Assessment of Fluid Power Modules Embedded in Junior Level Thermodynamics and Fluid Mechanics Courses

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Abstract

In collaboration with the National Fluid Power Association (NFPA), the faculty at Lawrence Technological University developed and implemented fluid-power based modules (i.e., classroom exercises) for two BS Mechanical Engineering (BSME) core courses: Thermodynamics and Fluid Mechanics. The project aims to teach students the basic theories and concepts in fluid power and expose them to real-world hydraulic and pneumatic applications. Modules designed for the Fluid Mechanics course focus on addressing hydraulics related applications, and modules designed for the Thermodynamics course focus on pneumatic systems. Fluid power modules include homework to be completed individually, in-class active and collaborative learning (ACL) exercises, and problem-based learning (PBL) team projects with entrepreneurially minded learning (EML) components. However, all modules are intended to foster a better student understanding of the theory, practices, and career opportunities associated within the fluid power industry.

Starting in the Fall of 2016, the authors developed the modules and implemented them in multiple sections (taught by different instructors) of Thermodynamics and Fluid Mechanics courses in three consecutive semesters (Fall 2016, Spring 2017, Fall 2017). Pre and post surveys were conducted to gage the impact on student learning on the fluid power content before and after the designed activities. Both direct and indirect assessment tools were developed and data were collected. This paper focuses on reporting the assessment results in both courses and making recommendations for future improvements of the modules.

Introduction

In collaboration with the National Fluid Power Association (NFPA), the faculty at Lawrence Technological University are incorporating fluid power theory and applications into the Bachelor of Science in Mechanical Engineering (BSME) curriculum. Two core courses – Thermodynamics and Fluid Mechanics – were selected for this work. In the previous curriculum, pneumatics and hydraulics (i.e., fluid power) often received little to no coverage. The work aims to teach students fluid power terminology, basic theories, and concepts as well as to expose students to real-world hydraulic and pneumatic applications. Building on initial work [1], the present study adds indirect assessment for both courses, previously unavailable direct assessment in Thermodynamics, and additional data points for indirect and direct assessment in Fluid Mechanics.

Fluid-power based modules for Fluid Mechanics and Thermodynamics courses were developed for potential continued future use that utilize active and collaborative learning (ACL), problem-based learning (PBL), and entrepreneurially-minded learning (EML) techniques to teach core BSME content while also creating awareness and engaging students in the area of fluid power.

Active learning requires that students participate and 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 to be collaborative learning [2]. PBL builds on ACL by introducing engaging real-world problems for students to solve as part of a group [2]. A new twist on PBL is the inclusion of student skills associated with an entrepreneurial mindset, such as integrating information from many sources to gain insight and/or identifying unexpected opportunities to create value. The resulting EML activities emphasize "discovery, opportunity identification, and value creation with attention given to effectual thinking over causal (predictive) thinking" [3].

Atman et al. [4] reported on the Academic Pathways Study to address research questions about student skill development, engineering identity, education, and entrance into the workplace. Among other findings about student perceptions of design in the Academic Pathways Study final report, many students feel unprepared for capstone design projects and wish capstone occurred earlier in the curriculum [4]. Another finding was that students engaged in design projects generally do not consider broad context [4]. A thrust of the current college-wide curricular modification is the inclusion of PBL and EML in the junior year, such as the present work. This should positively impact capstone design experiences in senior year by providing additional smaller-scale design experience (PBL and EML) and encouraging students to consider all stakeholders and the broader context of their work (EML).

Litzinger et al. [5] reviewed studies on the development of engineering expertise and connected that development to effective learning experiences. Effective learning experiences are those that "support the development of deep understanding organized around key concepts and general principles, the development of skills, both technical and professional, and the application of knowledge and skills to problems that are representative of those faced by practicing engineers" [5]. PBL is an effective learning experience that provides practice with complex problem solving outside of the context of a capstone experience. One study of employer evaluations indicated that PBL experiences improved graduates' problem solving skills [5]. From other works, PBL activities can substantially improve long-term student learning [6, 7, 8] and skill development [8]. Cooperative learning promotes academic success, quality of relationships, and self-esteem [9].

Problems presented to students as PBL activities must be authentic, which can be difficult for instructors to create. Jamaludin et al. [10] reviewed the studies on PBL problem creation and merged design problem criteria into five principles. From these principles, the PBL problem must be authentic and realistic, constructive and integrated, of suitable complexity, promote self-directed learning and lifelong learning, and stimulate critical thinking and metacognitive skills. EML activities pose an additional complication in the first principle as the customer must also be real or realistic. Jamaludin et al. provide a process for developing a PBL problem rooted in the learning objectives. The Fluid Mechanics EML presented here was developed in a very similar manner.

This work builds on the multi-year effort at Lawrence Tech to incorporate ACL, PBL, and EML into the engineering curriculum [11, 12, 3]. These courses span the curriculum from multidisciplinary Introduction to Engineering [13, 14] to undergraduate modules [15, 16, 17] to graduate level mechatronic design [18, 19]. As a partner school of the Kern Entrepreneurial

Engineering Network (KEEN), Lawrence Tech defines the entrepreneurial mindset in terms of the KEEN framework - Curiosity, Connection, and Creating Value, which is usually called the three C's framework [20]. In each of the three items, there are many example student behavior that are desired to be observed during the students' work. For example, 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 entrepreneurial mindset is not the same as entrepreneurship. The entrepreneurial mindset is the application of the "three Cs" to engineering practice and not necessarily the creation of new business. Inclusion of entrepreneurial education is a valuable addition to the traditional engineering curriculum [21, 22, 23] and aligns with portions of ABET Criterion 3a-k [24].

The rest of this paper is organized as follows. First, courses used in this work are introduced. Next, the detailed course modules are described. Then the methods of assessment are introduced. Finally the assessment results in each course are presented and discussed, and the conclusions are summarized.

BSME Courses Modified

This work focuses on two BSME core courses: Thermodynamics and Fluid Mechanics. A portion of the BSME curriculum is shown in Figure 1 to illustrate the locations of these courses. Also shown in the curriculum are free-choice technical electives. One of the participating faculty was also assigned to teach two technical elective courses (Introduction to Thermal Systems and Applied Thermodynamics). Having already developed materials for Thermodynamics, this faculty member also assigned the same Thermodynamics student activities to students enrolled in Introduction to Thermal Systems and Applied Thermodynamics. Data was collected for both of these courses in addition to the planned Thermodynamics and Fluid Mechanics sections.

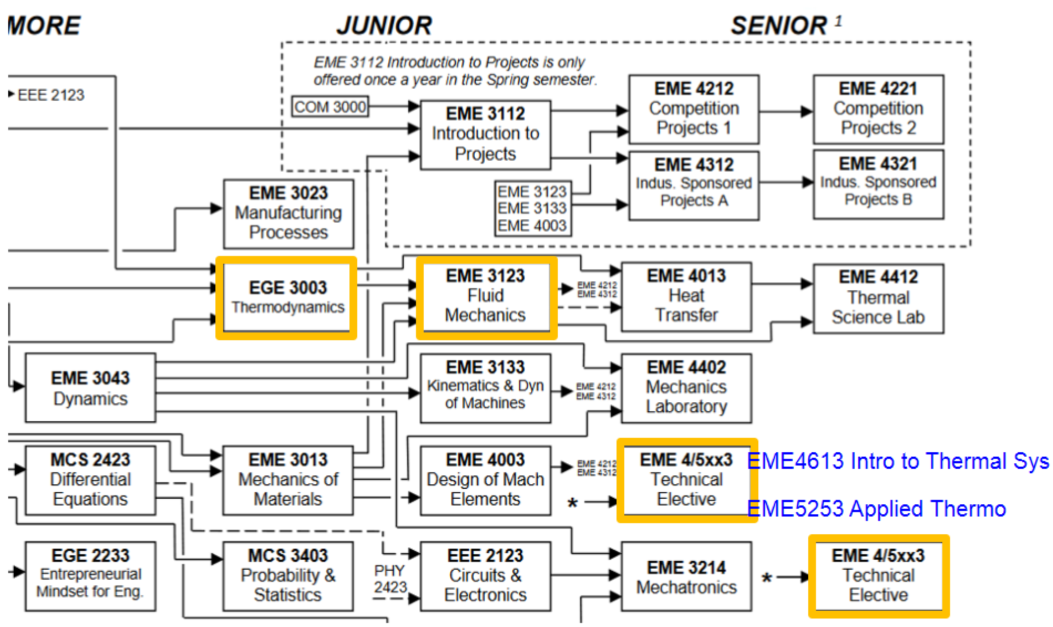


Figure 1 Courses with modified content highlighted in the BSME curriculum

Through 2016 Fall to 2017 Fall, the developed modules were implemented to introduce students into the area of fluid power. Eight different instructors were involved and a total of 239 students were exposed, as shown in Table 1. Results in different courses are presented in sections below.

