Enhancing Teaching Practices for Fluid Power Class with Interactive Learning Exercises and its Impacts on Students’ Performance

Dr. Maher Shehadi, Purdue Polytechnic Institute

Dr. Shehadi is an Assistant Professor of Mechanical Engineering Technology (MET) at Purdue University. His academic experiences have focused on learning and discovery in areas related to HVAC, indoor air quality, human thermal comfort, and energy conservation. While working with industry, he oversaw maintenance and management programs for various facilities including industrial plants, high rise residential and commercial buildings, energy audits and condition surveys for various mechanical and electrical systems. He has conducted several projects to reduce carbon dioxide and other building emission impacts by evaluating and improving the energy practices through the integration of sustainable systems with existing systems. His current research focuses on engaging and educating students in sustainable and green buildings’ design and energy conservation. He is currently investigating various ways to reduce energy consumption in office buildings.
Enhancing Teaching Practices for Fluid Power Class with Interactive Learning Exercises and its Impacts on Students’ Performance

Abstract

Applied Fluid Power is a major course in Mechanical Engineering Technology (MET) programs. This 3-credit hour is taught in a lecture-lab style with equal time distribution. However, all lab experiments have pre-established procedures and do not invoke many aspects that are currently required by employers when recruiting fresh graduates such as critical thinking, complex problem solving, team work skills, applying knowledge in real-world settings, and problem solving in diverse settings.

This paper investigated the effectiveness of two active learning exercises added to applied fluid power class (MET 23000) along with other traditional teaching exercises and compared the students’ grades to other classes that followed traditional learning environment. The two applied activities were designed to meet the course learning outcomes for fluid power class. The first activity challenged the students to build a small prototype of a hydraulic arm using syringes, polypropylene tubes, wooden sticks and other auxiliary items. The project was conducted in teams and students had one week to complete the exercise. The second activity asked the students to use a friction loss apparatus and were asked to evaluate the friction loss coefficient in multiple pipes, elbows and valves using different techniques and equations.

Students’ final designs and sample answers are presented and compared against the intended activities’ objectives. The grades obtained during the active-taught course were compared to six other grade sets where traditional lecturing was followed. The comparison showed that the average of the grades for the active-taught class was the median of the other averages. Students involved in this study experienced many outcomes in addition to gaining the knowledge such as product design and production stages, analytical reasoning, manufacturing, critical decision making and logical thinking. Students’ interest and retention were checked by comparing students grades against other courses and by surveying students’ feedback at the end of both activities introduced.

In addition to showing the effectiveness of active learning techniques in retaining students’ interests and increasing their engagement level in class, this paper provides interesting exercises for applied fluids and hydraulic classes by introducing the two activities that can help in creating a space or opportunity for engaged students to experience real world challenging problems.

Keywords: Active learning, Bloom’s Taxonomy, Knowledge Retention, Problem Based Learning, Student-Centered Learning.

Introduction

Problem-based learning is a process oriented, self-directed, and collaborative pedagogical strategy that guides the students’ learning process through an active learning environment. It is
heard from almost every employer when asked about the weakness of their entry level employees: “they struggle with applying the information they had learned in school/college”. Surveys and studies have shown that effectiveness of traditional learning has dramatically been decreasing [1], [2], [3], [4], [5], and [6]. According to a survey done by the Business Higher Education Forum in May 2012, 35% of four-year college students were math proficient but not interested in STEM [7]. In another survey, 42.1% of college students were not proficient and not interested, 15.2% were not proficient but interested, 25.4% were proficient but not interested and only 17.3% were proficient and interested. The middle two categories “not proficient and interested” and “proficient but not interested” contribute to approximately 41%. The students in both categories need some effort to either improve their learning outcome or to keep them focused during the learning process to retain their interests. Many traditional learning environments are following instructor-centered learning paradigm, whereas the core objective of the learning process are the students themselves. Thus, the learning process should be student-centered environment. A recent published study in June 2018 indicated that many active learning and team oriented exercises can retain students’ interest in learning while in class which is currently lacking with traditional lecturing class style [8].

