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Hands-on approach to Fluid Dynamics by using industrial fluid-power trainers for Engineering Students

Nelson A. Granda-marulanda (Assistant Professor)

Nelson A. Granda Marulanda is an Assistant Professor in the School of Engineering + Technology at Western Carolina University. Nelson has a BS in Electrical Engineering from the University of Puerto Rico at Mayaguez, a Masters in Manufacturing Engineering from the Polytechnic University of Puerto Rico, and a Ph.D. in Industrial and Systems Engineering from The University of Tennessee Knoxville. Before becoming a professor, he worked for several years in the Eolic and Aerospace industry. Nelson's research interest revolved around Sustainable Development through the triple bottom line and System Thinking approach. Nelson believes that education is the key to achieving a sustainable world.

Joseph Tang (Assistant Professor)

Joseph Tang is an assistant professor at the College of Engineering and Technology at Western Carolina University

Tom Spendlove

Tom Spendlove is a mechanical engineer working in the education field at Western Carolina University in Cullowhee, North Carolina. He has ten years of experience as a manufacturing design engineer and twenty as an engineering educator. His areas of interest are additive manufacturing, sustainable development, STEAM projects, student competitions and interdisciplinary projects.

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Abstract

Engineering students and Engineering Technology students at Western Carolina University have many similarities at the beginning of their curriculum, but as the students progress in their degrees, the differences become more pronounced and relevant to their respective programs. An upper-level Bachelor of Science in Engineering (BSE) student with a Mechanical Concentration takes the Fluid Dynamics course focused on a theoretical approach to fluids, while a Bachelor of Science Engineering Technology (BS-ET) upper-level student takes a Fluid Power Systems course with a focus on a more practical or applied approach to fluids. These differences in emphasis in the Fluids courses are also true in general between the BSE and BS-ET programs. This paper shows the implementation and assessment of a hands-on laboratory experience activity using the ET fluid power trainers for the BSE Fluid Dynamic course students. For the laboratory activity, the Industrial Fluid Power Trainers MF102 Series from the Fluid Power Training Institute were used to allow the students to directly work with the concepts of Pressure Drops, the relationships between Pressure-Force-Area, and the importance of the Bernoulli and Continuity equation. These concepts were presented to the students using a pressure in a series circuit, a regenerative circuit, and a weighted cylinder circuit. During the activity, the students were first introduced to the Trainers and showed how to build a simple circuit and then were guided to build the remainder of the circuits themselves. The laboratory activity was performed after the theoretical concepts were previously discussed in the Fluid Dynamic course in order to assess if the hands-on activity helped the students to visualize and better understand these concepts. The assessment method used to evaluate this experience was a retrospective survey where participants were provided a single survey after the end of the laboratory. The survey was a seven-question instrument with six 5-point Likert scale questions and one open-ended qualitative question. For each of the Likert questions, the participants were asked to reflect on each question and provide their answers describing their experience before and after the laboratory activity. The retrospective survey method was adopted to observe the effect of a short-term activity like the laboratory exercise and help mitigate the survey burden of having to answer two surveys in a short period. The instrument and survey data are presented in this paper. A paired difference statistical test is performed on the quantitative survey responses, and a histogram-generated word cloud of the qualitative responses is shown. The results show a very significant and positive learning experience for the BSE students, suggesting that the Fluid Power laboratory activity can teach, or effectively reinforce, fluids concepts that the students would not have otherwise learned, or learned as well, in the standard Fluid Dynamic course.

Introduction

The College of Engineering and Technology at Western Carolina University (WCU) is composed of two (2) academic Schools. The School of Engineering + Technology contains ABET accredited EAC and ETAC programs housed together in one academic unit. There are currently four (4) programs: Bachelor of Science in Electrical Engineering, Bachelor of Science in Engineering with Concentrations in Mechanical and Electric Power, Bachelor of Science in Electrical and Computer Engineering Technology, and a Bachelor of Science in Engineering Technology with a Concentration in Applied Systems Technology[1]. Given the relationship of these programs, their faculty frequently collaborate, providing a better educational experience to the students enrolled in their programs. The work presented in this paper was a collaboration between the BSE Mechanical Concentration Faculty, Dr. Joseph Tang, and the BS Engineering Technology Faculty, Dr. Nelson Granda Marulanda, and Mr. Tom Spendlove.

