Utilization of the Learning Cycle and Design of Experiments to Enhance Understanding of Mechanical Engineering Concepts

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Abstract
Through design of experiments, as part of an increasingly difficult series of laboratory exercises, students gain a greater understanding of the relevant engineering theory. This paper outlines a three part laboratory experience specifically designed to introduce freshmen to the variety of engineering disciplines. The three experiments increase in difficulty as the laboratory handouts become increasingly vague. The student's responsibility for their own learning is steadily increased through the reduction of detail associated with the laboratory handout. Ultimately, the students are provided only background theory and are required to design their own experiment and analysis to arrive at the required results. As described in education instruction theory, students who have a greater personal need for the knowledge are more apt to understand the information. This paper identifies the increased understanding of theory gained by students who personally created experiments and analysis regimes.

Introduction
As with many freshmen students, their understanding of their chosen major is limited to campus tours and some fragmented experiences. Engineering students are especially prone to have misconceptions about their impending four year experience; therefore, the University of South Carolina has initiated an "Introduction to Engineering" class for incoming freshmen. One of the primary goals of the class is to provide an overview of some introductory engineering concepts. An effective means of introducing complex concepts is through the use of experimental activities. Recently, these laboratory experiences, and especially the provided information, has been critically examined.

The laboratory handouts have been altered to take advantage of a proven educational method that has shown a student's understanding increases as the information becomes more personally meaningful. New engineering concepts are difficult to make personally meaningful; therefore, by requiring the students to become increasingly responsible for their learning, the theory becomes a personally needed aspect of their successful completion of the activity. This is in contrast to many traditional engineering laboratory experiences, in which, the theory, experimental procedure, and analysis expectations are outlined in great detail for the student.

The three laboratories focus on Statics and Mechanics of Materials, Fluid Dynamics, and Electric Circuit Theory. As the semester progresses, the students are provided less information at the beginning of their laboratory sessions and, in turn, are responsible for more of their learning.

During the Statics and Mechanics of Materials experiment, the first activity, students are provided a very complete set of instructions. Next, the Fluid Dynamics experiment has a great deal of detail, but the analysis portion requires the students to deduce some of their own equations. Ultimately, the simple Electric Circuit laboratory handout provides only needed theory and required results. It is left to the student to design an experiment that will provide the needed data and to develop an analysis method for generating the needed answers. The underlying educational theory and the details of these experiments is outlined in the following sections.

Educational Theory

The *Learning Cycle* and *Personalization of Information* are the primary educational tools used to improve the student's understanding of engineering theory. Through the use of these proven educational techniques, the students can become familiar with both the engineering theory and some underlying differences between many high school expectations and those of engineering school.

The learning cycle is a proven four step model used to introduce students to new information, especially scientific lessons.[1] During this freshmen course, the learning cycle is employed to initiate the three laboratory experiences. The four phase learning cycle is comprised of the following steps: Introduction, Exploration, Concept Development, and Application.

The introduction phase is designed to create student interest in the new material. One method that is effective with college students is the posing of challenging questions. For example, during the circuit laboratory introduction, the student's challenge was to determine the resistor values without disassembling the circuit. The challenge can be presented as a role-playing scenario to best intrigue the student.

Continuing with the circuit laboratory example, the students were told they needed to diagnose the failure of a piece of manufacturing equipment, and to do so, the values of three resistors must be known. Since it was a sensitive piece of machinery, the values of the resistors needed to be determined without disassembling the circuitry. This fictitious, but realistic scenario provides some motivation for the students to understand the introductory theory of electric circuits.

As an alternative to the role-playing introduction, interest can be generated through a discrepant event. The circuit used during the laboratory has an inherent discrepancy if a student tries to directly measure resistance across each of the three resistors. Two of the resistors are in parallel, so when measurements are taken, both resistors will exhibit an identical value. (See Figure 1, resistors R2 and R3.) However, the two resistors clearly have distinct color bands, and therefore, distinct values. This creates the discrepant event; the digital multimeter reads the same resistive value for both resistors, but the color bands indicate they have different values.

Following either the role-play or discrepant event introduction, the students begin the exploration phase of the learning cycle. During this stage, the students are encouraged to take an active role by investigating the posed problem. Students examine the governing equations, the circuit, and a digital multimeter. Through this explorations, students develop the needed experimental procedure and the simultaneous equations to solve for the unknowns. Therefore, students are responsible for their own construction of knowledge and understanding of the theory.

