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

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Abstract—Problem-based learning and entrepreneurially minded learning modules have been developed to include fluid power concepts into undergraduate Mechanical Engineering core courses Thermodynamics and Fluid Mechanics. Modules in Thermodynamics focus on pneumatics and modules in Fluid Mechanics focus on hydraulics. The purpose of this work is to assess the created modules for student awareness of fluid power, knowledge of fluid power concepts, and growth in the entrepreneurial mindset. Both direct and indirect methods were used for assessment. Assessment results indicate that students applied fluid power concepts that are traditionally not covered in these courses. Student surveys also indicate that students demonstrated sample behaviors associated with the entrepreneurial mindset, as defined by the Kern Entrepreneurial Engineering Network framework.

Keywords—Fluid Mechanics; Thermodynamics; Fluid Power; Problem-Based Learning; Entrepreneurially Minded Learning

I. Introduction

Lawrence Technological University (Lawrence Tech) is engaged in a multi-year process to incorporate active and collaborative learning (ACL), problem-based learning (PBL), and entrepreneurially minded learning (EML) into the engineering curriculum [1, 2, 3]. This effort was funded by an institutional grant from the Kern Family Foundation, but has become entrenched within the College of Engineering culture as a focus on novel pedagogical tools. Approximately 75% of the engineering curriculum, including mathematics and general education, has been modified to include ACL and PBL. EML course modifications are in-progress. Courses with ACL or PBL components span the curriculum and range from multidisciplinary Introduction to Engineering [4, 5] to junior level technical courses [6, 7] to graduate level mechatronic design [8, 9].

Faculty cohorts from across the university were trained in ACL, PBL, and EML techniques through summer workshops. Active learning course modifications require students to actively discuss issues or work problems in the classroom, rather than listening passively to a traditional lecture. If students informally assist one another (with encouragement from the instructor) in this process, the technique is deemed to be collaborative learning [10]. Problem-based learning, a subset of active learning techniques, introduces engaging real-world problems for students to solve, usually as part of a group [11]. These PBL activities may span several weeks or longer and may include both in-class and out-of-class time for student teams.

A new approach to problem-based learning is the inclusion of student skills associated with an entrepreneurial mindset, such as integrating information from many sources to gain insight and identifying unexpected opportunities. 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. The resulting entrepreneurially minded learning activities emphasize "discovery, opportunity identification, and value creation with attention given to effectual thinking over causal (predictive) thinking" [3]. While similar in nature to skills valued by entrepreneurs, the entrepreneurial mindset does not necessitate the creation of new ventures. Rather, it is the application of the "three Cs" to engineering practice.

In collaboration with the National Fluid Power Association (NFPA), faculty at Lawrence Tech are developing and implementing fluid power based modules for two BSME core courses: Fluid Mechanics and Thermodynamics. These new modules utilize PBL and EML techniques to address three aims. First, the modules engage students in the study of fluid power

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as an application of fluid mechanics and thermodynamics. Next, the modules help to create awareness of fluid power applications and careers in BSME students. Finally, the modules foster the entrepreneurial mindset through the application of traditional classroom studies to complex, real-world problems with a variety of stakeholders and economic constraints.

In Fall 2016, the authors developed and piloted the fluid power based modules in undergraduate Fluid Mechanics and Thermodynamics classes (two sections of each). The modules include student activities and assignments, team design projects, and in-class demonstrations, where appropriate for the course and material. Based on initial assessment results, the modules were improved and implemented again in Spring 2017. Modules for Fluid Mechanics focus on hydraulics applications and modules for Thermodynamics focus on pneumatics applications. Both direct and indirect assessment tools were developed. Direct assessment was used primarily to gauge student learning of traditional class material. Student surveys provided their perception of the learning experience and demonstration of entrepreneurial mindset example behaviors.

The remainder of this work is organized as follows. Section II introduces the course modules for Fluid Mechanics and Thermodynamics. Section III describes the assessment methods. Section IV discusses the results and Section V concludes the work.