In summer 2021, two units of the MF102D-H Double-Station Hydraulic Training Simulator (figure 1) were acquired from the Fluid Power Trainer Institute (FPTI) in Salt Lake City, Utah[2]. The targeted student population for this equipment are the students in the Fluid Power Systems course offered only to the Engineering Technology program at WCU. These trainer systems are very versatile and come with several educational materials, including schematics for training circuits which were used for the laboratory activity presented in this paper.

Figure 1 MF102D-H Double-Station Hydraulic Training Simulator

The use of the Fluid Power trainers was previously limited only to the Engineering Technology program, but with the inception of the laboratory activity *''Hands-on Approach to Flowrate and Pressure Drop''* developed by the authors and offered to the Bachelor of Science in Engineering Mechanical Concentration students during the Mechanical Engineering Lab II the trainers are getting used by more students in the School. This work aims to; (i) provide an example of the collaborative work done between two similar engineering programs, (ii) describe the laboratory activity and the fluid power circuits used, (iii) provide an example and benefits of a retrospective survey instrument, and (iv) present the assessment results of the laboratory activity.

Laboratory Activity Implementation

The title of the laboratory activity was *"Hands-on Approach to Flowrate and Pressure Drop."* The laboratory activity was designed to be able to start and finish in one day with an allotted time of 2.5 hours per session. Given the restrictions on the fluid trainer capacity of four stations and to give a better hands-on experience to the students by working on small teams, the authors spread out the laboratory activity in six days over two weeks. The total number of students, 51, were separated into different sessions, having no more than ten students per session and no more than four students per team during the activity.

Most of the students enrolled in this course and participating in the activity have never worked directly with a Fluid Power Trainer. Therefore, a quick introduction, with a description of the components of the trainer, was offered at the beginning of each session by the instructor.

The laboratory activity consisted of two stages: the introduction and hands-on stages. In the first stage, the students were introduced to the equipment and were shown by the instructor how the trainer station works. The instructor built a simple linear circuit- *pressure in a series circuit* (figure 2), carefully demonstrating to the students how to connect the components with the hoses provided and following the schematics. While at the same time, guided questions were asked to the students. For the second stage, the students were given the schematics for the circuits they had to build- *a regenerative circuit* (figure 3), *and a weighted cylinder circuit* (figure 4). The instructor discusses the circuits and divides the students into teams, assigning them to a station. The instructor supported the student while building the circuits and answered questions that came along the process. At the end of each build, the instructor checks the circuit for safety before turning the trainer station on and asks some discussion questions. A brief description of each of the circuits used during the laboratory activity and insight into the students' discussion is followed.

Pressure in a series circuit

The components used in this circuit are a flowmeter, three pressure gauges, a pilot-operated pressure relief valve (with the pilot not in use), and a direct-operated pressure relief valve. These are interconnected in series, with the pressure gauges connected before each resistive element and at the end of the loop. When the system is powered up, the fluid passes thru the flowmeter and is measured by the 1st pressure gauge. It passes thru the pilot-operated pressure relief valve and is measured by the 2nd pressure gauge. It continues to pass to the direct-operated pressure relief valve and is measured by the last pressure gauge[3].

This circuit is used to demonstrate the relationship between pressure in series by changing the pressure relief valves settings and seeing the responses on the pressure gauges. The students were asked questions about the relationship between Pressure, Force, and Area. Also, some discussion on why the measured flow rate didn't change when the pressure relief valves settings were modified, increasing the pressure. The objective of this part was to make the students think of the relationship and the implications of the Bernoulli equation.