Table 1 Course sections covered and number of students introduced to fluid power

Semester	Course	# of Students
2016 Fall	Thermodynamics (Section 01)	18
	Thermodynamics (Section 02)	18
	Fluid Mechanics (Section 01)	17
	Fluid Mechanics (Section 02)	8
2017 Spring	Fluid Mechanics (Section 01)	30
	Fluid Mechanics (Section 02)	34
2017 Fall	Thermodynamics (Section 01)	9
	Thermodynamics (Section 02)	19
	Thermodynamics (Section 03)	30
	Fluid Mechanics (Section 01)	12
	Fluid Mechanics (Section 02)	14
	Introduction to Thermal Systems	10
	Applied Thermodynamics	20
	TOTAL	239

Description of the Course Modules

Activities in Thermodynamics

The thermodynamics course (course number EGE 3003) that implemented the pneumatics module is typically taken in the junior year and is predominantly taken by mechanical engineering students. Some civil and architectural engineering students were also enrolled during this assessment. 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 to students that are presented and developed in this course. Another key point is that many of these students have not had industry experience and typically have not seen advanced industrial automation or manufacturing technology that could employ 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 were introduced to the basics of pneumatic technology, pneumatic terminology, and pneumatic concepts. Second, students were introduced to these concepts in order to gain an understanding of how pneumatics can be utilized and employed in industry, and to learn the basic components of pneumatic systems. Lastly, to address one of the NFPA goals for the funding grant, we wanted 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. To meet the third goal students were directed to the NFPA website and reviewed the related employment information it contains. These are detailed in the assignment (or module) A which is shown in Appendix A.

A second analytical computational assignment was 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. These are detailed in the assignment (or module) B which is shown in Appendix B.

Activity in Fluid Mechanics

Fluid Mechanics is a junior-level course that directly follows Thermodynamics in the BSME curriculum. Students usually have more understanding or experience with the concepts of fluid power. Therefore, a larger scale problem-based learning project with more complexity was assigned. Students were tasked to work in a self-selected team of three to design a fountain with hydraulically controlled nozzles. Each team was required to submit one technical report describing their detailed design. A brief description of the assignment is provided below, with more detailed information given in Appendix C.

Fountain with Hydraulically Controlled Nozzle System

> Three and half years ago, your rich uncle, Mortimer, purchased a large tract of land in the Upper Peninsula of Michigan. 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. After Uncle Mortimer restored the Overlook, his guest 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, Uncle Mort 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.

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. On top of all the details about their technical design, students are asked to provide an estimate on the budget of their proposed fountain (including the components and operating costs). Students should also 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.

The authors would like to point out that most Mechanical Engineering students at Lawrence Tech are very familiar with this stakeholder, rich Uncle Mortimer, because of his “appearance” in many PBL projects. “He” is vastly rich and had all kinds of crazy ideas of designing new products or systems for his business or recreational purposes. As the customer of many PBL/EML projects he becomes well known among the faculty and students in the department.

The PBL design exercise was assigned during the last four to five weeks of the semester, because the students need to integrate all the material they learned in order to complete the calculations and make proper decisions. Students were encouraged to discuss with each other and make their own member selections to form their team. The students who don’t or can’t find a team after a certain date will be assigned into one by the instructor. Most of the teams have three members, but depending on the total number of students in that section some team may end up with two or four members. This is mostly an outside-of-classroom assignment, but staging in class was conducted each week to make sure the students are in progress and can get help whenever they need.

Through 2016 Fall to 2017 Fall semesters, a total of six sections of Fluid Mechanics course were offered (two sections per semester), which were taught by three different instructors. The PBL project was assigned in each and every of the sections. However, the students got very different requirements about the design because their customer (instructor) has his/her preferences.

Assessment in Thermodynamics

Before each of the two thermodynamics assignments were created, a list of educational outcomes and learning objectives for each was developed. For the first assignment these listed objectives were, admittedly, somewhat basic, but still deemed very important to give the student a foundational understanding on the topic. These outcomes included the following:

1. Providing the student an opportunity to physically see simple but very clear mechanical operations of a pneumatic systems.
2. To have the student learn about, assess and review the advantages of a pneumatic system.
3. To give the student an opportunity to compare a simple pneumatic system to that of a possible manually done operation.
4. To have the student see, review and assess a pneumatic power operation that they might not have considered as a pneumatic application.

5. To review and list the various components required for a standard pneumatic power system.
6. For the student to access, list and review possible engineering applications, the engineering field of, and possible employment opportunities within the pneumatics field from the National Fluid Power Association (NFPA) organization's web site. It was deemed important that students know about the existence of such a professional organization and its available resources.

After the learning objectives were established then the assignment called Module "A" was developed (and is provided in the Appendix of this paper). For students to see working pneumatic systems various YouTube videos, that are easily accessible on the web, were listed for student review. Student work was evaluated using a fully-developed answer sheet for comparing the student's responses to the expected answers to the assignment.

For the second assignment a list of learning objectives were again generated. These outcomes included the following:

1. Provide the student an opportunity to gain a more detailed working understanding regarding the features of a pneumatic system's air compressor and what goes into the proper selection of an air compressor equipment.
2. To assess computationally if air, compressed to a given pressure, typical of pneumatic conditions, is or is not an ideal gas.
3. Apply the required equations to calculate the work required to compress a given volume of air.
4. Calculate the changes in compressed gas pressure after a gas heats, due to compression to a given volume, then cools to a new ambient temperature at that same volume.

Assessment of the second assignment also employed a fully developed grading sheet based on the above listed learning outcomes, and a computational understanding that were considered fundamental for basic application skills in the pneumatics industry.

The Fall 2016 courses results are not included here because the authors were, unfortunately, not able to obtain permission from the students to use or publish their results. This was deemed acceptable because the first issuance of each module was for evaluation of the questions themselves. In Spring 2017 no faculty members affiliated with the grant taught any of the thermodynamics class sessions, so the modules were not assigned and no data were collected for those classes. For the Fall 2017 semester five class sessions were issued thermodynamics modules "A" and "B".

The assessment results for Module "A" are given in Table 3. In the first column of Table 2, a class number is listed. There were 82 students issued the Module "A" assignment, with a total of 80 students completing this assignment.

Based on the student work for the first assignment, it was clear that the overall subject of pneumatics was new to the majority of the students in these classes. Students, however, were able to quickly relate subject matter to technologies that they did know about with concepts that they did not understand were also part of pneumatic systems. Students clearly understood requirements and components for pneumatic systems. Students were less clear on engineering aspects of compressed gases. Students were able to successfully access and understand NFPA website and pertinent employment opportunities regarding Fluid Power careers.

As would be expected, the graduate student class (Applied thermodynamics) overall did the best on this assignment. An undergraduate thermodynamics section did well, but this class had only eight students and is well taught by an experienced faculty member in the mechanical engineering department. There are some assignable reasons for this class's success: 1) this was an unusually small class with only eight students, 2) the class had an excellent and very experienced thermodynamics instructor, and 3) this class got to this assignment a little later in the semester and may have given students more time to lead-up to the materials covered. (Note that the Introduction to Thermal Systems class did not have the needed compressibility factor chart in their text and, therefore, was not able to complete questions 3a and 3b, and therefore, those questions from that class are not counted in the overall averages.)

The results for Module "B" are summarized in Table 3. In general, students were able to define ideality at elevated temperatures and pressures, although the graduate student class (Applied Thermodynamics) has some students who clearly, and surprisingly, struggled with this. The instructor in this graduate class discussed this with the students in that class and found that several were international students and were new to the US method of assignments and had some trouble with this question. Also, in general students had difficulty computing the work required to compress a gas to high pressures. Students had the most difficulty in computing a new pressure after a gas had cooled. These difficulties are attributed to this often being the student's first exposure computing work using thermodynamic methods and how to compute for pressurized systems.

An area that was disappointing on these assignments was when a written discussion and elaboration was requested; there was an unfortunate brevity in the answers provided by students, with a lack of expansion and development of their answers. Going forward this first assignment will need modification so as to contain more developed wording and questions that explicitly prompts students to provide 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 these assignments, there were also noted benefits. During short in-class discussions with students after the assignment was issued, there was a real consensus from students that they had gained a great deal of introductory knowledge regarding pneumatics. Some students expressed surprise that there is an entire industry built around pneumatics, and there are viable career opportunities in that field. In these regards, these instructional modules in pneumatics were viewed as successful.

Table 2 A summary of overall results for the Fall 2017 Thermodynamics classes issued the Module A assignment.