II. Description of Course Modules

A. *Modules in Fluid Mechanics*

Fluid Mechanics is a course required for all Mechanical Engineering undergraduate students at Lawrence Tech. Four sections were offered in the past year: two in Fall 2016 and two in Spring 2017. The enrolled students are predominantly juniors. During the last four or five weeks of the course, students were assigned a team PBL/EML project to design a fountain with hydraulically controlled nozzles. The students were allowed to select their own teams of three members, and each team submitted one technical report describing their detailed design. The detailed description of the project assignment is provided 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. Your design must be cost effective in regards to value; Uncle Mort wants his customers to be satisfied and a fair return on his investment.

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

- What major components are needed for a fountain and a hydraulically controlled device?
- Where will the fountain be located, what will be its overall footprint size, and when/how often will it be operational?
- What intriguing display features should the fountain exhibit, and how many nozzles does that require? How many of the nozzles are hydraulically controlled?
- 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 not 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, not 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.

While working on this PBL/EML project, the students needed to communicate frequently with their customer, Uncle Mort, role-payed by the course instructor. The students needed to learn about the requirements from their customer, and understand his perspective. They not only had to come up with the technical design, but also had to communicate their solution in economic terms (for example, provide the estimated cost of building and/or operating the system).

B. Modules in Thermodynamics

Engineering students at Lawrence Tech typically take Thermodynamics in their junior year. Students are predominantly BSME students with some civil and architectural engineering students also enrolled. The first challenge is that the course contains extensive exposure to and development of abstract concepts such as enthalpy and entropy. The introduction of these new concepts, frequently at the same time, forces the students to work aggressively and rapidly to keep pace with the course materials. There is always a challenge in adding more instructional materials to a course already "full" of content. In addition, many of these students have not had industry experience, may not have worked in an area involving industrial automation or manufacturing technology, and so may not be familiar with pneumatic systems.

To address these three issues, the topic of pneumatics was broken into two educational modules. The first module introduces the student to the widespread use of pneumatic systems in manufacturing and the importance of pneumatic technology, pneumatic terminology, and pneumatic concepts. The second module, still under development, will focus more on computational aspects of pneumatics including transitioning from ideal gas operational ranges to non-ideal gas pressure ranges.

In the first module, students learn how pneumatics are utilized and deployed in industry, and what constitutes the basics of pneumatic systems. This first module is completed by students outside of class using online resources such as YouTube videos. Students also learn there are viable engineering employment opportunities available to them in the pneumatics industry by directing them to the NFPA website and the related employment information it contains. Examples of the first module content is given below:

1. Watch the following three videos. Then answer the questions after each.

"Introduction to pneumatics"
https://youtu.be/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://youtu.be/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.

In the second module, students will focus on computational aspects of pneumatic systems. This module will 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. An important outcome for students is also to know typical operation pressures of pneumatics systems and their relationship to ideal gas assumptions. Examples of this second module's content is given below:

1. Most industrial pneumatic systems operate using standard 100 psig compressed air (available in most industrial operations). Watch the following Youtube video to understand some basics of pneumatic air compressors:

"How to Choose and Use an Air Compressor"
https://youtu.be/u6zddqNIdFs

2. Two engineers are discussing if typical 100 psig compressed air used in a pneumatic driven and controlled manufacturing operation can be considered an ideal gas and, therefore, allows them to use the ideal gas law. You can assist them by referencing the compressibility factor "Z". Use the compressibility factor Z and the information from Figure A-1 (on page 1021 of our course textbook) to quantitatively and computationally justify if the 100 psig shop air can, or cannot, be considered an ideal gas. (Recall that for many applications values of "Z" within the range of 0.96 to 1.04 could easily allow the use of the ideal gas law with few problems and little error.)