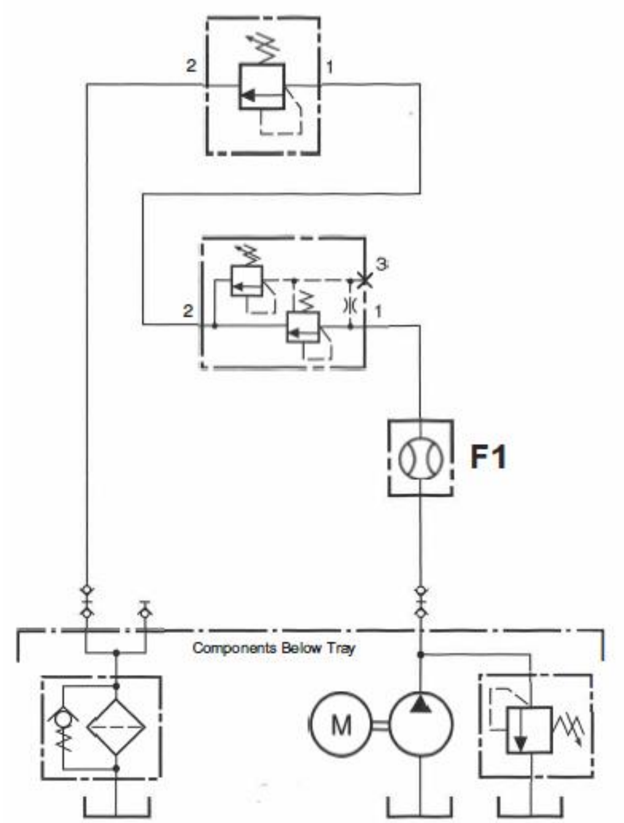

Figure 2 pressure in series circuit by FPTI

Regenerative circuit

The components used in this circuit are more complex, and the students took more time to understand and connect this circuit. The instructor helps the teams find the right components to use for this circuit. The Regenerative circuit uses the following, a pilot-operated relief valve, a tandem-center 3/4 directional control valve, a 2/3 directional control valve, and a double-acting single rod cylinder[3]. The operating concept of this circuit is that in normal mode, the cylinder extension speed is half of the retraction speed. During regenerative mode, the extension speed of the double-acting cylinder matches the same as the retraction; this is done by routing fluid exiting the rod end of the cylinder back to its cap end instead of routing the fluid to the tank[4].

This circuit was used to demonstrate the relationship between flow rate, speed, and area to the students. This shows that the speed of the cylinder changed when the 2/3 directional control valve was activated. The students were asked to evaluate the system and propose reasons for why the speed changed. Then the instructor explains how the cylinder rod reduces the effective cross-sectional area for the acting forces, the regenerative concept, and how the flow is looped back into the cylinder, increasing the flow and the speed. The students were encouraged to think about the basic form of the Bernoulli energy balance equation and the simplified equation of $v = q/a$.