The current real-world problems are more global and they usually do not fit within the boundaries of a single discipline. The knowledge needed by an engineering or engineering technology program graduates, upon joining an industrial factory, is various and comes from different domains and disciplines. Some skills and competencies that current employers are looking for in recent graduates, according to a survey done by Purdue University in 2013, included innovation as a priority, followed by problem solving in diverse settings, critical thinking, and then complex problem solving. The survey revealed that innovation, critical thinking, complex problem solving are becoming more significant for employers. To meet these new challenges and requirements, active learning provides a rich environment with the many ways that it can be offered such as: design projects, technology driven homework assignments, exercises in the classroom, working problems in small groups, guided and facilitated discussions, online quizzes, online threaded discussions, students presenting new material to the rest of the class, discussion-based learning, and plant tours.

However, research and surveys have shown that activity-based approach or problem based learning is the best. Activities, such as a one-week project or paper discussion have proven to have more impact and attracts more students. A semester based project learning technic might be risky as some students might be ignored or left behind other students.

Wlodkowski [10] indicated that analyzing and studying real life problems are essential for any problem-based learning (PBL) environment in order to motivate critical thinking, collaboration, and professional skills. Weber [11] indicated that it is important for PBL to define the rubrics for success in order to meet its goals. It is important to define achievable and reasonable rubrics that the students can follow and achieve successfully. Those rubrics can be structured as the objectives of the project that should reflect a safe and successful environment where students are
encouraged to participate instead of feeling embarrassed. It should promote an interesting and relevant experience, as well, where the students are allowed to fully engage in a professional role to fulfill the goal they are working on.

In this paper, two project-based activities are discussed along with their impact on sophomore and junior students’ performance. The new structured course grades were compared to traditionally taught class environment grades. The comparison allowed assessment of the activities’ impact on students.

Research Questions

The questions that this study tried to answer were:

- How to retain students’ interests during the class while covering the curriculum as required by the college and department?
- How does the overall performance of the students change when taking the course in a format or style that is different than traditional learning?

Methodology - Development and use of hands-on active learning exercises

Fluid power class is a traditionally taught course in the School of Engineering Technology at Purdue University. Students enrolled in this class are usually sophomores or juniors. The course learning outcomes (CLOs) are as follows:

1. Design fluid power systems with off the shelf components.
2. Analytically analyze fluid power systems for proper operation.
3. Demonstrate understanding of operational theory of pressure vs. flow in hydraulic systems.
4. Demonstrate understanding of operational theory of pressure vs. flow in pneumatic systems.
5. Demonstrate understanding of the conservation of energy equation to fluid power systems.
6. Demonstrate the operation and function of working fluid power systems.
7. Demonstrate application of compressible and incompressible fluids
8. Demonstrate conventional solenoid control valve vs. servo control valve technology application to motion control circuits.
9. Use application software for analyzing, documenting, and presenting the results of technical work.

To meet the above CLOs, the course was originally designed to have 9-10 predetermined labs. The laboratory experiments cover a wide set of topics including fluid properties, piston speed analysis, to motor and pump performance analysis. However, students follow predetermined procedures and, thus, they lack critical thinking, real and complex problem solving as they are guided through the steps of the experiment and through its analysis by the guided questions. To
help improve the students’ experiences and knowledge, two hands-on exercises were designed and added to the course content. The objectives of each exercise were designed to meet the CLOs of the course. Students would have to design, conduct tests and submit a report with a limited duration of time in and out of class.

The first active learning exercise asked the students to build a mini-hydraulic arm using simple tools and equipment including plastic syringes, polypropylene tubes, wooden sticks and other auxiliary items. Student groups of 3 were randomly formed. Groups were given a full week to allow them to work on the preliminary design, fabrication, and final design of their products. The students were given a set of objectives and goals that they needed to achieve as shown in Table 1 along with assessment rubrics. Grades were assigned based on oral questions that the instructor asked to each member of the teams. Failure to answer two questions or more required the instructor to investigate the contribution of the member and was assigned a lower grade than the other team members. Upon completion of this exercise, students would fulfill the following outcomes from the list of the previously presented CLOs: 1, 2, 3, and 4. Student teams would have to go through any design process followed in an industrial plant to reach to their final product. The project started with lower-order skills by searching for applicable and similar products and then the level of learning and thinking escalated as the students started to implement their designs. The final products required testing and redesigning which required higher-order thinking and analysis skills.