Once the students have had sufficient exploration time, the class is convened for the learning cycle's third phase: concept development. Students report their findings and their methodologies to the class. Often, these informal presentations lead to discrepancies among procedures and conclusions. This provides the opportunity for the instructor to guide the class to the correct conclusions, and it is through this discussion that students continue to learn the newly presented material.

During concept development, the instructor has the opportunity to discuss terminology and to introduce supporting material, such as text reading. It is important that textbook material be presented after exploration. By doing so, the students are able to confirm their own findings. This promotes understanding of theory and enhances the student's responsibility for their learning. In contrast, if the accepted textbook material is presented first, the students will be confirming accepted material. This discourages students from finding their own answers and advocates the notion that only experts can have accepted theories.

Through the concept development phase, the students will gain an accurate approach to the laboratory, and this leads to the fourth phase: application. It is during the application phase that students complete the laboratory assignment. The student or student group will use the procedures and analysis developed during the exploration phase and refined during concept development to answer the questions provided with the laboratory handout.

The learning cycle outlined above is a core notion in constructivism theory and is an extension of Piaget's Theory of Intellectual Development.[2] Essentially, these theories demonstrate individuals construct their own knowledge. A more detailed explanation follows:[3]
"They [learners] do not simply mirror and reflect what they are told or what they read. Learners look for meaning and will try to find regularity and order in the events of the world…."

Students grow their knowledge base and understanding by personalizing the information. They construct new knowledge by applying new information in a personally meaningful way. By designing their own experimental procedure and analysis regime, the students generate a personally meaningful scenario: one in which they use and expand the given information to reach a needed conclusion.

Three Freshmen Laboratory Experiences
As outlined above, the approach to introducing freshmen to elementary engineering theory is done through three increasingly difficult laboratory experiences. The complete laboratory handouts can be examined in the appendix. However, below is an overview of the three sessions with emphasis on the final laboratory, "Resistance is Futile."

The first laboratory session, "Full Body Contact Statics," is an introduction to static forces and beam bending theory. The materials provided prior to the lab are complete and detailed. The laboratory handout explicitly explains the procedure; therefore, the students are only responsible for following directions, recording data, and creating a report. The premise of the laboratory experience is to use the weight of a classmate to deflect a beam simply supported on two scales. Data include forces at each end of the beam and beam deflection from nominal.

The next session, "Head Pressure," introduces the Bernoulli principle. Again, the laboratory handout is complete, inclusive of a detailed procedure. However, the students are required to derive some of the analysis equations from the given theory. This represents an increase of student responsibility for their own learning. The laboratory experience focuses on correlating fluid head to jet exit velocity. It also allows students to review their high school physics principles by establishing the exit velocity based on horizontal and vertical distance traveled by the fluid jet.

The third and final laboratory, "Resistance is Futile," provides an overview of basic electric circuit theory. This session is the focus of this paper due to the laboratory handout's lack of experimental procedure or analysis routine.

The students are provided a handout that outlines Ohm's law, addition of resistors in series, and addition of resistors in parallel. It also supplies a circuit diagram and the requirements that the students find the value of the three resistors without removing them from the circuit. Students are then required to write a laboratory report that not only provides the three resistive values, but includes their experimental procedure and analysis derivation. The report can be extended by requiring students to generate a complete laboratory handout, similar to the "Full Body Contact Statics" handout, that could be used by the instructor to complete the laboratory.