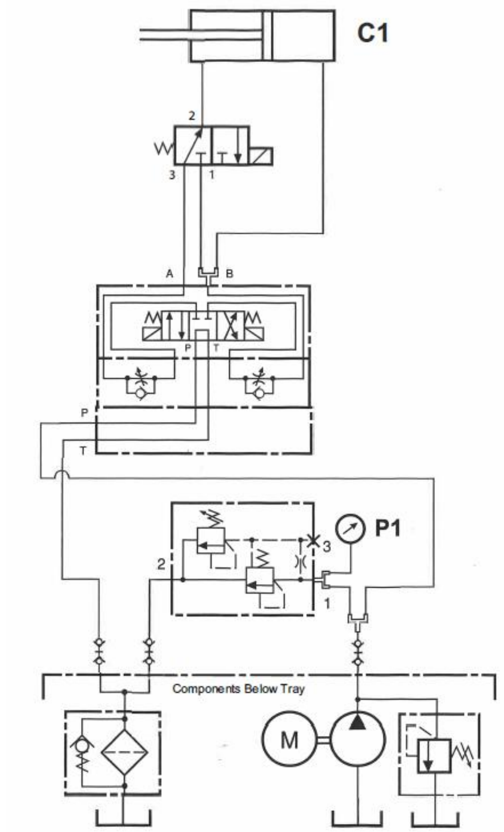

Figure 3 Linear and Regenerative circuit by FPTI

Weighted cylinder circuit

This circuit was the last one that the students built; they are now more confident about how the fluid trainer simulator work and how to connect the required components. The circuit components used here are; a direct-operated relief valve, a tandem-center 3/4 directional control valve, and a weighted cylinder in a vertical position.

This circuit was used to demonstrate the relationship of the $P = F/A$. First, the student controlled this circuit to extend the cylinder without the added weight while seeing the pressure in the gauge. Then the student adds the wight to the cylinder and repeats the process. This gave the students real experience to see how the added weight was reflected in the increased pressure. The instructor asked the student if, given the known specifications of the cylinder, they could approximate the weight added by using the difference in pressures seen with and without the added weight.

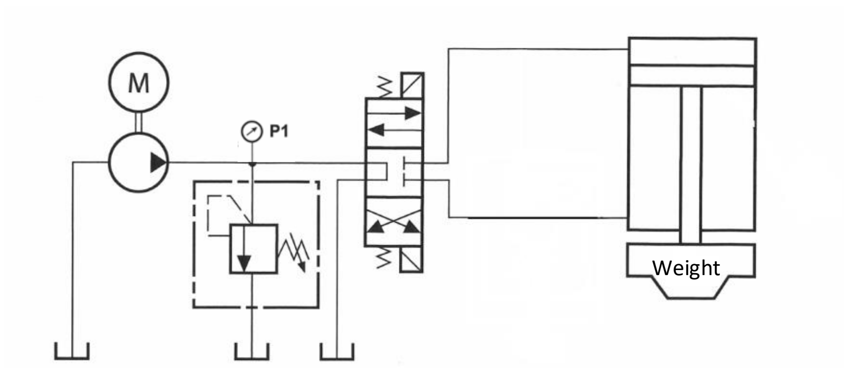

Figure 4 weighted cylinder circuit by FPTI

An example of the instructor guided questions can be found in Table 1

Table 1 instructor questions by stage

Stage	Circuit Built	Example of Questions
1. Introduction	Pressure in series	What are the expected pressures on the gauges?
		Why do you think the pressure dropped on the gauge?
		What is the relationship between pressure and resistance to flow?
2. Hands-on	Linear and Regenerative	What do you expect to see when you turn the trainer on?
		Can you explain what is happening on this circuit?
		Why does the speed of the cylinder change from linear to regenerative?
		How this behavior relates to Bernoulli's Equation?
	Weighted cylinder	What is the relationship you are seeing?
		Based on the data from the pressure gauges, can you calculate an approximate weight added to the cylinder?

At the end of the practical session, Stage 2, the students were asked if they had any comments or questions regarding the activity before asking them to participate in the survey. Some of the most interesting anecdotal comments from them at that moment were "I wanted to learn more about the trainers", and "Can I use the trainers for other circuits?" Other students tried to build other circuits not used during the activity- the motor speed controller- but it was not possible due to time limitations. This type of engagement was very positive and perceived by the instructor as a benefit of the activity to the students.

Survey

The survey style used in this activity was the retrospective survey, where the instrument is provided only once at the end of the activity, but it asks the participants to reflect on their knowledge prior to the laboratory activity, and after the laboratory activity, they just had. This type of survey has been used successfully at Professional Development conferences and after-school programs[5]. In our case, this style of the survey was chosen since it can reduce the survey burden that most of the students have been presenting since the COVID 19 pandemic started. Instead of a pre-and post-survey, the students were only inquired to respond to one. The use of this style of surveying also increases the willingness of the participants to participate.