<table>
<thead>
<tr>
<th>Mini Project Objectives</th>
<th>Outcome Evaluation Rubric</th>
<th>% of total grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The arm should be able to have 3 degrees of freedom: angular, horizontal, and vertical</td>
<td>Functionality</td>
<td>10%</td>
</tr>
<tr>
<td>- The angular rotation should cover a minimum of 90-deg angle</td>
<td>Neatness</td>
<td>5%</td>
</tr>
<tr>
<td>- The horizontal and vertical allowances should be at least 3 inches each way</td>
<td>Vertical movement</td>
<td>20%</td>
</tr>
<tr>
<td>- The arm should be able to lift a small object using an electromagnet</td>
<td>Horizontal requirement</td>
<td>20%</td>
</tr>
<tr>
<td>- The tubes (hoses) should not pop up from the cylinders (syringes) when in operation while carrying the ball from one location to another.</td>
<td>angular requirement</td>
<td>20%</td>
</tr>
<tr>
<td>- Air bubbles inside hoses should be minimized.</td>
<td>Lifting</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Successful continuous operation</td>
<td>15%</td>
</tr>
</tbody>
</table>

The second exercise included working on a friction loss apparatus that was designed and built by the author of this paper and is shown in Figure 1. The unit included four horizontal pipes made
of different materials and sizes (smooth and rough material with diameters of ½” and 1”)

Pressure connection ports that connect to manometers were built at Purdue Polytechnic, Kokomo
location using a 3D printer to allow the design of a connection port that matched the different
pipe contours. A copper nozzle was threaded into the 3D printed connections allow plastic tubes
to be connected that in turn were connected to manometers. A small single speed pump was used
to circulate water through the system. Pipes included two different materials (smooth and rough)
and two different diameters. This allowed different comparison combinations: rough against
smooth material with same diameter, and same material but different diameters comparisons.
Short and long radius elbows were used along with Tee- and Y-elbows. Three different types of
valves were installed (ball, gate and butterfly valves) providing control for the water flowrate
and allowing performance comparisons of the three different valves. Finally, two mass flow
meters were installed at the exit pipe of the unit: the first one is an Omega Rota meter (at the far
right side in Figure 1) and the second one is an Omega digital ultrasonic flow meter (gray box in
Figure 1). Four activities with significant outcomes were identified and assigned to students
during this exercise. The objectives of the four activities were listed in Table 2. Sections of the
actual assignments for Activities 1 & 3 and Activities 2 & 4 are provided in Appendix A and
Appendix B, respectively to help other instructors reproduce the activities. Upon completion of
this exercise, students fulfilled the following outcomes from the list of the previously presented
CLO: 2, 3, 4, 5, 6, 7, and 9.

Figure 1. Friction loss determination apparatus
Table 2. Objectives for the 4-activities identified with the friction loss exercise

<table>
<thead>
<tr>
<th>Activity #</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Comparison of friction loss coefficient for different pipes with different sizes and materials</td>
</tr>
<tr>
<td>2</td>
<td>Determination and comparison of the K-values for various hydraulic fittings</td>
</tr>
<tr>
<td>3</td>
<td>Investigating and analyzing the effect of flow rate on head loss</td>
</tr>
<tr>
<td>4</td>
<td>Determining K-values for different valves at different opening positions</td>
</tr>
</tbody>
</table>

Results

For the first hands-on exercise, students came up with three different built up designs. Two designs (Figure 2a and 2c) were similar in scope and function. The other product design, shown in Figure 2b, was closer in operation to an excavator than being a hydraulic arm, but it met the objectives listed in Table 1. All of the three presented products successfully met the requirements presented Table 1. (The assigned QR codes on the lower left corners of Figure 2 (a, b, c) are links to video demonstrations of each built product).

Figure 2. Built up products from hands-on exercise # 1

Selected students’ results for exercise # 2 are presented in Figures 3, 4 and 5 showing pressure loss across the 4-pipes, across different valves and the friction loss coefficient, respectively. Results shown in Figures 3 and 5 met objectives 1 and 3 in Table 2; Results in Figure 4 met objectives 2 and 4.
Figure 3. Selected students’ results from exercise 2 meeting objectives 1 and 3 listed in Table 2

Figure 4. Selected students’ results from exercise 2 meeting objectives 2 and 4 listed in Table 2

Figure 5. Selected students’ results from exercise 2 meeting objective 1 listed in Table 2
The students’ performance in both activities was evaluated based on the rubrics presented in Table 1 for exercise 1 and based on quantitative reasoning, correct answers and analysis for exercise 2. The overall course grades distribution is shown in Figure 6. The average of the class was 84.3 out of 100 with a maximum grade 92 and a minimum 47. One of the students, out of 15 students, was not interested at all during this course and he did not participate in most homework assignments, laboratory reports, or the hands-on activities and thus scored 47. The impact of this low score will be discussed in analysis section.