		Problem # for Module "A"													
		1a	1b	1c	1d	1e	2	3a	3b	4a	4b	4c	4d	4e	Average of Student Scorea for Assignment
		Points possible for each problem													
		2	2	2	2	2	5	2	2	2	2	2	2	3	30
Class	n	Average points earned for each problem in each class													
Thermodynamics Class #1	17	1.18	1.59	1.76	1.12	1.88	3.47	0.88	1.29	1.71	1.71	1.59	1.65	2.88	22.71
Thermodynamics Class #2	8	1.50	1.88	2.00	1.38	1.88	4.13	1.25	1.88	2.00	2.00	1.75	1.25	2.50	25.38
Thermodynamics Class #3	26	1.38	1.88	1.88	1.50	1.73	3.81	1.12	1.31	1.81	1.88	1.77	1.00	2.42	23.50
Applied thermodynamics Class	19	1.74	1.89	2.00	1.79	1.95	4.63	1.32	1.53	1.84	1.89	1.84	1.68	2.79	26.89
Intro to Thermal Systems Class	10	1.60	1.90	1.90	1.50	1.70	4.70	0.00	0.00	1.90	1.90	1.70	1.60	2.70	23.10
	80	1.46	1.83	1.90	1.48	1.83	4.08	1.13	1.43	1.83	1.86	1.74	1.40	2.65	24.28
	Average %	73.1%	91.3%	95.0%	73.8%	91.3%	81.5%	56.4%	71.4%	91.3%	93.1%	86.9%	70.0%	88.3%	80.9%

Table 3 A summary of overall results for the Fall 2017 Thermodynamics classes issued the Module B assignment.

		Problem # for Module "B"				
		2	3a	3b	3c	Average of Student Scorea for Assignment
		Points possible for each problem				
Class	n	5	8	7	5	25
Thermodynamics Class #1	15	2.87	4.13	1.73	1.73	10.47
Thermodynamics Class #2	7	5.00	7.14	4.43	2.71	19.29
Thermodynamics Class #3	25	4.20	4.88	2.68	2.52	14.28
Applied thermodynamics Class	18	3.00	6.17	2.94	2.33	14.44
Intro to Thermal Systems Class	9	4.67	5.67	2.11	2.00	14.44
	65	3.77	5.35	2.65	2.27	14.04
	Average %	75.4%	66.9%	37.8%	45.4%	56.2%

Assessment in Fluid Mechanics

A survey was distributed to students at the end of the project to acquire their perspective of the learning experience. The first part the survey was targeting about their technical learning. The students were asked to provide their opinion about a series of statements "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 second part of the survey was targeting about the students' entrepreneurial mindset learning. Students were asked to provide their perception about the project experience to the following statements:

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.

They were also asked to give answers using the same scales from 1 to 5, with one the lowest and 5 the highest.

Sample student behavior from the KEEN three C's framework were also assessed. Students were asked to provide their opinion about a series of statements directly addressing student outcomes from KEEN by answering a series of 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.

The answers were provided in five 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 were provided in five scales:

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

Direct assessment about students' technical learning was conducted using a PBL rubric that the instructors used to grade their design reports. This score indicates the quality of their design and how much actually they satisfied their customer. Sometimes there is a discrepancy between how much the students believe they learned and how much the instructor determines they learned. One of the contributing factors is that the students' perspective reflected from the survey above is individual, while the technical grading is based on the team report (from a combination of three students). Therefore, some of the opinions were averaged out. More details about the direct assessment are presented in [1].

Students came up with very different designs of the hydraulically controlled water fountains. Many of the students expressed that the open-ended nature of the problem motivated them to do their best work. They also mentioned that they were compelled to learn about hydraulic systems out of the classroom in order to complete the assignments. Two examples of the students' work are shown in Figure 2 and Figure 3.

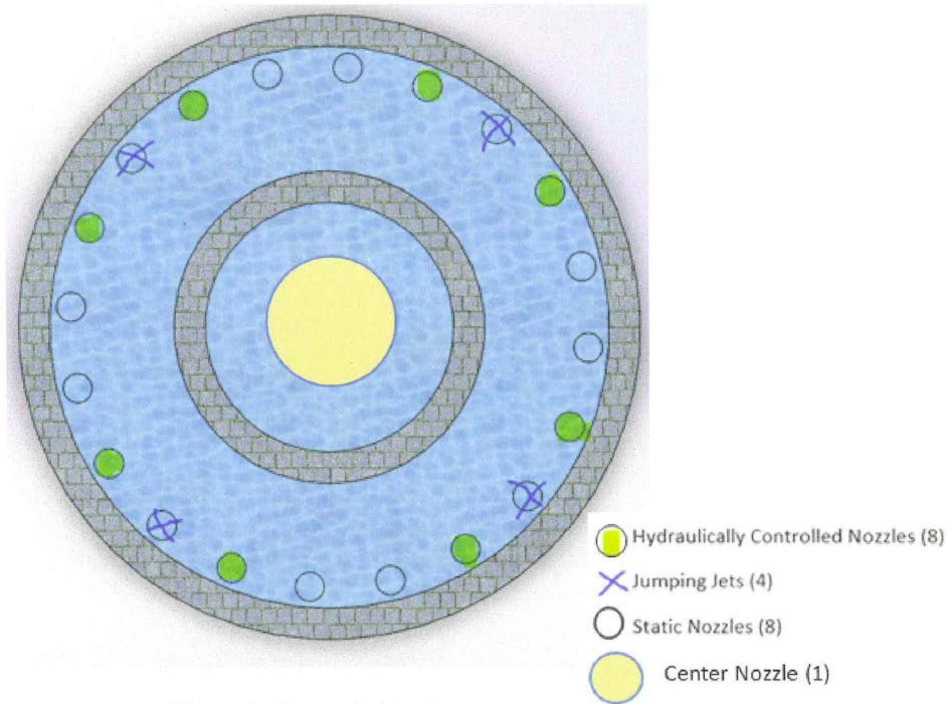


Figure 2 Student work sample 1: Top view of the fountain layout

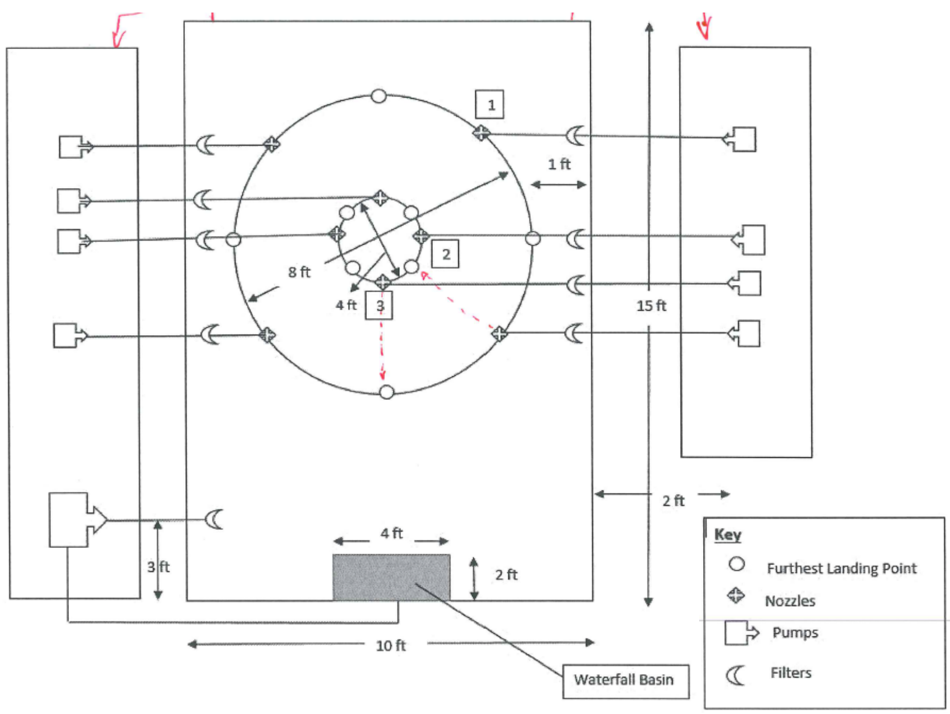


Figure 3 Student work sample 2: Water delivering system of the fountain

The survey results assessing the students' perception about technical learning are presented in Figure 4. The horizontal axis shows the ten survey questions, and the vertical axis shows the average response from all the students' answers. Data from three consecutive semesters were collected and were presented as blue columns, orange columns, and gray columns, respectively. The black bars indicate the standard deviation of the data.

Figure 4 reveals that the results from each semester are relatively consistent, even with different instructors and various student demographics. The average number for all the ten questions is above 3.0, indicating that the students perceived that the problem-based learning exercise helped them improve their learning on the technical content. The two items always with high performance in all the three semesters are item "i" (Identifying the components and functions of a pipe system) and 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 (question "ix").