The survey was approved by the Institutional Review Board (IRB) of Western Carolina University under the exemption category. The participants responded to the survey at the end of the laboratory activity; this included both stages, using a QR Code or a web link that routed the student to a Qualtrics website. The students responded to the survey anonymously, and no grade was connected to their participation. Although attendance at the laboratory was mandatory, participation in the survey was not.

Table 2 shows the demographics of the students enrolled in the course ME 311 Mechanical Engineering Lab II during the Fall 2021 term. Still, since the survey was anonymous, this information cannot be tied to the responses.

Table 2 Demographics of activity participants

Number of Students enrolled	51
Gender	
Male	41
Female	10
Ethnicity Distribution	
White	43
Hispanic	4
Black	1
Multiple races	1
Non-Provided	2

The survey consists of seven questions, of which six were retrospective Likert 1-5 style and one open-ended question. The Likert Code used on the survey was 1 for extremely bad to 5 for extremely good. Table 3 shows the Likert Code used in the survey.

Table 3 Likert scale codes

Likert scale codes	
Extremely bad	1
Somewhat bad	2
Neither good nor bad	3
Somewhat good	4
Extremely good	5

The survey questions used can be found in Table 4. Also, an example of the retrospective question format as shown to the students for question 1 can be seen in Table 5.

All Survey questions:

Table 4 Survey Questions and Type

Num	Question Text	Question Type
1	My general understanding of the topics discussed in the Laboratory activity “Hands-on Approach to Flowrate and Pressure Drop”	Retrospective Quantitative (5 point Likert)
2	My ability to demonstrate comprehension of the topics discussed in the Laboratory activity “Hands-on Approach to Flowrate and Pressure Drop”	Retrospective Quantitative (5 point Likert)
3	My ability to apply concepts to an actual problem or situation of the topics discussed in the Laboratory activity “Hands-on Approach to Flowrate and Pressure Drop”	Retrospective Quantitative (5 point Likert)
4	My ability to comprehend pressure drops as flow encounters resistance	Retrospective Quantitative (5 point Likert)
5	My ability to comprehend the Bernoulli equation concept that states that pressure increases as flowrate decreases	Retrospective Quantitative (5 point Likert)
6	My ability to use industrial fluid-power equipment	Retrospective Quantitative (5 point Likert)
7	Please provide any comments you have about the Laboratory activity “Hands-on Approach to Flowrate and Pressure Drop”	Qualitative

Question 1, as shown in the survey:

Table 5 Example of the format used in the survey for retrospective questions

My general understanding of the topics discussed in the Laboratory activity "Hands-on Approach to Flowrate and Pressure Drop"					
	Extremely bad (1)	Somewhat bad (2)	Neither good nor bad (3)	Somewhat good (4)	Extremely good (5)
PRIOR to attending the trainers session was:	○	○	○	○	○
AFTER attending the trainers session was:	○	○	○	○	○

Survey Results and Discussion

The responses received to the survey were 48, which gave us a response rate of 94.1%. This good response rate was surprising since the participant had no external benefit or motivation to respond. The survey was designed to be completed in less than five minutes to reduce survey fatigue. The average time per respondent was 2.36 minutes, with a minimum of 0.34 minutes and a maximum of 5.62 minutes.

The reliability of the survey was evaluated across all 48 responses. The coefficient alpha was calculated for the survey instrument separating the pre-test (Prior) from the post-test (After) responses, see Table 6. The coefficient alpha value for the prior retrospective scale of the survey was 0.805, while the coefficient alpha for the retrospective after scale of the survey was 0.842. This tells us that the internal consistency across the survey was good for both prior and after retrospective questions.