![Grades distribution among students who were involved in the course that included the hands-on activities presented in this paper](image.png)

**Figure 6.** Grades distribution among students who were involved in the course that included the hands-on activities presented in this paper

**Discussion**

The two activities presented in this paper that were implemented in the fluid power class engaged the students in many aspects that current employers are seeking in fresh graduates. In the first exercise, for instance, defining the necessary hydraulic arm operation and linking the operation and limitations with other design aspects is a key element to make the final product successfully operate. Team work was essential to achieve a successful and functioning product. The students distributed the work among themselves to meet the objectives within the allocated time. Resource finding, critical and logical thinking, along with analytical reasoning were all necessary when moving from one step to another. The students used various resources including online videos and demonstrations, consulting other hydraulic equipment sites and checking similar systems’ operation and assemblies. Despite of the source used, the students were enjoying as a team. They struggled many times and failed in achieving the goals listed in Table 1 from the first trials. Students learned that there has to be a brainstorming before any design where they could list the resources, and capabilities against the objectives. The “90-degree turning” objective in exercise 1 was one of the most challenging tasks to achieve due to the rotation of the arm on the base of the hydraulic arm. The students did put extra time outside class and lab time to finish their products. This activity included many of the high level items in the Bloom’s Taxonomy chart, shown in Figure 7, invoking not only knowledge understanding and application, but analysis of the product, evaluation of the output, and then redesigning and creating an improved product. For example, in the first exercise the brainstorming would meet
the lower Bloom’s Taxonomy levels and then the students’ knowledge would increase when applying trial and error in the design and manufacturing to meet the objectives listed. Product development from brainstorming till manufacturing would require students analysis, synthesis and evaluation which are higher-order thinking levels. This activity also introduced the students to many hydraulic topics that are not usually discussed in details during class time, such as: the significance of the hose length and its impact on the overall system operation, the cons and pros of having too little air compared to too much air bubble in the tubes, etc.

![Bloom’s Taxonomy Triangle](image)

**Figure 7. Bloom’s Taxonomy Triangle**

On the other hand, the objectives of exercise 2 had huge impact on the learning outcomes not only in fluid power class but in other fluids related classes such as advanced fluid power, applied fluid mechanics, and air-conditioning classes. Friction loss coefficient determination and comparison for different materials is usually discussed in these classes analytically with the aid of Moody’s diagram. Students usually get confused between pipe roughness and friction loss coefficient. The four objectives set for this exercise helped the students on one hand in understanding and analyzing the effect of each of the pipe properties (size, length, material and roughness) on the friction loss inside the pipe, and on the other hand in evaluating the relation between flow rate and friction loss. A strong example is the friction loss coefficient “f” determination shown in Figure 5: one method to calculate it was by using the known Darcy’s Equation, presented in equation (1), and the other one was using Reynold’s number (N_R) or the Blasius equation shown in equations (2) and (3), respectively (where h is the head loss, f is the friction loss coefficient, L is length of the pipe, V is the velocity, g is the gravitational acceleration, N_R is the Reynold’s number). The two rows for f shown in Figure 5 contain huge amount of information including: distinguishing laminar versus turbulent flows and head loss calculations which were all main learning outcomes for this course.

\[
h = \frac{f L V^2}{2g} \quad \text{(1)}
\]

\[
f = \frac{64}{N_R} \quad : \text{For laminar flow} \quad \text{(2)}
\]

\[
f = \frac{0.1364}{N_R^{0.25}} \quad : \text{Blasius equation for turbulent flow} \quad \text{(3)}
\]
Looking into the students’ feedback at the end of exercise #1 and exercise #2, it was noticed that a major challenge that was raised at the beginning of this paper, which is keeping high participation from the students, keeping them attracted and interested, while achieving success, was met. Students’ feedback are summarized in Table 3 below.