One item that showed consistently lower results is question "ii" (Identifying the components and functions of a hydraulic system). This was expected because hydraulic systems were never covered in the class lectures. It is the purpose of this PBL assignment to expose students in this area and facilitate their self-learning outside of classroom. Therefore, it is an area that students found challenging. However, the results are still well above 3.0 which indicates sufficient student learning in this fluid power application.

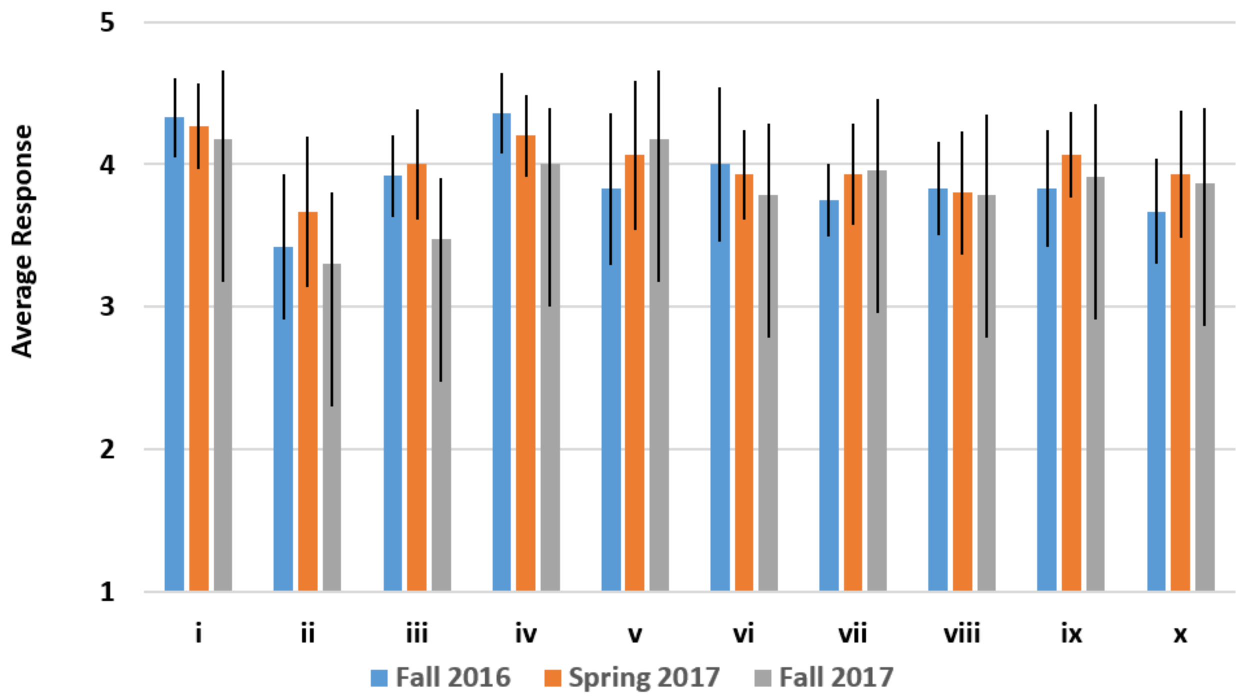


Figure 4 Students' response about technical learning

The data shown in Figure 5 are the student feedback about entrepreneurial mindset learning to the PBL/EML activity implemented in Fluid Mechanics. Again data from three consecutive semesters were collected and were presented as blue columns, orange columns, and gray columns, respectively. As shown in the Figure, the design project allowed students to gain various practice of entrepreneurial skills. Many students considered the results of their projects successful (survey question “b”). 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 (survey question “s”).

One item that showed consistently lower response is item “h”. The students did not feel that they created extraordinary value, which may be addressed by two reasons. First, “extraordinary” is a very strong term. This is the first experience students have had to design an entire fountain. Many of them felt that they could design a better one with more experience and/or with more expert guidance. Second, the students felt 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.

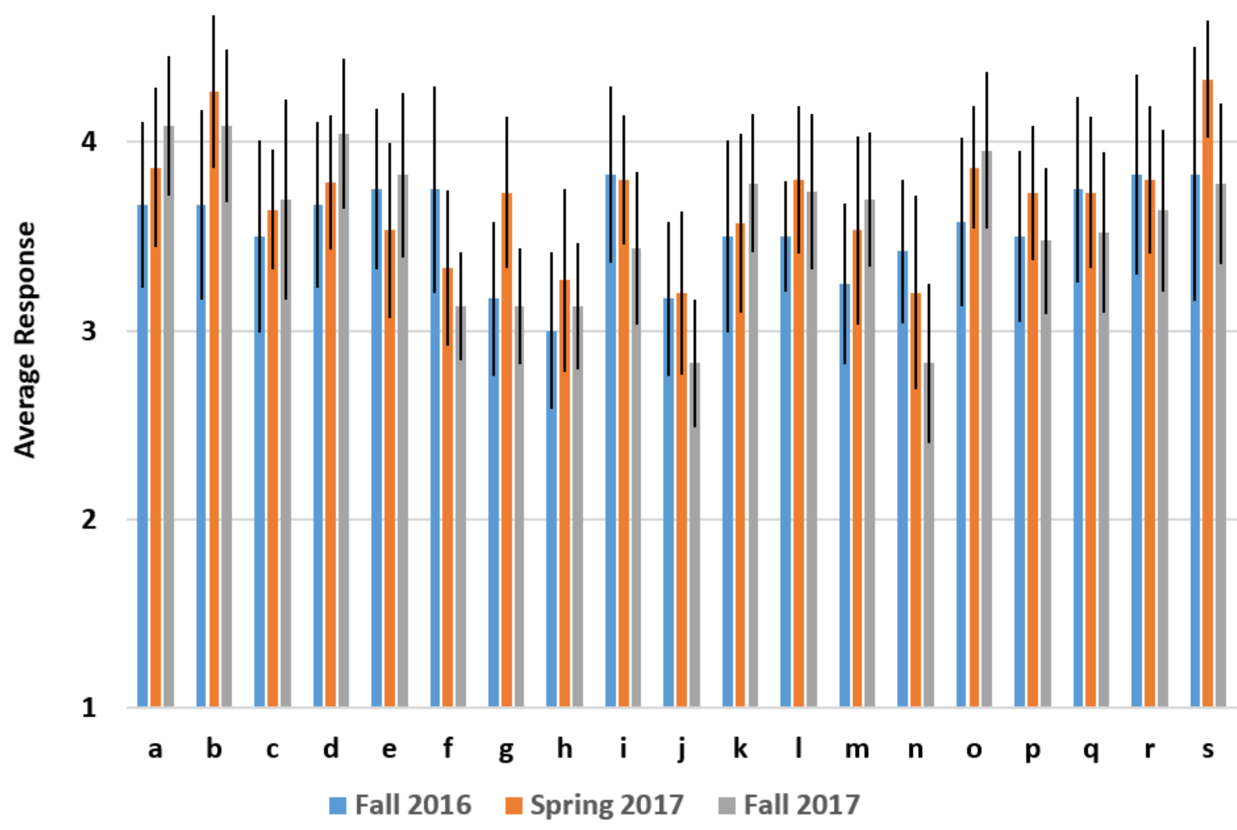


Figure 5 Survey results for entrepreneurial mindset in the Fluid Mechanics Course

Many written comments were received from students sharing their learning experience working on this PBL/EML assignment. Most of the students mentioned that they enjoyed applying the theories learned to an out-of-classroom design exercise, and they appreciated the open-ended nature of the problem. Some examples of such comments are shown below:

- "I enjoyed the open-endedness of the project, as it allowed for more creativity and real world problem solving."
- "It was realistic and I could apply what we're learning directly to the problem. It relied on using a lot of references (not) from the book directly instead of relying on outside… for what I was struggling to work with. My partner was very good at helping me understand."
- "The 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."

Some students also shared their struggling due to the fact that the element of fluid power is not officially covered in class lectures. It was also observed that some student teams were confused by the difference between fluid power hydraulics and "general hydraulics" such as the use of a pump. This is something that needs to be clarified to students in future classes. Examples of student suggestions are shown below:

- "A little more direction with the hydraulic component. We struggled with that. I guess we could've come to you earlier though."
- "Assign the project earlier in the semester to give students more time to work on it. The turn in deadline came up fast and it would have been nice to have a few more days to complete it."