Table 6 Coefficient Alpha Reliability Measurement

	Questions	**Coefficient Alpha**
Pretest: Prior to the lab activity	1-to-6	0.805
Posttest: After the lab activity	1-to-6	0.842

The survey responses for questions 1 to 6 were analyzed per question using a pair samples t-test. The pair samples t-test reveals that each prior and after scores were statistically significantly different at the .05 alpha level. Looking at the descriptive statistics, we found an increase in all the questions means. This tells us that the whole laboratory activity, the introduction Stage, and the hands-on stage successfully provided new knowledge to the students. Moreover, this can be validated by the comments received in the open-ended question 7.

For question 1, *My general understanding of the topics discussed in the Laboratory activity "Hands-on Approach to Flowrate and Pressure Drop"* the pair samples t-test result can be found in Table 7

Table 7 Descriptive Statistics for question 1

	Q1		
	PRIOR	AFTER	Difference
Mean	3.27	4.5	1.23
Std dev	0.95	0.5	0.90
t-stat	-9.41		
two-tail p	2.2 E-12		

The mean increase of understanding (M=1.23, SD=0.90, N=48) was significantly greater than zero, t(47)= -9.41, two-tail $p < .001$, providing evidence that the laboratory activity was effective in increasing the general understanding of the topics related to flowrate and pressure drop.

For question 2, *My ability to demonstrate comprehension of the topics discussed in the Laboratory activity "Hands-on Approach to Flowrate and Pressure Drop"* the pair samples t-test result can be found in Table 8

Table 8 Descriptive Statistics for question 2

	Q2		
	PRIOR	AFTER	Difference
Mean	3.08	4.48	1.40
Std dev	0.89	0.54	0.76
t-stat	-12.65		
two-tail p	9.79E-17		

The mean increase of ability to demonstrate (M=1.40, SD=0.76, N=48) was significantly greater than zero, t(47)= -12.65, two-tail $p < .001$, providing evidence that the laboratory activity was effective in increasing the students' ability to demonstrate comprehension of the topics related to flowrate and pressure drop.

For question 3, *My ability to apply concepts to an actual problem or situation of the topics discussed in the Laboratory activity "Hands-on Approach to Flowrate and Pressure Drop"* the pair samples t-test result can be found in Table 9

Table 9 Descriptive Statistics for question 3

	Q3		
	PRIOR	AFTER	Difference
Mean	3.29	4.52	1.23
Std dev	0.84	0.50	0.83
t-stat	-10.24		
two-tail p	1.46E-13		

The mean increase of ability to apply (M=1.23, SD=0.83, N=48) was significantly greater than zero, t(47)= -10.24, two-tail p < .001, providing evidence that the laboratory activity was effective in increasing the students' ability to apply the concept learn to an actual problem of situation ability to demonstrate comprehension of the topics related to flowrate and pressure drop.

For question 4, *My ability to comprehend pressure drops as flow encounters resistance,* the pair samples t-test result can be found in Table 10

Table 10 Descriptive Statistics for question 4

	Q4		
	PRIOR	AFTER	Difference
Mean	3.38	4.6	1.23
Std dev	0.86	0.53	0.81
t-stat	-10.57		
two-tail p	5.11E-14		

The mean increase of ability to apply (M=1.23, SD=0.81, N=48) was significantly greater than zero, t(47)= -10.24, two-tail p < .001, providing evidence that the laboratory activity was effective in increasing the students' ability to understand that pressure drops as flow encounter resistance.

For question 5, *My ability to comprehend the Bernoulli equation concept that states that pressure increases as flowrate decreases,* the pair samples t-test result can be found in Table 11

Table 11 Descriptive Statistics for question 5

	Q5		
	PRIOR	AFTER	Difference
Mean	3.65	4.46	0.81
Std dev	0.88	0.71	0.73
t-stat	-7.67		
two-tail p	7.94E-10		

The mean increase of ability (M=0.81, SD=0.73, N=48) was significantly greater than zero, t(47)= -7.67, two-tail p < .001, providing evidence that the laboratory activity was effective in increasing the students' ability to understand the Bernoulli equation concept that states that pressure increases as flow rate decreases. Of the six retrospective questions scores, this question was the lowest mean increase; this might be that the theoretical understanding of the Bernoulli equations still offers some difficulty to the students.