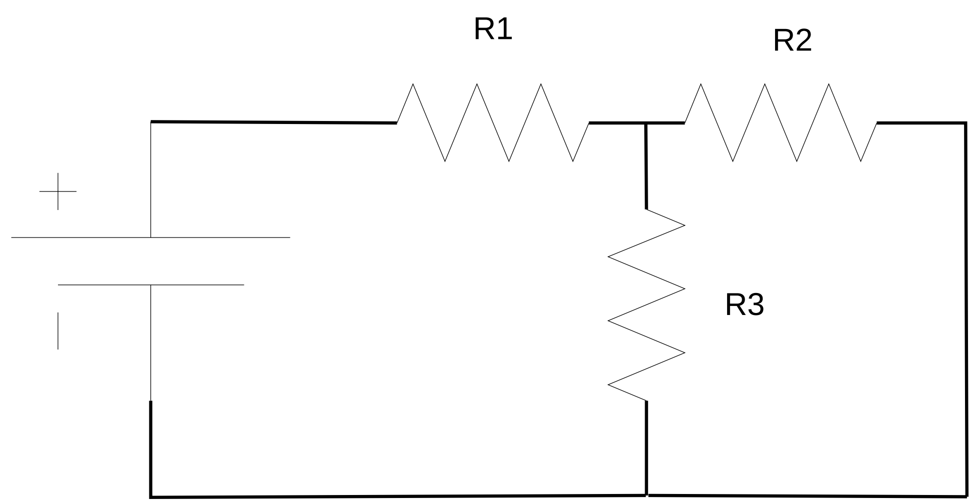

Figure 1 Schematic of Circuit

"Resistance is Futile" is divided into three classroom sessions and homework. Following the introduction phase on the first day, students are provided the laboratory handout, form groups, and begin the exploration phase of the learning cycle. Homework is assigned to complete the development of their experimental procedure and analysis equations.

The second classroom session begins as the third phase of the learning cycle, concept development. The students share their procedure and analysis plans and have the opportunity to ask questions. Once all the groups have a complete and correct approach to the laboratory, the groups begin recording data from their circuit and start the analysis; this represents the application phase of the learning cycle. The students enthusiastically approached studying the circuit because it was an immediate application of the concepts developed.

For the third session, the students meet with the instructor in a computer classroom. There, the students continue work on the analysis utilizing MathCAD. This provides the instructor an opportunity to introduce the software and allows the students to use a computational tool to help with solving the simultaneous equations of their analysis routine. Finally, homework is assigned to complete the laboratory experience by generating a complete handout that has enough detail so the instructor could complete the experiment, using only the provided handout.

Evaluation

Several class periods after the completion of "Resistance is Futile," the students were given a survey about the laboratory experience. The evaluation survey consisted of several statements regarding the students' attitudes toward designing their own experiment and their ability to learn material themselves, without being taught by the instructor. The students had the opportunity to strongly agree, agree, feel neutral, disagree, or strongly disagree with the statements. Listed below are the results from several of the pertinent questions.

1. All students either strongly agreed or agreed that the laboratory experience reinforced the introductory electric circuit theory.
2. All students either strongly agreed or agreed that designing the experimental procedure challenged them to understand the underlying theory better.
3. All students either strongly agreed or agreed that compared to the first two experiments, the "Resistance is Futile" laboratory required them to think more creatively.
4. Most students (86%) agreed that the laboratory session helped them to realize they could learn engineering material without being taught by an instructor. The remaining students felt neutral about the statement.
5. All students disagreed that they learned less during the "Resistance is Futile" experiment than the other laboratory sessions.

Considering the results of the survey, the requirement to design the experimental procedure and analysis routine enhanced the students' understanding of electric circuit theory. Although the program and survey was an initial pilot study and conducted with a small, single engineering class, the overwhelming agreement outlined in the above results indicates promise for broader implementation in the future. Students were required to think more creatively, but the addition of creative thought did not detract from their ability to learn the theoretical material. Furthermore, the laboratory experience helped the majority of the students to feel more responsible for their own education. They recognized they were able to learn complex material without being spoon-fed.

The three activities described above have been used successfully with first-semester freshmen students at the University of South Carolina. According to student survey results, students in the course sections that used the laboratory data as the basis of the computer tool training component found the experience more interesting. Student comments noted that through the labs, they actually got to see engineering principles in action instead of just reading about them.

Although this paper discusses a curriculum approach still in its infancy, many of the initial findings align with other introductions of creative work into freshmen engineering experiences. Results from the Gateway Engineering Education Coalition from 1992 through 1997 found that as professors facilitated active learning, as opposed to simply lecturing, freshmen changed their mindset about learning, they were able to be more creative, and the colleges had an increase of engineering student retention.[4]

Conclusion

An introduction to a broad range of mechanical engineering principles through the use of laboratory experiences has been developed for incoming engineering students. This overview of mechanical engineering through increasingly difficult experiments helps the students to better understand the underlying theory and allows for creative thinking and active learning. Initial results indicate active learning and increased understanding can be facilitated through the use of the learning cycle as an introduction to new material. Furthermore, the use of the learning cycle as an instructional methodology combined with design of experiments enhances a students learning of new engineering material.