3. A piston-cylinder system has the following configuration. A piston has an outer diameter of 5 cm, and slides freely within a cylinder with the same inner diameter. The cylinder is fully sealed and closed at one end and the other end is open, allowing for the movement of the piston. Initially the piston is located 1 meter from the closed end of the cylinder. Initially conditions of the air are:

$$T_1 = 26\,°C$$
$$P_1 = 1 \text{ atmosphere}$$

   a) At these initial conditions it is reasonable to use the ideal gas law. The piston, however, is then very rapidly pressed into the cylinder. No air leaves the piston-cylinder assembly. The piston is pressed quickly into the cylinder (within a fraction of a second) and locked into place. The piston movement is so rapid that the air/system can initially be assumed to be adiabatic. At this new piston position, the air temperature within the cylinder correspondingly and momentarily rises to 550ºC and the air pressure increases to 100 atmospheres. At the instant of the new piston position is it still reasonable to assume the air in the cylinder is an ideal gas? Quantitatively and computationally verify this using "Z" from Figure A-2.

   b) Compute the work that was rapidly applied to the piston to move it to the new position within the cylinder.

   c) The piston and cylinder are left at the new piston position remains locked into place, and left to sit for several hours such that the temperature of the gas and the cylinder are allowed to return to the initial temperature of 26ºC, but the piston does not move from the new position. Determine the pressure of the air within the cylinder under these conditions.

The Fluid Mechanics and Thermodynamics modules presented above were developed in Fall 2016. Initial implementation and assessment were also carried out in the same semester, with valuable feedback collected from course instructors and students. The modules were then modified and improved based on the assessment results. Fluid Mechanics modules were implemented and assessed again in Spring 2017, while the Thermodynamics modules will be re-implemented in Summer and/or Fall 2017.

III. Assessment Methods

A. Assessment in Fluid Mechanics

Upon completing the project, students were directly and indirectly assessed for technical skills. The indirect assessment was administered via student survey which attempts to gauge 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

The direct assessment of technical learning was conducted using a problem-based learning rubric to evaluate the quality of the problem solutions. There are a total of nine rubric criteria:

xi. Identification of problem
xii. Data collection
xiii. Representing data
xiv. Verify and evaluate information
xv. Draw conclusions and make appropriate applications
xvi. Justify and support decisions, strategies, findings and solutions
xvii. Communicate purpose and/or main idea for audience
xviii. Organization
xix. Supporting details and/or visuals

Each criterion was graded as five scales:

0. No demonstration
1. Attempted demonstration
2. Partial demonstration
3. Proficient demonstration
4. Sophisticated demonstration

Besides the evaluation of students' technical learning, they were also assessed for entrepreneurial mindset learning. The team members were given the following statements and were asked to provide their perception in scales 1 to 5 where 1 corresponds to "strongly disagree" and 5 corresponds to "strongly agree":

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 also asked to provide their perception in regards to example behaviors of the entrepreneurial mindset with questions "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.

These questions directly assess student outcomes from Kern Entrepreneurial Engineering Network (KEEN). Answers to the questions were provided in five scales:

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

Besides the students were also asked about their team dynamics and experience with question:

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

B. Assessment in Thermodynamics

The assessment of the first thermodynamics module was done 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. Assessment of the second module (still being developed, as previously mentioned) contains greater computational emphasis for basic application skills in the pneumatics industry. The assessment of this second module will be done using a grading rubric, based on the pre-determined educational knowledge outcomes and computational understanding considered important for basic knowledge in the pneumatics industry. Once the rubric is developed, it can be used to compare the student's responses to the desired responses in the rubric to assure answer compliance.

IV. Results and Discussion

A. Fluid Mechanics

While working on the PBL/EML project, students were exposed to fluid power and related applications, which is traditionally not covered in this course. Some of the student work samples are shown in Figure 1 and Figure 2.