**Table 3. Students’ feedback after the hands-on activities**

<table>
<thead>
<tr>
<th>Feedback</th>
<th>Students’ Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>We’d like to see more mini hands-on projects</td>
<td>Helps me see the process of real world applications</td>
</tr>
<tr>
<td>I enjoy hands-on projects</td>
<td>Will remember these classes for very long time</td>
</tr>
<tr>
<td>Projects help me learn</td>
<td>Challenging but enjoyable learning environment</td>
</tr>
<tr>
<td>Teacher guidance with minimal support was helpful in making us discover our capabilities</td>
<td>We’d like to have more labs and more hands-on things to do</td>
</tr>
</tbody>
</table>

To evaluate the effectiveness of the hands-on exercises on the overall scores of the students, the average, minimum and maximum of the grades obtained in the class were compared against six other data sets for the same course. Figure 8 shows these comparisons with the colored bars (last set) representing the course with the two added hands-on activities. Purdue Polytechnic Institute which is one of the colleges of Purdue University has a location at the main campus in West Lafayette, Indiana and 9 other locations distributed in the State of Indiana. The number of students and the diversity of students are always higher at the main campus than other remote site locations. Data sets 1 through 6 were pulled from different locations and kept anonymous to represent various students taking the same course in a traditionally taught environment (exams, assignments and predetermined lab sets). The mean value for the “hands-on” grades was the median of the 7 means presented (Set 2, 3 and 4 fell below, and 1, 5 and 6 were above hands-on average). However, it should be noted that the low number of students makes the average-value highly sensitive to each individual grade. For example, it was noticed that the minimum grade for the added “hands-on” course was 47; checking the instructor’s notes, this outliner student was not interested at all during the course and did not participate in most activities and his performance was too low in the exams, his grades were the lowest among the seven data sets presented. If this outlier grade is removed, then the average for the hands-on category would rise to 86.7 making the average for hands-on set in second rank after the highest average of all sets which is 87. Despite this, the overall performance was at an acceptable level compared to other grades during other semesters and at other locations. This indicates that the information was delivered to the students successfully although less lecturing was done.
Summary and Conclusions

This paper presented a change in teaching style for fluid power course towards a more student-centered based learning. This course is already rich with laboratory work, but students’ interest was noticed to have decreased due to the routine in following predetermined procedures. Also it was noticed that there was lack in using critical thinking and complex problem solving. Based on the previous studies, active learning techniques did not provide improvements in student test scores, but are likely to positively influence student attitudes and study habits over the long run. Students involved in this study experienced many outcomes in addition to gaining the knowledge such as product design stages, analytical analysis and reasoning, manufacturing and building up of a product, critical decision making and logical thinking. The students’ performance at the end of the course was competing to other traditional learning environments, but it had the advantage of keeping the students interested in learning more about the material. Many researchers claim that active and hands-on learning do not cover as much of the curriculum as the traditional learning styles. However, looking into the CLOs linked with each of the two hands-on exercises presented, it is seen that the course learning outcomes are covered in one way or another, except CLO#8. This can be easily compensated for by the other assessment tools used in addition to the activities presented such as exams and other assignments (labs and home assignments). The students’ performance and the overall grades at the end of the course, which included their grades for exams, term project, and homework assignment, showed that students are still able to score high in exams with this type of flipped learning.

It is expected that the impact of active-learning classes will vary in strength from time to time and from location to location. There are some obvious results due to students’ engagement in these activities that are reflected on students’ interest in learning, their overall grades, and post-
graduation knowledge. Content discussed through class demonstrations and hands-on activities tend to be remembered over the long term more than material taught using traditional teaching styles that are instructor-centered instead of being student-centered. However, not the entire course needs to be team-based [12]. Students’ individual responsibility is a key factor in these learning environments. Nevertheless, extensive and credible evidence supports the concept that nontraditional teaching environments is vital nowadays to achieve students’ success [13].

Each study that presents outcomes of some class learning techniques and practices is unique and has its own limitations. No matter how data is presented, faculty who try to adopt instructional practices from literature should expect some narrow or wide differences in the outcomes than those of the adopted study. Even if the faculty excels the new techniques and the new instructional methods, other variables can’t be controlled. Demographic differences among students, connection between students and their instructors, and students to instructor ratio per class are all significant variables that can affect the results of any practices or exercises followed.

References

Appendix A

Actual Assignments for Activities 1 & 3 in Table 2

**OBJECTIVES**

1) Compare the friction loss coefficient for different pipes with different sizes and materials.