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Biographical Information

JOHN BRADER is currently researching advanced actuators and mechatronic design while completing his Ph.D. in mechanical engineering. He is the chairman of the ASME Midlands Section K-12 Educational Outreach Committee and is working to develop "Engineering Clubs" in local elementary, middle, and high schools. John also teaches 4th grade science and mathematics through the NSF GK-12 fellowship program.

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Appendix

UNIV 101 E Laboratory
Full-Body Contact Statics
John S. Brader
August 25, 2001

Objective: To introduce students to engineering concepts related to experimental procedure, analysis of data using Microsoft Excel, and technical report writing. The experiment, itself, will focus on an introduction to Statics (EMCH 200) and Solid Mechanics (EMCH 260) by demonstrating some of the subjects' basic theory.

Reference: Schaum's Outline Series Theory and Problems of Strength of Materials 3/ed, William A. Nash Pp 196 – 198, 209 – 211

Introduction: The experiment consists of recording reaction forces and deflections of a simply supported beam placed under a variety of loading conditions. The loading conditions will be produced by the weight of a student(s) standing on a beam supported at each end by a scale. The numbers recorded on each scale represent the reaction force at the end of the beam and the distance between the unloaded beam position and the loaded beam position represents the deflection of the beam. The values obtained during the experiment will be compared to those calculated by the theoretical functions.

Definitions and Theory: The following introduces the needed terminology, variables, and theory related to the experiment.

Applied Load (P): The force that is placed onto the beam. In this experiment the force is the weight of a student standing on the beam.

Reaction Forces (R): The forces that are equal and opposite to the applied load. These forces are exerted by the scales onto the beam and prevent the beam from falling.

Deflection (y): This value is the amount that the beam deflects in the vertical direction. It is measured indirectly by obtaining the distance between the beam and the floor.

Modulus of Elasticity (E): This is a proportionality constant that relates load to deflection in a given material. It is a measure of the resistance of deformation and is often referred to as the Young's modulus.

Moment of Inertia (I): This is dependent of the beam's cross section and is a measure of the beam's resistance to bending or deflection.

Beam Length (L): This is a fixed value that is the measure of the overall length of the beam.

Location of Load (a): This is the distance from one end of the beam to the location of the applied load.

Location of Deflection (x): This is the distance from one end of the beam to the location of the deflection measurement.

Reaction Forces: To obtain the theoretical reaction forces, the first step is to sum the forces in the y direction using a free body diagram and Eq. 1. See Figure 1 and Figure 2.

$$R_1 + R_2 = P \qquad \text{Eq. 1}$$

Since the only known value is P, this equation is insufficient to predict the value of each of the reaction forces. (Note: One must always have the same number of equations as unknowns to obtain complete solutions.) Therefore, another equation must be used.

For this case, sum the moments. The moments are the forces multiplied by their distance from a fixed point. The summation of the moments must equal zero so the beam does not rotate. Summing the moments about the end where reaction force R_1 is applied results in the following equation.

$$P \cdot a - R_2 \cdot L = 0 \qquad \text{Eq. 2}$$

Why is R_1 not included in the summation of moments?

Solving Eq. 1 and Eq. 2 simultaneously will give functions for both reaction forces.

$$R_1 = P \cdot \left(1 - \frac{a}{L}\right) \qquad \text{Eq. 3}$$

$$R_2 = \frac{P \cdot a}{L} \qquad \text{Eq. 4}$$

Beam Deflections: The development of the equations for the deflection of the beam is a more complex procedure and is based on the double integration of the bending moments in each section of the beam. For now, it is sufficient to say the beam deflection at any point along the length of the beam is a function of the beam's material and dimensions, the load, and the location of the load. See the provided reference material for details of the derivation.

$$y(x) = \frac{1}{E \cdot I} \cdot \frac{P \cdot (L-a) \cdot x}{6 \cdot L} \cdot (L^2 - (L-a)^2 - x^2) \qquad (0 \le x \le a) \qquad \text{Eq. 5}^{1}$$

$$y(x) = \frac{1}{E \cdot I}\left[\frac{P \cdot (L-a) \cdot x}{6 \cdot L} \cdot (L^2 - (L-a)^2 - x^2) + \frac{P \cdot (x-a)^3}{6}\right] \qquad (a \le x \le L) \qquad \text{Eq. 6}^{1}$$

[1] Gere and Timoshenko Mechanics of Materials Third Edition PWS-Kent

The deflection at any point in the beam can be found through either the use of Eq. 5 or Eq. 6 depending on the location of the load relative to the location of the deflection that is being calculated.