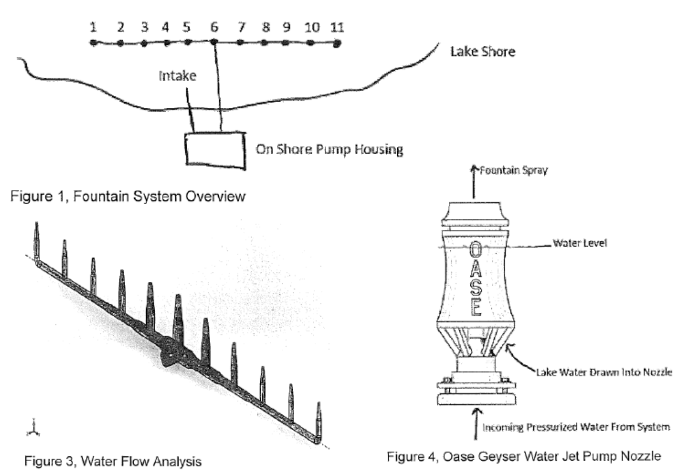
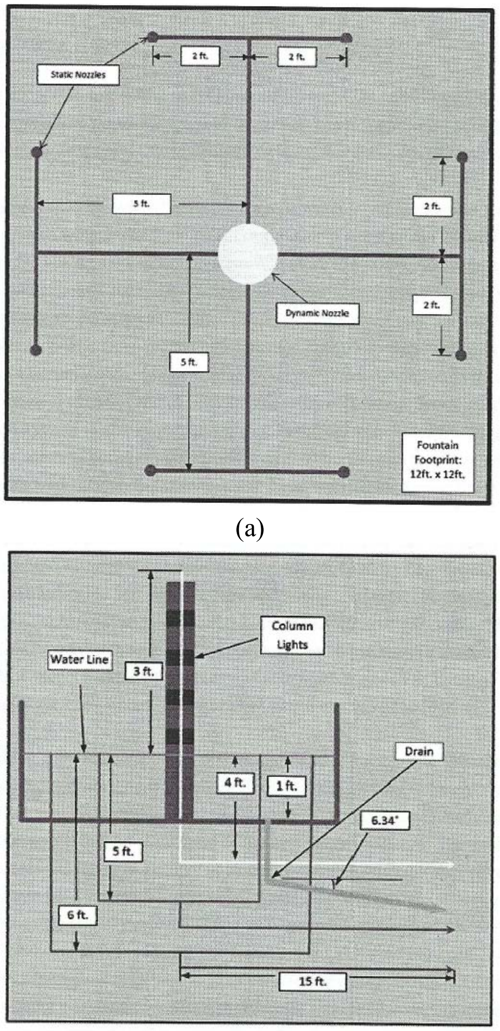


Fig. 1. Student work sample from course section 1



(a)

(b)

Fig. 2. Student work sample course section 2; (a) Comprehensive schematic of the overview of fountain; (b) Comprehensive schematic of the fountain piping system

Survey results assessing students' perception about their own technical learning are presented in Table I (N = 12 from Fall 2016 and N = 15 from Spring 2017). Each of the ten questions had average student response above 3.0, indicating that the students perceived that the PBL/EML exercise helped them improve their learning on the technical content. The primary purpose of this course is the introduction of technical content and these results indicate that the PBL/EML exercise is of value to that aim in the perception of the students.

The two technical items with highest student perceived performance (consistently in both Fall 2016 and Spring 2017) are item "i" – Identifying the components and functions of a pipe system (mean 4.33 and 4.27) and item "iv" - Analyzing the function of various flow components (pumps, valves, etc.) (mean 4.36 and 4.20). 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 (mean 3.83 and 4.07 in item "ix").

TABLE I. SURVEY RESULTS ASSESSING TECHNICAL SKILLS IN THE FLUID MECHANICS COURSE

Question	Fall 2016 (N=12)		Spring 2017 (N=15)	
	Mean	Standard Deviation	Mean	Standard Deviation
i	4.33	0.49	4.27	0.59
ii	3.42	0.90	3.67	1.05
iii	3.92	0.51	4.00	0.76
iv	4.36	0.50	4.20	0.56
v	3.83	0.94	4.07	1.03
vi	4.00	0.95	3.93	0.62
vii	3.75	0.45	3.93	0.70
viii	3.83	0.58	3.80	0.86
ix	3.83	0.72	4.07	0.59
x	3.67	0.65	3.93	0.88

Students' answer to item "ii" - Identifying the components and functions of a hydraulic system - shows the lowest performance among all the ten questions (again consistently in both semesters). 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 required them to do a lot of research and reading in this area.

Student deliverables were directly assessed using a general PBL rubric, as described in section III. Results are provided in Table II; note that the rubric scales from 0 to 4. While the general rubric was not aligned with the survey dimensions, the instructor scoring the reports was applying it in the context of Fluid Mechanics and the assigned PBL/EML activity. All the nine items "identification of problem", "data collection", "representing data", "verify and evaluate information", "draw conclusions and make appropriate applications", "justify and support decisions, strategies, findings, and solutions", "communicate purpose and/or main idea for audience", "organization", and "supporting details and/or visuals" were all scored with mean 3.00 or higher, indicating "proficient demonstration". Combined with student surveys of perceived learning, the direct assessment indicates that the course is successful in teaching Fluid Mechanics concepts through the use of a PBL/EML module that also embeds fluid power concepts.

