semesters. The authors will collect more comparison data and a pre-survey will also be developed to get student feedback before and after the activities.

## Conclusions

Active learning and problem-based learning modules were developed and implemented in Thermodynamics and Fluid Mechanics courses to engage students in the area of fluid power. These collaborative learning activities allow students to work in teams, integrate information from many sources, and apply creative thinking to ambiguous problems. In addition, the students gained insight into the field of fluid power and employment opportunities, material which was previously neglected in the courses. Indirect assessment results indicate that students perceive extensive practice in various aspects of entrepreneurial skills.

## Acknowledgement

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