2) Investigate the effect of flow rate on head loss.

**APPARATUS**

Fluid friction apparatus is located in KC144. There are four main paths through which water can flow as indicated in the below schematic. The testing pipes and fittings are mounted on a wooden frame. Water is fed-in from a plastic tank where a pump is installed (Little Giant Pump – Data Sheet). Water can flow through the network of pipes and fittings, and is fed back into the volumetric tank via the exit tube. Two units are installed to allow flow rate reading: rotameter (Data Sheet available in the lab) and an Omega Ultrasonic Flow meter (please don’t alter the locations of the transducers or change the settings of the flow meter; Ask for help if you need to change something). The pipes are arranged to provide facilities for testing the following:

1) Four pipe sections. Two different sizes and two different materials are used. Sizes are \( \frac{3}{4} \) inch and 1 inch whereas material includes PVC and galvanized steel pipes.
2) Different connections such as short 90-deg elbow, tee connection, y-connection, globe valves, gate valves, butterfly valves, strainer, etc..

![Figure 1 - Fluid Friction Apparatus](image-url)
**BASIC THEORETICAL BACKGROUND**

Two types of flow may exist in a pipe: Laminar (smooth flow) or Turbulent (chaotic or random motion).

1) Laminar flow has low velocities. The head loss “h” linearly increases with the velocity when the flow is laminar $h \propto v$.

2) Turbulent flow has relatively high velocities. The head loss “h” increases exponentially (parabolic behavior) with the velocity $h \propto v^n$ (where n is an exponent).

For a circular pipe flowing full, the head loss due to friction is determined using Darcy's equation:

$$h = \frac{fL V^2}{2g} \quad (\text{m or ft})$$  \hspace{1cm} (1)

where $f$ is the friction loss coefficient, $L$ is the length of the pipe (m or ft), $V$ is the velocity (m/s or ft/s) and $g$ is the gravitational acceleration (m/s$^2$ or ft/s$^2$).

The velocity of water inside any section can be determined using continuity equation:

$$Q = A \cdot V$$  \hspace{1cm} (2)

where $Q$ is the volumetric flow rate in (gpm, lit/min, m$^3$/s, or in$^3$/min, or any units based on your system calculations) and $A$ is the cross-sectional of the pipe (Make sure you use consistent units for $A$ and $V$ to have the proper units for $Q$).

The state of the flow is determined based on Reynold's Number

$$N_R = \frac{V \cdot D}{\nu}$$  \hspace{1cm} (3)

where $\nu$ is the kinematic viscosity of the fluid (approx. $10^{-6}$ m$^2$/s for water at standard room temperature). If $N_R < 2000$, then the flow is laminar and the friction loss coefficient can be determined using equation (4), otherwise if it is $2000 < N_R < 4000$ it is transitional and equation (4) can still be used; if $N_R > 4000$ then it is turbulent and the friction loss coefficient can be determined using either Moody diagram or can be estimated using equation (5) below (if $N_R < 100,000$).

$$f = \frac{64}{N_R} : \text{For laminar flow}$$  \hspace{1cm} (4)

$$f = \frac{0.1364}{N_R^{0.25}} : \text{Blasius equation for turbulent flow}$$  \hspace{1cm} (5)

In addition to pipe friction loss, the systems fittings such as elbows, contractions, and valves incur additional pressure drops. The head loss is determined using equation (6) where $K_v$ is friction loss coefficient for each fitting and can be best estimated using manufacturer’s catalogues or industrial codes such as ASTM or ASHRAE.

$$h_m = K_v \cdot V^2 / 2g$$  \hspace{1cm} (6)
PROCEDURE:

A. **Pipe Friction Loss: (Fill Data Sheet # 1)** [Complete steps 1 through 6 and then start working on part B to allow other teams to record their data. Steps 7 to 12 are calculations and analysis and can be done at a later time]