Beam Properties: L = 8 ft; E = *** psi; I = *** in^4 to be discussed in class.

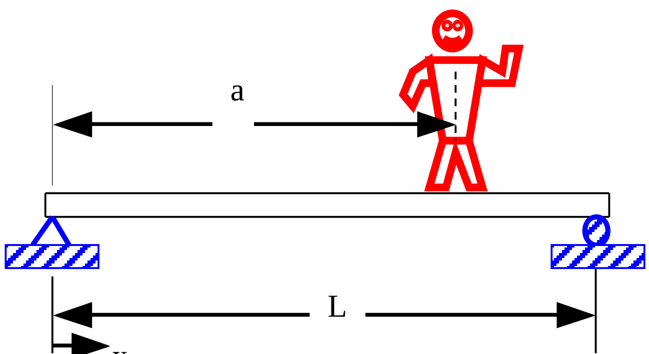

Figure 1

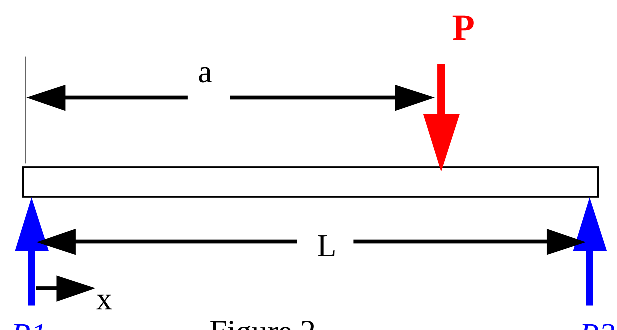

Figure 2

Experimental Procedure

Reaction Forces:

1. Measure the weight of the person(s) acting as the load, P.
2. Place the beam onto the scales. Note the values of the scales with no load (no people standing on the beam.)
3. Place the load at multiple locations (a) on the beam according to Table 1. Record the reaction forces R_1 and R_2.

Load P = ______________ Beam Length L = _____________

R1 no load = _____________ R2 no load = _____________

Table 1

a (ft)	0	1	2	3	4	5	6	7	8
R_1 (lbs)									
R_2 (lbs)									

Beam Deflections:

1. Measure the weight of the person(s) acting as the load, P.
2. Measure the unloaded distance (D unloaded) between the beam and the floor at multiple locations per Table 2.
3. Place the load in the middle of the beam (a = 4ft) and measure the distance (D loaded) between the floor and beam at multiple locations per Table 2.
4. Subtract D loaded from D unloaded to obtain the deflection (y).

Load P = _____________

Table 2

x (ft)	1	2	3	4	5	6	7
D unloaded (mm)							
D loaded (mm)							
y (mm)							

Data Analysis & Report

The next step is to analyze the data that has been obtained and compare it to the theoretical values from the equations. Before proceeding, a very important consideration to examine is the different units used when measuring data. Think about the consequences of combining pounds, millimeters, and pounds per square inch. Perform unit conversions as necessary.

One of the primary goals of this experiment is to compare theoretical values to actual data obtained during the experiment.

Reaction Forces:

Analysis:

1. Using Excel, plot the experimental Reaction Forces (R_1 and R_2) vs. Load Position (a).
2. Fit a linear trend line to each.
3. Print the equation associated with each trend line on the graph.

Report:

1. In the results section, insert the plot and compare the slope of the trend lines to the slope from the theoretical equations. Recall the slope (m) of a line is the derivative of the line's equation.

$$Y = m \cdot X + b \qquad\qquad \frac{dy}{dx} = m$$

Beam Deflections:

Analysis:

1. Using Excel, plot the experimental deflection (y) values vs. the location of deflection (x).
2. On the same graph, plot the theoretical deflection (y) values vs. the location of deflection (x) based on Eq. 5 and Eq. 6.

Report:

1. In the results section, insert the plot and compare the experimental vs. deflection curves.

General Report Requirements:

Ensure that the graphs are well labeled so one can distinguish between the different plots. An example of an acceptable graph is below.