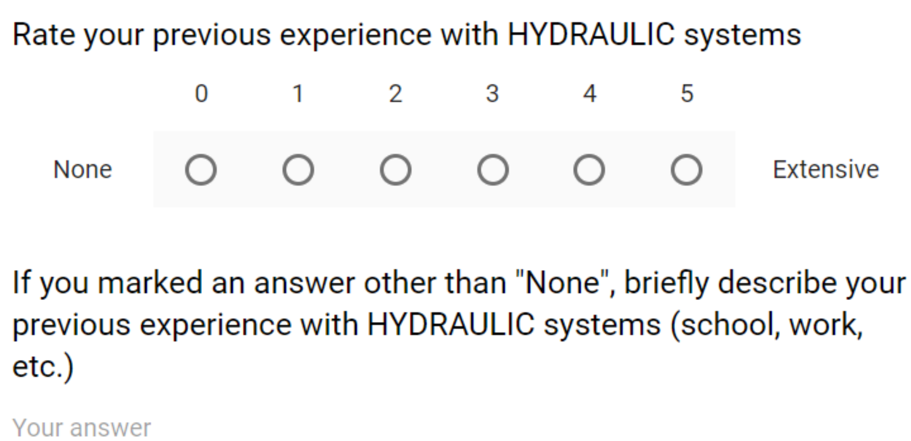
Indirect Assessment in All Courses: Student Learning in Fluid Power

Student learning was indirectly assessed with a paired pre/post survey. Both surveys were administered electronically using Google Forms. One advantage of Google Forms for this application was that student email addresses were captured without student entry. Email addresses were used only to connect pre to post surveys. Some students completed the survey more than once. In these cases of duplicate responses, only the last entry was kept.

The pre and post surveys were designed to facilitate measurement of changes in student learning. Contents of the pre and post surveys are shown in Table 4. The pre survey asked students to rate their previous experience with hydraulic and pneumatic systems and provided a space to explain. This question is shown in Figure 6. Both pre and post surveys provided a list of terms and asked the students to identify those that they could define, as shown in Figure 7. The list of definable terms served two purposes. First, the number of definable terms was used as an assessment of comprehension. Second, thinking about the terms was intended to trigger a more accurate self-assessment of comprehension on the following question shown in Figure 8. The post survey asked students to self-assess comprehension both at the beginning of the semester and at the conclusion of the semester. This allowed two deltas to be calculated: pre-post and post-post, as shown in Figure 9.

Table 4 Pre and Post Survey content

Dimension	Pre Survey	Post Survey
Student demographics	Sex, Class	Sex, Class
Previous experience	Rating Explanation	
Overall knowledge	Definable terms	Definable terms
Start of the Semester Understanding	Hydraulic theory and applications Pneumatic theory and applications	Hydraulic theory and applications Pneumatic theory and applications
End of the Semester Understanding		Hydraulic theory and applications Pneumatic theory and applications

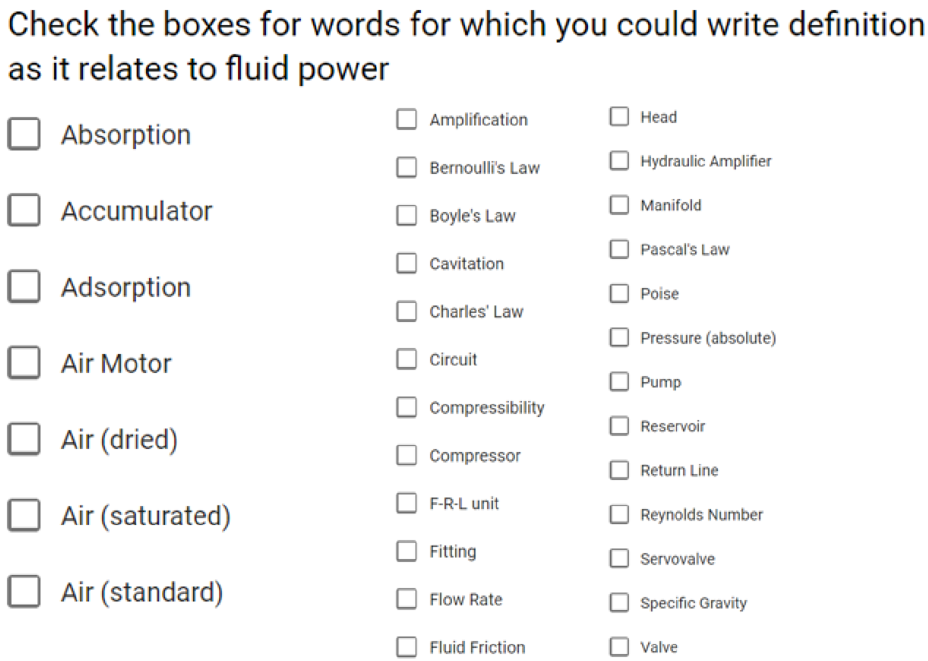

Rate your previous experience with HYDRAULIC systems

	0	1	2	3	4	5	
None	○	○	○	○	○	○	Extensive

If you marked an answer other than "None", briefly describe your previous experience with HYDRAULIC systems (school, work, etc.)

Your answer

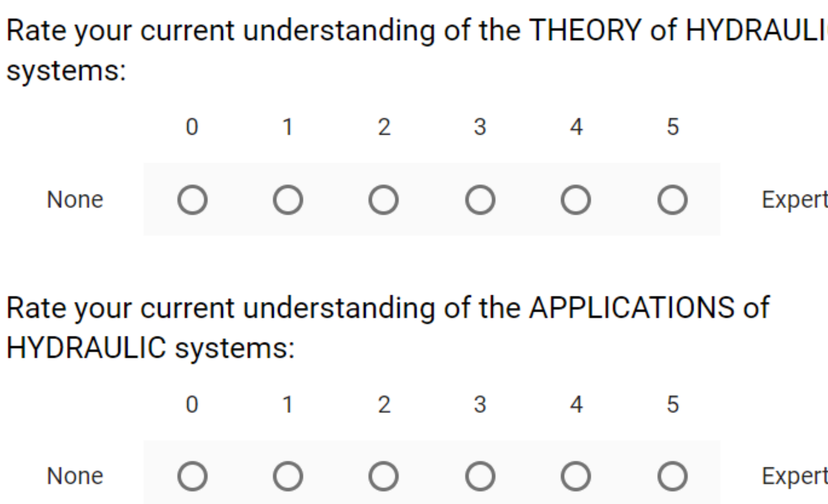
Figure 6 Question about students’ previous experience with hydraulic systems



Check the boxes for words for which you could write definition as it relates to fluid power

- [ ] Absorption
- [ ] Accumulator
- [ ] Adsorption
- [ ] Air Motor
- [ ] Air (dried)
- [ ] Air (saturated)
- [ ] Air (standard)
- [ ] Amplification
- [ ] Bernoulli's Law
- [ ] Boyle's Law
- [ ] Cavitation
- [ ] Charles' Law
- [ ] Circuit
- [ ] Compressibility
- [ ] Compressor
- [ ] F-R-L unit
- [ ] Fitting
- [ ] Flow Rate
- [ ] Fluid Friction
- [ ] Head
- [ ] Hydraulic Amplifier
- [ ] Manifold
- [ ] Pascal's Law
- [ ] Poise
- [ ] Pressure (absolute)
- [ ] Pump
- [ ] Reservoir
- [ ] Return Line
- [ ] Reynolds Number
- [ ] Servovalve
- [ ] Specific Gravity
- [ ] Valve

Figure 7 List of definable terms (condensed from survey for display purposes).



Rate your current understanding of the THEORY of HYDRAULIC systems:

	0	1	2	3	4	5	
None	○	○	○	○	○	○	Expert

Rate your current understanding of the APPLICATIONS of HYDRAULIC systems:

	0	1	2	3	4	5	
None	○	○	○	○	○	○	Expert

Figure 8 Question to acquire a more accurate self-assessment of comprehension in the specific area

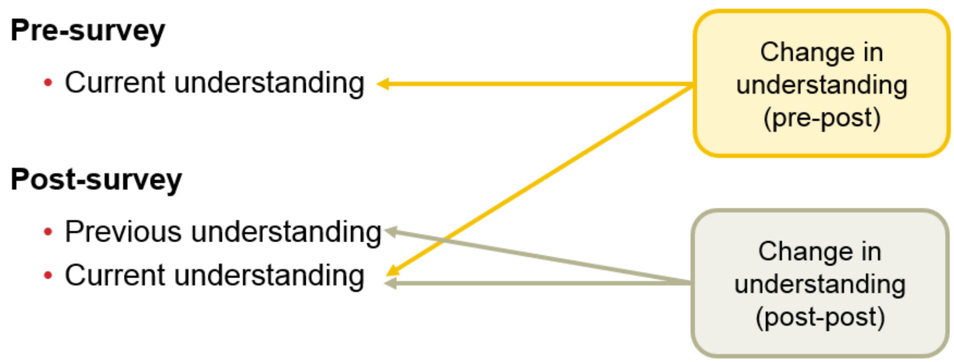


Figure 9 Two deltas were evaluated from the students' feedback: pre-post and post-post

The number of unique responses for each course are shown in Table 5. Due to the small sample sizes, responses from Intro to Thermal Fluids and Applied Thermodynamics are only included in the aggregate.

Table 5 Number of responses to Pre and Post Surveys.