1. Before turning on the pump, make sure all pressure ports are in closed position.
2. Turn on the pump and make sure the three valves at the end of the system are completely opened.
3. Open and close appropriate flow control valves at the end of each pipe section to allow water to flow through it accordingly. Make sure to only open the valves for the testing section and shut the others, otherwise the flow rate will be divided and results will be incorrect.
4. Measure the pressure difference for each pipe section and convert to head units m, in or ft.
5. Measure the length of each pipe and record its material.
6. Read the flow rate using the Omega Ultrasonic Flow meter or the rotameter (consult with the instructor to ensure the Omega Flow meter settings are set appropriately)
7. Evaluate the flow velocity in each pipe using equation (2) with the proper internal area. (make sure to use consistent units in your calculations)
8. Evaluate the friction loss for each of the four pipe sections using equation (1).
9. **Compare the friction loss coefficient for same size pipes ... which one has the highest friction loss coefficient.**
10. Determine the Reynold’s number for each pipe using equation (3).
11. Determine the friction loss coefficient based on equations (4) and (5).
12. **Compare the friction loss coefficient for each pipe determined in step 8 and step 11. Make your comments and conclusions show a percentage difference between the two answers.**

B. **Effect of flow rate on head loss: (Data sheet # 2)**

1. For each of the four-pipes, adjust the flow rate and record down the corresponding head loss in datasheet # 2.
2. Using either one of the three valves located at the exit pipe of the system, adjust the flow and record the head loss as a function of flow rate for each of the 4-pipes [you don’t have to follow the exact gpm in datasheet # 2, but rather cross the given values and put your actual gpm read directly from the ultrasonic flowmeter].
3. Plot the head vs. Q for all 4-pipes on one plot (separate plots will receive penalty. For better comparisons, you need to show all four curves/lines on one plot). If the values are different you can use primary and secondary y-axis for the same plot. Ask if you don’t know how to do it.
4. Compare and explain.

**MAKE SURE TO LABEL ALL PIPES and FITTINGS YOU CONSIDER ON A SEPARATE LAYOUT THAT SHOULD BE ATTACHED WITH THE REPORT.**
<table>
<thead>
<tr>
<th>parameter</th>
<th>units</th>
<th>Pipe 1</th>
<th>Pipe 2</th>
<th>Pipe 3</th>
<th>Pipe 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Diameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>head loss &quot;h&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow rate &quot;Q&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter &quot;D&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area &quot;A&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity &quot;V&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f (from head loss)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reynold's # Nr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminar or Turbulent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f (from Nr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q (gpm)</td>
<td>Pipe #</td>
<td>Pipe #</td>
<td>Pipe #</td>
<td>Pipe #</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max gpm &gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

Actual Assignments for Activities 2 & 4 in Table 2

OBJECTIVES

1) Determine the head loss across different valves, elbows, and connections.

2) Determine K-values for different valves, elbows, and connections.

APPARATUS

Fluid friction apparatus is located in KC144. There are four main paths through which water can flow as indicated in the below schematic. The testing pipes and fittings are mounted on a wooden frame. Water is fed-in from a plastic tank where a pump is installed (Little Giant Pump – Data Sheet). Water can flow through the network of pipes and fittings, and is fed back into the volumetric tank via the exit tube. Two units are installed to allow flow rate reading: rotameter (Data Sheet available in the lab) and an Omega Ultrasonic Flow meter (please don’t alter the locations of the transducers or change the settings of the flow meter; Ask for help if you need to change something). The pipes are arranged to provide facilities for testing the following:

1) Four pipe sections. Two different sizes and two different materials are used. Sizes are ½ inch and 1 inch whereas material includes PVC and galvanized steel pipes.

2) Different connections such as short 90-deg elbow, tee connection, y-connection, globe valves, gate valves, butterfly valves, strainer, etc..

Figure 1 - Fluid Friction Apparatus
BASIC THEORETICAL BACKGROUND

Two types of flow may exist in a pipe: Laminar (smooth flow) or Turbulent (chaotic or random motion).

1) Laminar flow has low velocities. The head loss "h" linearly increases with the velocity when the flow is laminar \( h \propto v \).

2) Turbulent flow has relatively high velocities. The head loss "h" increases exponentially (parabolic behavior) with the velocity \( h \propto v^n \) (where \( n \) is an exponent)

For a circular pipe flowing full, the head loss due to friction is determined using Darcy's equation:

\[
h = \frac{fLv^2}{2g} \text{ (meters)}
\]

where \( f \) is the friction loss coefficient, \( L \) is the length of the pipe (m), \( V \) is the velocity (m/s) and \( g \) is the gravitational acceleration (m/s^2).