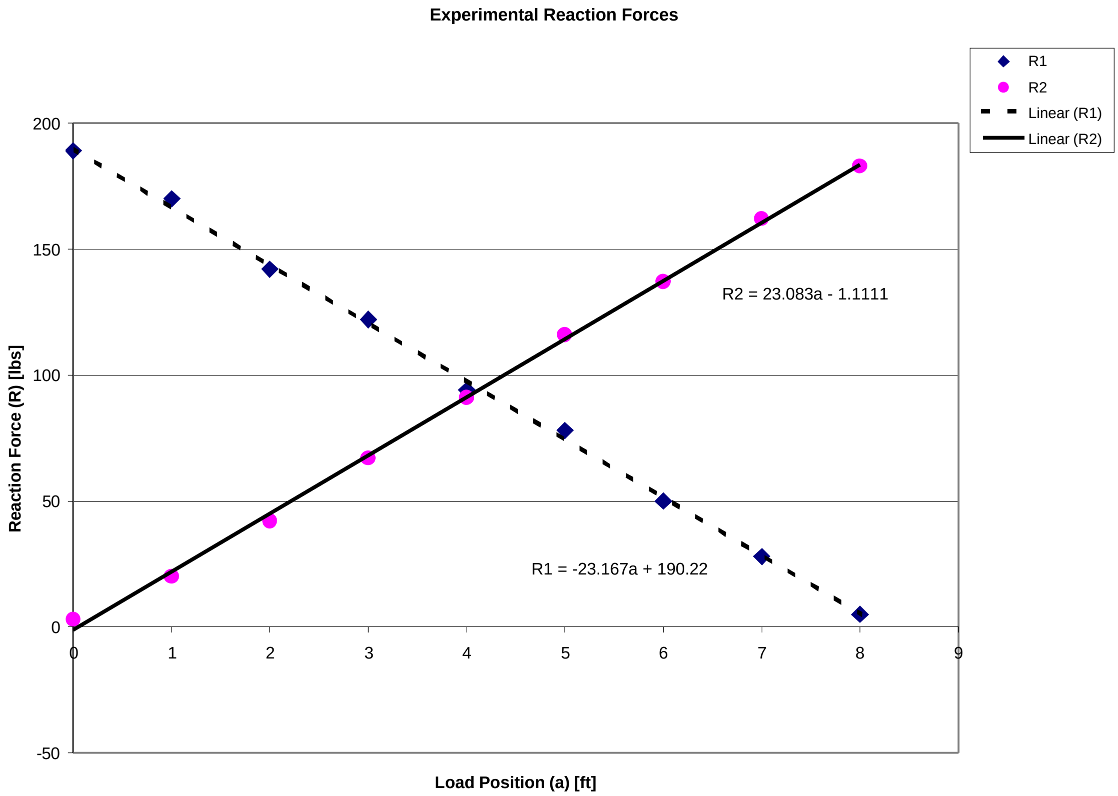

Figure 3 Sample Reaction Force Graph

Create the report so someone that was not witness to the experiment can understand and repeat the experiment. The report should consist of the following sections.

- Abstract: Briefly tell the reader what the report covers.
- Objective: Describe why the experiment was completed.
- Experimental Procedure: Explain how the experiment was conducted.
- Results: Insert the equations used to generate the plots and the graphs, themselves.
- Discussion: Explain what was learned; account for any differences between the theoretical plots and the actual data.
- Conclusion: Tell the reader what they just finished reading.

Formatting: The appearance of the report will be graded.

- Title, Name, and Date should be on the first page
- 12 point font
- 1 inch margins
- single spaced
- no more than four pages

UNIV 101 E Laboratory
Head Pressure
John S. Brader
September 30, 2001

Objective: This experiment will introduce students to finding/verifying mathematical relationships. In addition, students will be introduced to the principle of conservation of mass and Bernoulli's equation. Finally, students will use MathCAD to perform calculations and develop analysis pages for their final report.

Introduction & Theoretical Background: Tap water and hydroelectric power plants are common examples of flowing fluids, but fluid mechanics extends to many other engineering achievements; for example, the flight of aircraft is governed by the study of fluids.

Through the study of fluid mechanics, Bernoulli (an eighteenth-century Swiss scientist) proposed an energy balance of fluid flow:

$$\frac{p}{? \cdot g} + \frac{V^2}{2 \cdot g} + h = \text{constant on a streamline} \qquad (1)$$

where, p = pressure
ρ = density of fluid in streamline
g = gravitational constant
V = velocity of fluid
h = elevation of fluid

In this lab, a water column similar to figure 1 will be used to demonstrate the Bernoulli equation. The pressure will be constant (atmospheric pressure) and the water on the top will be stationary (V = 0). As a result, the velocity out of the holes will only depend on the height from the water surface (see figure 1) to the hole according to equation 2.

$$V = \sqrt{2 \cdot g \cdot h} \qquad (2)$$

In addition, the volumetric flow rate out of the hole, is defined by equation 3:

$$Q\,(\text{Flowrate}) = V \cdot \text{hole area} = V \cdot \frac{p \cdot d^2}{4} \qquad (3)$$

where, d = hole diameter.