Course	# Completed Pre Survey	# Completed Post Survey	# Completed Pre & Post
Thermodynamics	38	41	34
Fluid Mechanics	26	23	22
Intro to Thermal Fluids	10	7	6
Applied Thermodynamics	18	15	13

First, student self-assessment of prior fluid-power experience was considered. Students rated their experience on a scale from 0 (none) to 5 (extensive), as shown in Figure 10. Most students had no prior experience with hydraulic or pneumatic systems. Among those that had prior experience, most cited work experience as the source.

Figure 11 shows histograms of the number of fluid-power terms that students could define and Figure 12 shows histograms of the change in number of fluid-power terms that students could define. Figure 12 shows an increase in the number of definable terms for both courses considered. This indicates that the fluid power modules are contributing to student knowledge. Also interesting is that some students demonstrated a decrease in the number of definable terms. This is attributed to the effect of the fluid power modules on assisting students to identify misconceptions. These misconceptions may not have been fully corrected.

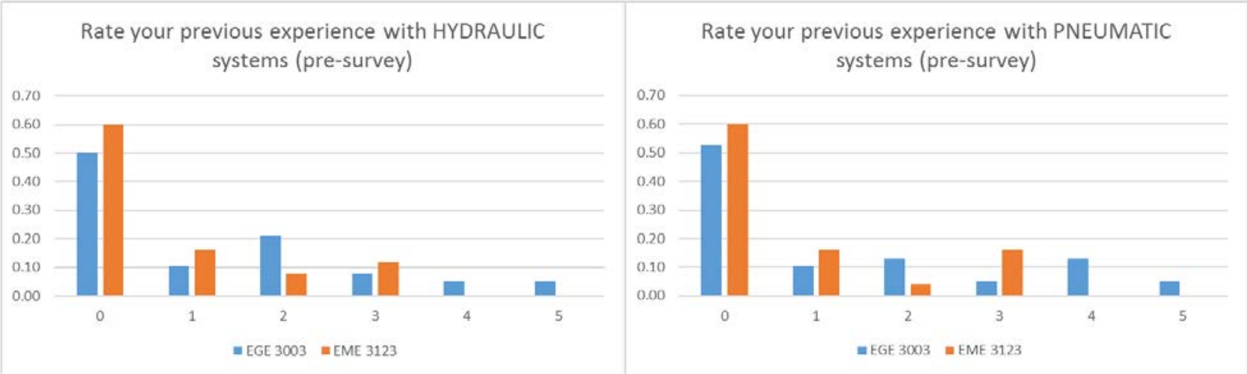


Figure 10 Normalized self-assessment of previous experience on a scale from 0 (none) to 5 (extensive).

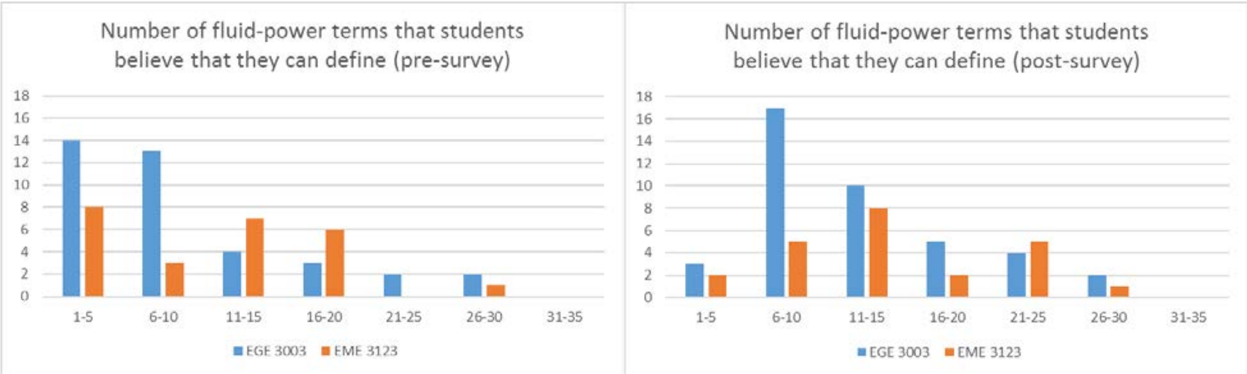


Figure 11 Number of fluid-power terms that students believe that they can define from pre and post survey.

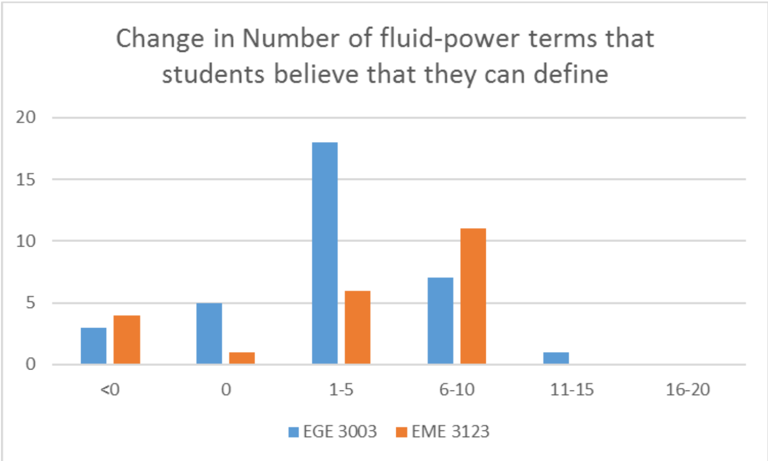


Figure 12 Change in number of fluid-power terms that students believe that they can define (pre to post survey).

Student self-assessment of comprehension was broken down into hydraulic and pneumatic systems with theory and applications for both. Students responded on a range from 0 (none) to 5 (expert) in both the pre and post survey. Normalized responses from the pre-survey are shown in Figure 13 and normalized responses from the post-survey are shown in Figure 14. From the pre-survey responses, most students had little to no comprehension of fluid power theory while some had an understanding of applications.

Following the nomenclature of Figure 9, student gains in understanding of fluid-power were calculated from the pre- and post-surveys. The pre-post comparison is shown in Figure 15 and the post-post comparison is shown in Figure 16. Pre-post and post-post comparisons result in different values but similar trends. From both comparisons, most students showed gains in understanding of fluid-power. As expected, students in Fluid Mechanics demonstrated larger gains in comprehension of hydraulic systems and students in Thermodynamics demonstrated larger gains in comprehension of pneumatic systems. However, both groups saw gains in both domains of fluid power.

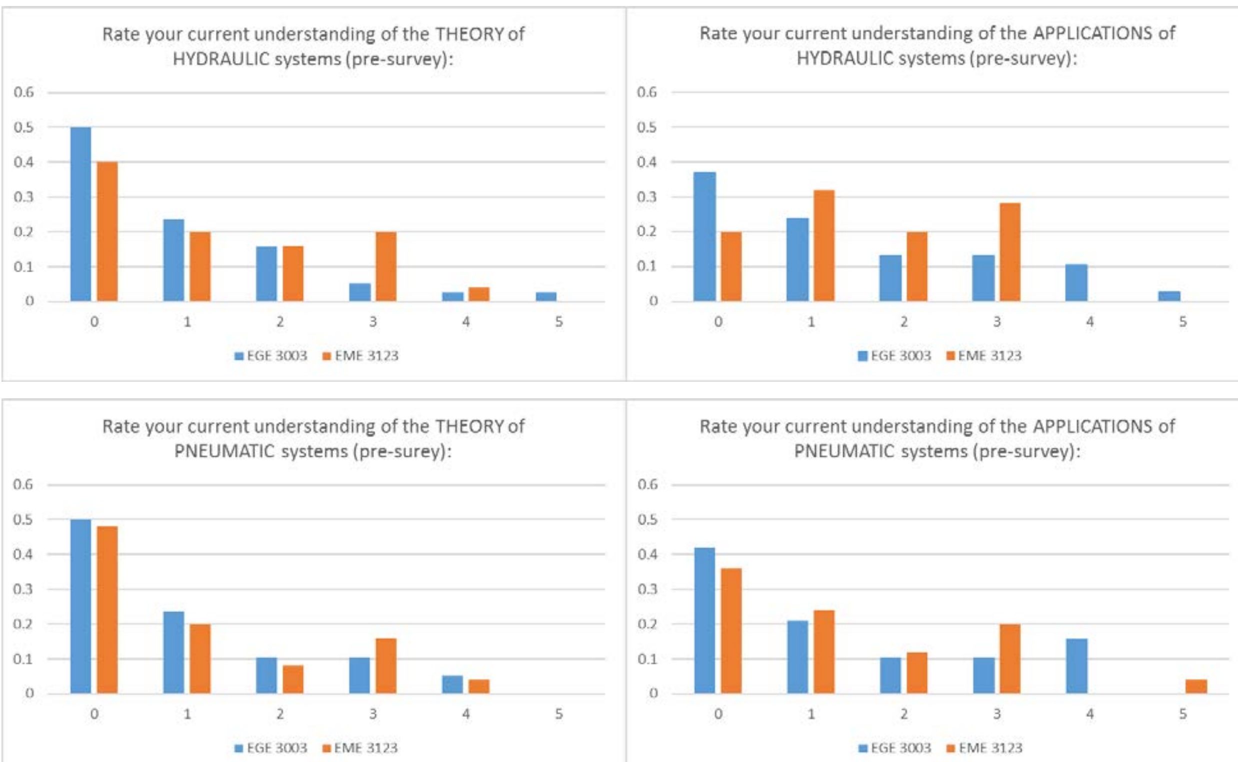


Figure 13 Normalized student self-assessment of fluid-power comprehension (pre-survey) on a range from 0 (none) to 5 (expert).