TABLE II. DIRECT ASSESSMENT RESULTS FOR FLUID MECHANICS COURSE

Criteria	Mean	Standard Deviation
Identification of problem	3.35	0.53
Data collection	3.15	0.53
Representing data	3.30	0.59
Verify and evaluate information	3.00	0.67
Draw conclusions and make appropriate applications	3.30	0.48
Justify and support decisions, strategies, findings and solutions	3.20	0.54
Communicate purpose and/or main idea for audience	3.90	0.32
Organization	3.55	0.55
Supporting details and/or visuals	3.15	0.78

Table III shows student feedback about perceived demonstration of entrepreneurial mindset during the Fluid Mechanics PBL/EML activity. The design project allowed students to practice various dimensions of the entrepreneurial mindset. For each general question (a to e), the average result was above 3.0, indicating general student satisfaction with the project and their results. For each entrepreneurial mindset sample behavior (f to r), the average results was at or above 3.0, indicating that the students perceived themselves to have demonstrated that behavior at least "sometimes". Thus, the PBL/EML activity succeeded in fostering the entrepreneurial mindset.

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 in Fall 2016 and 3.80 in Spring 2017 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 in Fall 2016 and 4.33 in Spring 2017 to survey question "s"). The students did not feel that they created extraordinary value (item "h"). There are likely two explanations for this. First "extraordinary" is a strong term. This is the first experience students have had designing 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.

TABLE III. SURVEY RESULTS FOR ENTREPRENEURIALLY MINDSED LEARNING IN THE FLUID MECHANICS COURSE

Question	Fall 2016 (N=12)		Spring 2017 (N=15)	
	Mean	Standard Deviation	Mean	Standard Deviation
a	3.67	0.78	3.87	0.83
b	3.67	0.89	4.27	0.80
c	3.50	0.90	3.64	0.63
d	3.67	0.78	3.79	0.70
e	3.75	0.75	3.53	0.92
f	3.75	0.97	3.33	0.82
g	3.17	0.72	3.73	0.80
h	3.00	0.74	3.27	0.96
i	3.83	0.83	3.80	0.68
j	3.17	0.72	3.20	0.86
k	3.50	0.90	3.57	0.94
l	3.50	0.52	3.80	0.77
m	3.25	0.75	3.53	0.99
n	3.42	0.67	3.20	1.01
o	3.58	0.79	3.87	0.64
p	3.50	0.80	3.73	0.70
q	3.75	0.87	3.73	0.80
r	3.83	0.94	3.80	0.77
s	3.83	1.19	4.33	0.62

Many written comments from students described their learning experience through this PBL/EML project. Most 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 problem, 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.”

B. *Thermodynamics*

Initial reviews of the first thermodynamics module from students was positive. All eighteen students in this class successfully completed the assignment. The authors, however, have not included examples of student responses 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 say, however, that student responses did indicate that the subject of pneumatics was completely new to the majority of students in the class. Some had knowledge of air-driven tools, and compressor air systems, but they did not at all see those systems as part of pneumatic technologies. Once students related pneumatic systems to technology that they did have knowledge of, they were able to better grasp the broader concepts of pneumatics. In future efforts relating to thermodynamics, the authors will incorporate topics such as air-driven tools to better introduce the field of pneumatics.

V. Conclusions

Problem-based learning and entrepreneurially minded learning modules were developed and implemented in Thermodynamics and Fluid Mechanics courses to teach core technical concepts, engage students in the area of fluid power and create awareness of related career opportunities, and foster an entrepreneurial mindset. Both direct and indirect assessment were implemented in Fall 2016 and Spring 2017 to evaluate students’ technical learning as well as the development of an entrepreneurial mindset. The results show positive feedback in all target outcomes – students learned technical skills, explored fluid power content, and demonstrated sample behaviors associated with an entrepreneurial mindset.

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