For question 6, *My ability to use industrial fluid-power equipment*, the pair samples t-test result can be found in Table 12

Table 12 Descriptive Statistics for question 6

	Q6		
	PRIOR	AFTER	Difference
Mean	2.65	4.35	1.71
Std dev	1.2	0.59	1.18
t-stat	-9.99		
two-tail p	3.26E-13		

The mean increase of ability to use (M=1.71, SD=1.18, N=48) was significantly greater than zero, t(47)= -9.99, two-tail p < .001, providing evidence that the laboratory activity was effective in increasing the students' ability to use industrial fluid-power equipment. Of the six retrospective questions, this is the one with the higher mean increase; we can attribute this to the fact that this was their first experience using a fluid-power trainer for most students.

For question 7, *Please provide any comments you have about the Laboratory activity "Hands-on Approach to Flowrate and Pressure Drop."* The analysis was made using a word cloud application to evaluate word frequency[6]. Using this type of visual analysis, we can identify a pattern between the responses, providing us with qualitative data on the student learning of the laboratory activity. Figure 5 shows the word cloud that the responses generated. We can see that "lab", "help" and "understand" are among the top-ranking terms used by the students when responding to the open-ended question[7].

Figure 5 world cloud output from question 7

Table 13 provides the top 20 ranked words and their frequency used by the students who responded to the question. For question 7, only 30 participants responded with a comment.

Table 13 top 20 ranked word frequency for question 7

Rank	**Word**	**Frequency**
1	lab	15
2	help	10
3	very	9
4	good	8
5	really	8
6	understand	8
7	enjoyed	7
8	hands	7
9	like	6
10	more	6
11	answer	5
12	experience	5
13	my	5
14	think	5
15	class	4
16	concepts	4
17	definitely	4
18	fluid	4
19	time	4
20	able	3

Some representative responses that validate the pattern observed by the word cloud are; (i) "*This definitely helped! These hands-on experiences like this definitely help my engineering understanding. Would love to have more of these application-based experiences in the BSE curriculum!*", (ii) "*I think with more time that a lot of my answers would change, such as another session or two. This lab was very good, but I think another session or two would help out a lot. It would change my answers from somewhat good to extremely good*", (iii) "*I like that we were able to see things move, and if we had questions, we were able to test our questions to see the answer instead of just being told the answer*". These comments show that the activity was beneficial to the students' acquisition of new knowledge and a need for more activities hand-on in the Bachelor of Science in Engineering Mechanical Concentration curriculum.

Concluding thoughts

The results show a very significant and positive learning experience for the BSE students, suggesting that the Fluid Power laboratory activity can teach, or effectively reinforce, fluids concepts that the students would not have otherwise learned or learned as well in the standard Fluid Dynamics and Mechanical Engineering Lab II courses.

After the analysis and discussion of the Laboratory activity "Hands-on Approach to Flowrate and Pressure Drop" some concluding findings for the case of the Engineering Students in the Bachelor of Science with a Mechanical Concentration (BSE-ME) at Western Carolina University are addressed below:

- The use of a retrospective survey method is a good approach to assessing short-term laboratory activities.
- The use of Fluid Power Trainers like the MF102 is beneficial to the understanding of theoretical concepts of Fluid Dynamics by Engineering Students in the Bachelor of Science with a Mechanical Concentration (BSE-ME).
- Most engineering students in the Bachelor of Science with a Mechanical Concentration (BSE-ME) prefer integrating more hands-on activities into their engineering curriculum.
- More laboratory activities like the *"Hands-on Approach to Flowrate and Pressure Drop"* should be developed and incorporated into the Bachelor of Science in Engineering with a Mechanical Concentration curriculum.
- Collaboration between faculty of different programs will significantly benefit the students' experience and knowledge acquisition.

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