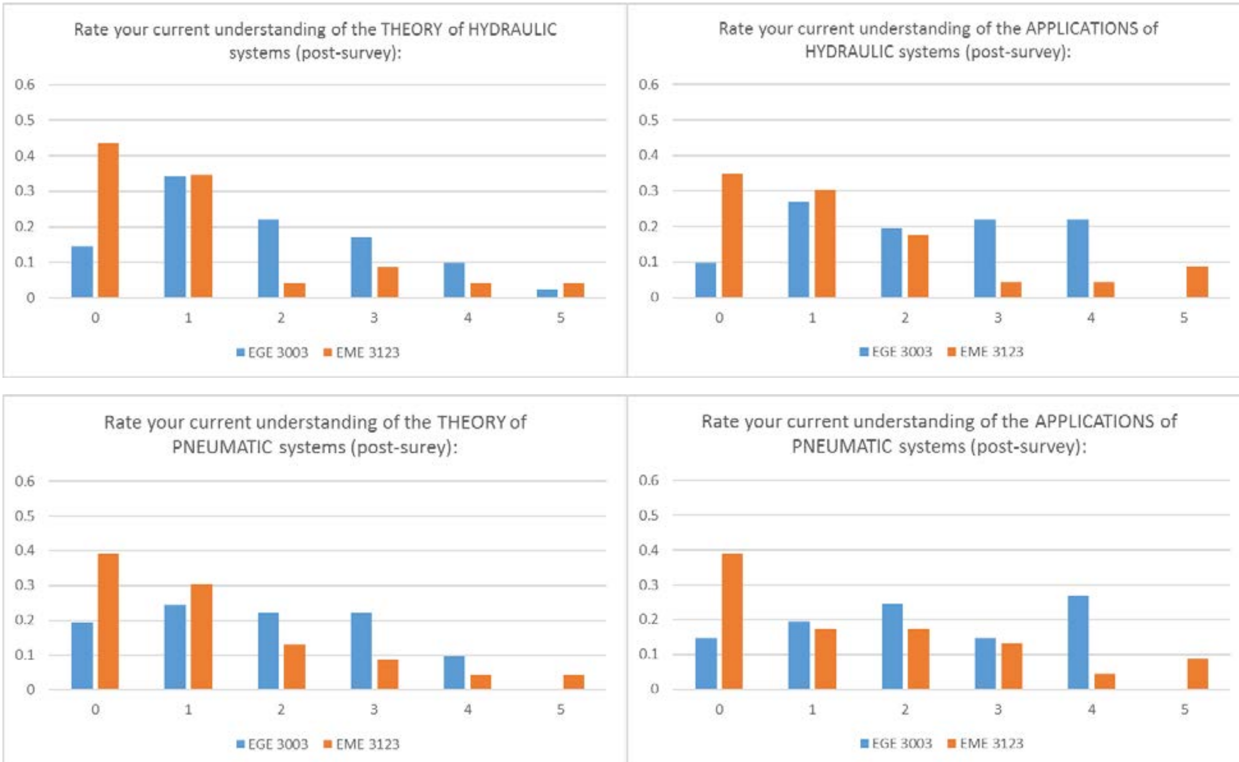


Figure 14 Normalized student self-assessment of fluid-power comprehension (post-survey) on a range from 0 (none) to 5 (expert).

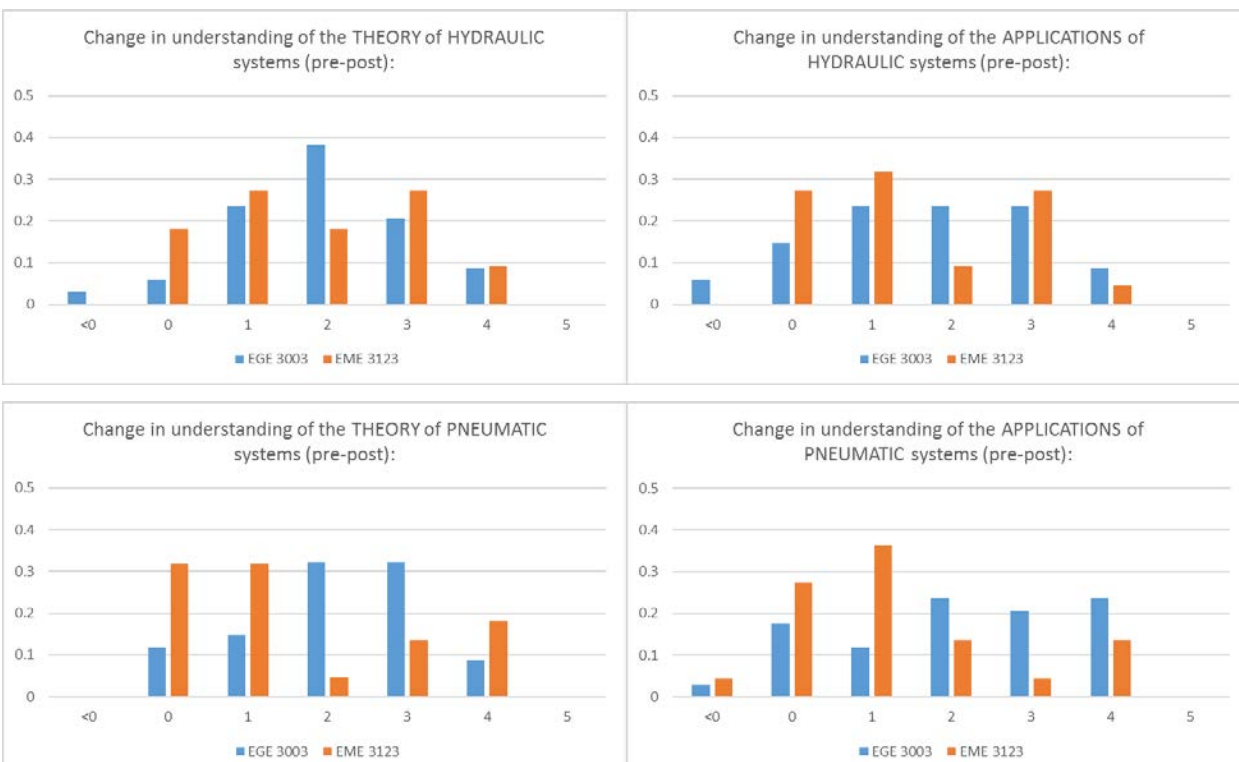


Figure 15 Pre-post comparison of student self-assessment of fluid-power comprehension.