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From the theory of conservation of mass, it is known that if the mass of a control volume (i.e. the tube used in this lab) stays constant, the flow rate into the volume must equal the flow rate out of the volume (equation 4).

$$\sum \text{flowrate}_{\text{in}} = \sum \text{flowrate}_{\text{out}} \tag{4}$$

Which means if the water level in the tube drops, the flow rate out is greater than the flow rate in, and vice versa.

In order to calculate flow rate, the student needs to have the velocity of the fluid leaving the tube. The velocity of the exiting fluid is difficult to directly measure; therefore, it must be calculated based on the time the fluid takes to travel from the tube to the ground. However, it is difficult to measure the time the fluid takes to leave the tube and impact the ground, so the time must be calculated based on the distance the fluid falls before impacting the ground. To calculate the time for the water coming out of a hole to hit the ground, the equation for motion of a free falling object can be used (assuming air resistance is negligible).

$$y = v_{0y} \cdot t + \frac{g \cdot t^2}{2} \tag{5}$$

where, y = vertical distance traveled
v_{0y} = vertical initial velocity.

The variable v_{0y} equals zero because the water has no vertical velocity when it leaves the tube. As a result, the time for the water to hit the ground as a function of y is shown in Eq. 6.

$$t(y) = \sqrt{\frac{2 \cdot y}{g}} \tag{6}$$

By knowing the time the fluid takes to fall from the hole to the ground, and the distance from the tube to the ground (x or horizontal distance), the exit velocity can be calculated. This velocity is the value used for V in Eq. 3. It is left to the student to find a mathematical relationship for exit velocity.

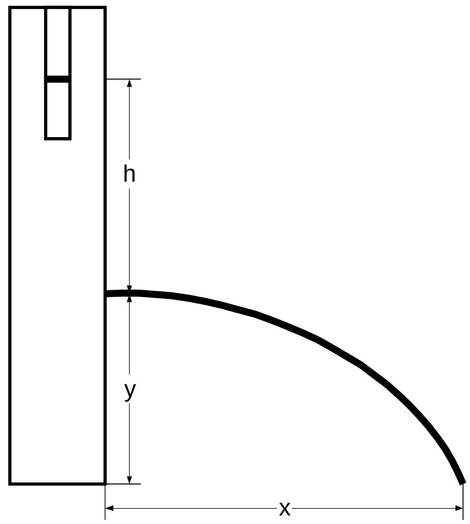

Figure 2

Experimental Procedure:

1. Fill the tube with water to the marked level with tape over the holes.
2. Uncover the top hole in the tube and try to keep the water level constant (55”) by adjusting the tap.
3. Take the can and collect water from the hole until one third of the can is full. Record mass, time and h (average). Replace the tape over the hole.
4. Repeat the measurements for the bottom two holes in the tube.
5. Without adjusting the tap, collect water from the hose into the can for the same amount of time used in the previous steps. Record mass.
6. With only the top hole open, record the distance (x) from the tube to the point of water impact on the floor. During this procedure, maintain a steady water level by adjusting the tap as needed.
7. Repeat step 6 for each of the remaining holes.

Report Requirements

Create the report so someone that was not witness to the experiment can understand and repeat the experiment. The report should consist of the following sections.

- Abstract: Briefly tell the reader what the report covers.
- Objective: Describe why the experiment was completed.
- Experimental Procedure: Explain how the experiment was conducted.
- Results: See Below.
- Discussion: Explain what was learned; account for any differences between the theoretical data and the actual data.
- Conclusion: Tell the reader what they just finished reading.

The Results Section created using MathCAD should include the following.

1. A comparison between the velocity calculated using Bernoulli's equation from Eq. 2 and the velocity calculated based on the measured distance (x) between the tube and the ground. This must be done for all three holes.
2. A comparison between the measured mass flow rate and the calculated value based on Eq. 3. For the calculation use the velocity calculated based on the measured distance (x) between the tube and the ground. (Hint: To compare the collected mass of water to the calculated volumetric flow rate, the density of water must be used to convert volumetric flow rate into mass flow rate.)