The velocity of water inside any section can be determined using continuity equation:

\[
Q = A \cdot V
\]

where \( Q \) is the volumetric flow rate in (gpm, lit/min, m^3/s, or in^3/min, or any units based on your system calculations) and \( A \) is the cross-sectional of the pipe (Make sure you use consistent units for \( A \) and \( V \) to have the proper units for \( Q \)).

The state of the flow is determined based on Reynold's Number

\[
N_R = \frac{V \cdot D}{\nu}
\]

where \( \nu \) is the kinematic viscosity of the fluid (approx. \( 10^{-6} \text{ m}^2/\text{s} \) for water at room standard temperature). If \( N_R < 2000 \), then the flow is laminar and the friction loss coefficient can be determined using equation (4), otherwise if it is \( 2000 < N_R < 4000 \) it is transitional and equation (4) can still be used; if \( N_R > 4000 \) then it is turbulent and the friction loss coefficient can be determined using either Moody diagram or can be estimated using equation (5) below (if \( N_R < 100,000 \)).

\[
f = \frac{64}{N_R} : \text{For laminar flow}
\]

\[
f = \frac{0.1364}{N_R^{0.25}} : \text{Blasius equation for turbulent flow}
\]

In addition to pipe friction loss, the systems fittings such as elbows, contractions, and valves incur additional pressure drops. The head loss is determined using equation (6) where \( K_r \) is friction loss coefficient for each fitting and can be best estimated using manufacturer’s catalogues or industrial codes such as ASTM or ASHRAE.

\[
h_m = K_r \cdot V^2/2g
\]
PROCEDURE:

A. **Head loss across valves: (Fill Data Sheet # 1)**
   1. Before turning on the pump, make sure all pressure testing ports are shut off.
   2. Turn on the pump.
   3. Open and close appropriate valves at the end of each pipe section to allow water to flow through the considered valve/elbow accordingly. Make sure to only water to flow through the section you are testing otherwise flowrate will be divided and results will be incorrect.
   4. For each fitting being tested, measure the diameter of the pipe upstream, and record the flow rate from the digital flow meter (make sure it matches the flow rate on the rotameter otherwise the settings are incorrect).
   5. Using equation (2), find the velocity of water through the considered fittings.
   6. Measure the head loss across the fittings using digital meter or a manometer.
   7. Evaluate K-value using equation (6).
   8. Fill in Data sheet # 1 for the following list:
      a. One short 90-deg elbows at different locations (label the selected one on the schematic)
      b. Long 90-deg elbow.
      c. The globe valves at the end of the four pipe sections (label them) [consider those that valve pressure connecters only]
      d. The three valves located at the end of the exit section.
   9. Add a column to data sheet 1 and list the K-value as given during lecture or from “Esposito” used for MET230 (a short table was provided in the lecture handouts for chapter 2).

B. **K-values for valves with different opening positions**
   1. Consider the three valves located at the end of the exit pipe.
   2. Measure the head loss and record the flow rate for fully open valve, ¾ open, ½ open, ¼ open for each of the three valves one at a time. [using the scale as Pascal on the digital manometer helps see the differences as it has better accuracies for this lab]

The opening degree position for each valve can be determined by following the below procedure

- Open the valve full
- Put a mark on the hand wheel of the valve
- Close the valve to fully closed position while counting the number of revolutions
- Calculate the required opening by adjusting the number of rotations
  - ¾ : 0.75 x total # of rotations
  - ½ : 0.5 x total # of rotations
  - ¼ : 0.25 x total # of rotations

3. Plot the open position on x-axis and the head loss for each of the three valves on the y-axis on the same chart.
4. Compare and explain.
MAKE SURE TO LABEL ALL PIPES and FITTINGS YOU CONSIDER ON A SEPARATE LAYOUT THAT SHOULD BE ATTACHED WITH THE REPORT.

Data Sheet # 1

<table>
<thead>
<tr>
<th>parameter</th>
<th>D</th>
<th>h</th>
<th>Q</th>
<th>A</th>
<th>V</th>
<th>K-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Data Sheet # 2

<table>
<thead>
<tr>
<th>Valve Open Position</th>
<th>Globe Valve</th>
<th>Gate</th>
<th>Butterfly</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>h</td>
<td>Q (gpm)</td>
<td>h</td>
</tr>
<tr>
<td>fully opened</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>¾ opened</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>½ opened</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>