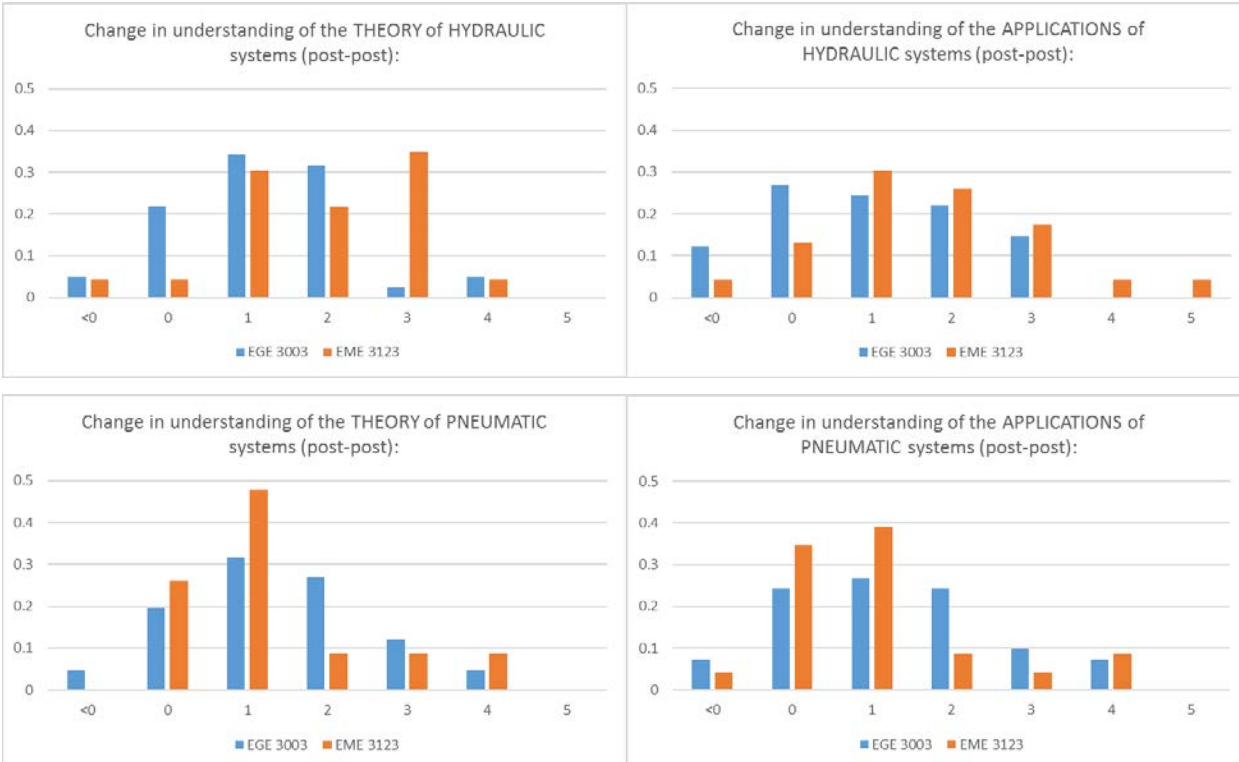


Figure 16 Post-post comparison of student self-assessment of fluid-power comprehension.

Conclusions

Collaborating with the National Fluid Power Association, faculty at Lawrence Tech incorporated fluid power based modules into the Mechanical Engineering curriculum. The works aims to teach students the basic theories and concepts in the area of fluid power and expose them to real-world hydraulic and pneumatic applications. The learning was accomplished by active learning and problem-based learning activities (mainly) outside of classroom due to the very compacted schedule. The modules were implemented in three consecutive semesters (Fall 2016, Spring 2017, Fall 2017). A total of eight faculty were involved and 239 students were impacted. Assessment results indicate that the modules helped students gain insight into the field of pneumatics and hydraulics, which is content not explicitly covered during class lectures. Student survey results also indicate that students perceive extensive practice in many aspects of entrepreneurial skills.

Acknowledgement

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Appendix A: Assignment A in Thermodynamics

EGE3003 Fall 2017

HW "A" on Pneumatics Engineering – 30 points
Issued: September 11, 2017
Due: September 18, 2017

Introduction: The area of Pneumatics Engineering is an important one for many industries involved in manufacturing, production, or material conveyance. It falls under the larger classification of "Fluid Power". In this assignment you will begin to learn about the area of Pneumatics Engineering and how it relates to our EGE 3003 Thermodynamics course.

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

https://www.youtube.com/watch?v=fM11hGJnqtQ (Youtube video titled "Introduction to pneumatics")

a) Describe in some detail the basic operations you see in this video that are powered by pneumatic systems, or compressed air. (2 points)

b) List and discuss the advantages to pneumatic systems given in this video. (2 points)

https://www.youtube.com/watch?v=0zlINr3Vqj4 (Youtube video titled "Pneumatic Desktop capping machine with printing function for semi-auto shampoo production line")

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? Would this be better done by manual labor? Why, or why not? (2 points)

https://www.youtube.com/watch?v=uRpxhlX4Ga0 (Youtube video titled "A car that runs on air")

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. (2 points)

e) What are the advantages to using a compressed air vehicle? Do you think it is practical? Why or why not? (2 points)

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. Go online to find references that can supplement and justify your answers. List and describe these references. (5 points)

3) 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. (2 points)

b) How would a thorough understanding of these topics be beneficial in pneumatics engineering applications and systems? Why? Elaborate upon your answer in detail. (2 points)

4) The area of pneumatics engineering falls under the larger umbrella of Fluid Power. This area is so important in industry that 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. (2 points)

b) Under the "What is Fluid Power?", they discuss several topics. Briefly describe these various topics. (2 points)

c) How they define pneumatics? (2 points)

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 (diameter) of approximately 6½ in. to develop the same force." Quantitatively (by calculations) show how this is so. (2 points)

d) Go to the "Fluid Power Education & Careers" section on the upper heading of website. Under the "Students" section review, list and describe in five or six sentences each three different types of job positions and the associated responsibilities. In addition pick three companies and describe how they may use pneumatics. (3 points)

Appendix B: Assignment B in Thermodynamics

EGE3003 Fall 2017

HW “B” on Pneumatics Engineering – 25 points
Issued: October XX, 2017
Due: October XX, 2017

Background: The area of Pneumatics Engineering is an important one for many industries involved in manufacturing, production, or material conveyance. It falls under the larger classification of “Fluid Power”. In this assignment you will learn about typical operation pressures of pneumatics systems and their relationship to ideal gas assumptions.

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 - This Old House” at www.youtube.com/watch?v=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 (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 0.97 to 1.03 could easily allow the use of the ideal gas law with few problems and little error.) (5 points)

2) 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^{o}C
P_1 = 1 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 550^{o}C 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. (8 points)

b) Compute the work that was rapidly applied to the piston to move it to the new position within the cylinder. (7 points)

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 26^{o}C, but the piston does not move from the new position. Determine the pressure of the air within the cylinder under these conditions. (5 points)

EME 3123 – Fluid Mechanics – Design Project

Fountain from Youth

(a.k.a. Bellagio's Little Cousin)

Spring 2017, Section 1, Dr. Gerhart

Assigned: Thursday, March 16
Preliminary Reply: Monday, March 27
Interim Design Review Due: Monday, April 10
Final Design Due: Monday, April 24

Instructions:

You must work in a team of three of your choosing. Submit one report for the entire team. The Preliminary Reply is a list of responses by the team concerning preliminary problem solving. For the Interim Design Review, I will carefully inspect your work and make comments to improve your design and process. Then you will have time to work-out any problems or issues, fix mistakes, or alter your design. This should allow you the chance to develop a very good and practical design (assuming that you have substantial work attempted for the Interim Design). The Interim Design does not need to be typed and formal, but have it very neat so that I can clearly inspect your work. Your final design report will be typed with the format indicated below. Sample calculations can be done by hand in the appendix, but your calculation/design steps with some equations should be in the main body of the report. I also want your design explained well and readable (i.e., pay attention to presentation, clarity, and grammar). Since a design report is not the same as a homework assignment, don't just do some calculations with a few numbers in boxes. Explain your steps and show all of your work neatly. A good design with sloppiness and poor explanation will appear like a bad design. I do grade grammar and clarity.

Format:

Abstract – This section is one paragraph or two short paragraphs that briefly describes the main components of your design. It should be a stand-alone section that reveals the major conclusions that are of interest to your customer.

Introduction – Describe the problem to be solved, objectives/goals, assumptions.

Description – Include a comprehensive schematic(s) of your final design near the beginning of this section. Then go through the design process with important calculated results and/or graphs, tables, etc. and include additional sketches and drawings if necessary. Be logical in your sequence of this section. Always title (caption) and label any figures. As common practice, any figure in the report must be discussed somewhere in the text.

Conclusion – Summarize the features of your design, the estimated cost to produce it, and the estimated yearly operational cost.

References – Use a standard format for references (e.g., APA, MLA, Chicago)

Appendix – This section is not required, but may include useful items that add detail which was not completely necessary in main body of the report. Examples include hand calculations, lengthy computer print-outs, or anything else that supports your design. Everything in the Appendix should be noted in the report. For example, "Appendix A shows the detailed calculations of the previous result." Otherwise, the material does not belong in the Appendix and hence the report.

Fountain with Hydraulically Controlled Nozzle System

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

Continued on reverse side

the mountains of Colorado.) After Uncle Mortimer restored the Overlook, his guest 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, Uncle Mort 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. You must keep in mind that Uncle Mortimer is miserly with his expenses; he did not get rich by wasting money. But Uncle Mortimer is very generous with his family. Therefore if you can design an efficient and cost effective system, you will not only be paid well, you will likely inherit the land and hotel in Uncle Mortimer’s will!

Preliminary Reply Investigation: some (not all) considerations during the first ten days. If necessary, consult your customer.

- What major components are needed for a fountain and a hydraulically controlled device?
- Where will the fountain be located?
- What should be the overall footprint size of the fountain?
- When and/or how often is the fountain operational?
- What intriguing display features should the fountain exhibit, and how many nozzles does that require? How many of those 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 <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> any potential electronic control system, and <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.