Formatting: The appearance of the report will be graded.

- Title, Name, and Date should be on the first page
- 12 point font
- 1 inch margins
- single spaced
- no more than four pages

Homework: After completing the laboratory, but **prior to the analysis session in the computer room**, the student must find the following.

1. The value for the density of water.
2. Any conversion factors that may be necessary, for example, inches to centimeters or pounds to kilograms.
3. An equation to calculate the exit velocity from the tube based on the time the fluid takes to fall to the ground and the horizontal distance between the tube and the point of impact.

UNIV 101
Resistance is Futile Laboratory
John S. Brader
October 12, 2001

Objective: To introduce design of experiments and basic concepts of electric circuit theory.

Introduction and Theoretical Background: Until now, students have been provided documentation outlining experimental procedures and theory as an introduction to engineering. This laboratory experience will allow the students to design their own experimental procedure by providing only the final requirements and some basic electric circuit theory.

The objective of the experiment is to find the values of three resistors (R1, R2, and R3) within the circuit. Measurements of resistors removed from the circuit is not allowed; therefore, the student must design an experiment that will allow for the calculation of the resistors values within the circuit. See Figure 1.

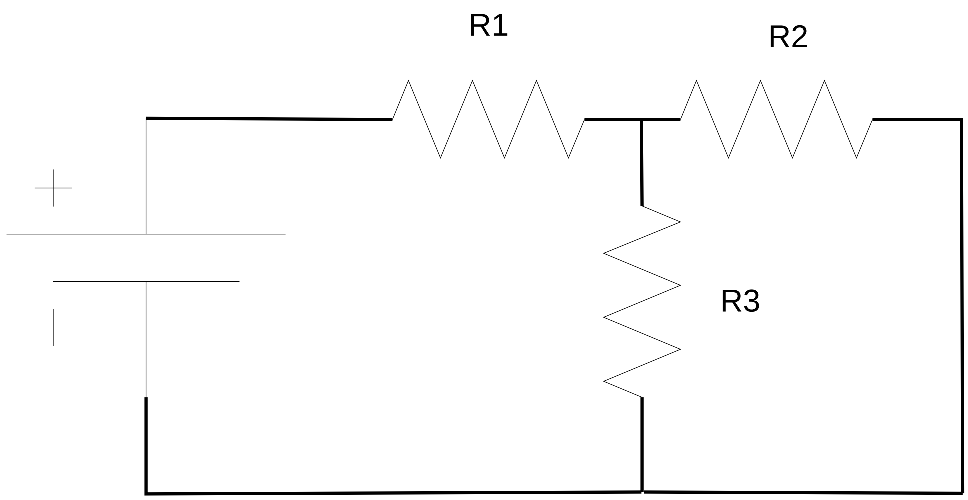

Figure 3

Ohm's Law: For time invariant current, the voltage across a component is equal to the current flowing through the component multiplied by the resistance of the component.

$$V = I \cdot R \qquad \text{Eq. 1}$$

Where V is the voltage in volts, I is the current in amps, and R is the resistance in Ohms.

Series Circuit Calculations: The combined resistance of resistors connected in series is the sum of the individual resistors. See Equation. 2.

$$R_t = R_1 + R_2 + R_i \qquad \text{Eq. 2}$$

Parallel Circuit Calculations: The combined conductance (the inverse of resistance) is the sum of the conductance of each component connected in parallel. See Equations 3 and 4.

$$G_t = G_1 + G_2 + G_i \qquad \text{Eq. 3}$$

Where G is the conductance or the inverse of resistance as shown in Equation 4.

$$G_t = \frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_i} \qquad \text{Eq. 4}$$

Report Requirements: Instead of the normal laboratory report produced during the previous experiments, the student is required to create a laboratory handout that could be used for future students. The handout shall be formatted similarly to previous handouts (Full Contact Statics and Head Pressure.) Provide an Objective, Introduction and Theoretical Background, Laboratory Procedure, Report Requirements, and any additional information that would be beneficial to the next group of experimenters. Along with the laboratory handout, the student must also provide the values of R1, R2, and R3 found using their new procedure.

Formatting: The appearance of the handout will be graded.

- Title, Name, and Date should be on the first page
- 12 point font
- 1 inch margins
- single spaced
- no more than four pages