AC 2008-1431: A MODULAR APPROACH TO A FIRST-SEMESTER ENGINEERING COURSE: TEACHING THE FUNDAMENTALS OF FLUID MECHANICS

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1. Introduction

One of the most important responsibilities of a university faculty is to design the curriculum that their students will experience. The design of a first-semester engineering course is an especially important and challenging responsibility, because it forms the foundation of the students' future educational experiences. Many different philosophies have been developed regarding the students' first-semester experience as an engineering student, and each of these different philosophies has unique benefits and liabilities. While some conclusive statements can be made based on rigorous pedagogical research, it is likely that the unique culture and context of a particular university will require careful consideration and adaptation of any of these philosophies and structures in order to maximize students' learning.

In this paper, we will first present an overview of several different methods being used to teach first-year engineering students at programs throughout the country. Next, a summary of the first-year engineering program at Valparaiso University will be presented, highlighting the modular nature of the course and the balance between classroom and hands-on experiences. This structure will be further illustrated by presenting a detailed description of the fluid mechanics experience presented to students in this course, and the paper will conclude with a detailed assessment and analysis of the effectiveness of that experience.

2. Review of Previous Work in First-Year Engineering Programs

Several very different approaches to teaching first-year students have emerged over the past several decades. Each of them has merit, and each has arisen as a result of real needs of first-semester students. Considering these diverse systems and the learning objectives underlying each is an essential first step to designing a first-semester engineering course.

Traditionally, some first-year engineering courses have been similar to "freshman orientation" courses in other disciplines, which focus on skills such as time management, exam preparation, and, balancing work and social life.[1] Such courses do not explicitly focus on engineering topics, but they provide engineering students with skills that will be valuable to them throughout their academic and professional careers.

Another traditional approach for first-year engineering courses is to provide students with an overview of the different engineering disciplines, helping them to select their major. Courses at universities such as Vanderbilt[2] and Purdue[3] provide such breadth of knowledge, helping their students to make informed decisions about their majors. Frequently, such courses are designed in a modular structure, such that students can complete different modules and different hands-on projects based on their particular interests. Enabling students to make an informed choice of major has traditionally been one of the most important objectives of the first-semester engineering course at Valparaiso University, and it is still a secondary purpose of the course.[4-5]

Other programs devote at least a part of their first-year program to teaching students to use computational tools and solve engineering problems.[6-7] From spreadsheet skills to high-level language programming, such knowledge will be important for all disciplines, but especially so for electrical and computer engineering students.

Because engineering drawing and visualization skills are so important to engineering students, some universities either require or have required all first-year students to take a course in mechanical drawing and computer-aided design.[8] Such a course provides a balance of useful skills that will serve at least some students (especially mechanical and civil engineers) in their future courses, and it helps students to develop visualization skills that benefit them in advanced calculus classes.

Over the last decade, a number of forces (especially ABET's Engineering Criteria 2000 and the National Academy of Engineering's "The Engineer of 2020" report) have prompted changes throughout the engineering curriculum. Many universities [8-14] increased the emphasis on engineering design and engineering analysis in their first-year engineering course, including the introduction of hands-on context-rich design projects to be completed by teams of students.[15] Some universities created courses that explicitly attempted to increase their students' teamwork skills,[16] while others sharpened their focus on improving their students' problem-solving skills[9] and creative and critical thinking skills.[17] Perhaps the most difficult mandate of Engineering Criteria 2000 is that students be able to work effectively in multidisciplinary teams, which has led universities such as Purdue to create courses that explicitly build interdisciplinary connections within their students' minds.[18]

Many emerging philosophies in first-year engineering education focus on a holistic approach to engineering education. For example, a great deal of work has been done to validate the usefulness of learning communities, which are being implemented at several universities.[9,19] Other universities, such as Texas A&M and the Air Force Academy, are working very hard to provide their students with an integrated curriculum that combines engineering, mathematics, and science into one course sequence, helping students to better see the interconnections among those topics.[20-22]

Another important area of pedagogical innovation is development of a student-centered structure in which the instructor is more of a guide to help the students discover knowledge rather than being the source of that knowledge. Courses at universities such as Virginia Tech and Bucknell have created an environment in which in-class hands-on projects are used to illustrate the material. Such courses have been shown to be more effective at holding the students' interest and helping them to more effectively learn important engineering concepts.[23-26] Still others have used students' natural inquisitiveness to help them develop the skills necessary to investigate, model, and analyze very complex systems.[18, 27-28]

Although some of these philosophies do appear to be mutually exclusive, an optimal first engineering course would benefit from adopting the best characteristics of each. By balancing these different philosophies, it may be possible to design a course that is more effective than any one philosophy could be. We have attempted to design such a balanced course, modeled after work done at Purdue University[9], which helps students to learn the fundamentals of several engineering disciplines and build interdisciplinary connections among those disciplines, and we do so through a balance of traditional classroom and hands-on laboratory and design experiences.

3. GE 100 Overview

Valparaiso University's first semester engineering course is entitled "Fundamentals of Engineering." The faculty involved in designing the course selected 26 topics that they felt composed the fundamental concepts of engineering. These topics were chosen the engineering disciplines offered at Valparaiso University, Civil, Mechanical, and Electrical and Computer, with a rough balance of each. Throughout the semester topics are mixed; for example, not all of the civil engineering topics are taught together in a single block but rather are interspersed between topics from other engineering disciplines. Topics are arranged in logical sequence, however, so that Engineering Statistics comes before Transportation, which uses statistics extensively. In all topics, the interdisciplinary nature of engineering is emphasized. Earthquakes, radio waves, and engines are all discussed in Vibrations, and the Heat Transfer laboratory measured the natural and forced heat convection coefficient for cooling of a resistor.

The course meets four times a week for 50 minutes. Each section of the course has a maximum enrollment of 24 students. On Monday and Thursday, lectures are given using a detailed PowerPoint presentation. The lecture begins with learning objectives and then a concept map (Figure 1) to show where the topic for the day fits within the three disciplines. About 30 slides are used for each topic. In-class exercises (ICE) are interspersed throughout the lecture. In each of these, about five minutes is given to complete the problems which are similar to the homework. These illustrate a particular concept from the lecture and provide a chance for the students to ask questions about concepts that they may not understand. Homework is assigned in each lecture and is due in lab the next day. The lectures end with Key Takeaways which summarize the key points in the lecture. Each lecture also includes a handout called Critical Student Information (CSI). The CSIs cover a variety of topics from time management to homework formatting to advanced graphing in Excel and are discussed if time is available at the end of class. The CSIs are an opportunity to include some of the "freshman orientation" topics without spending a lot of time on them. There are CSI questions on each exam, so the students must read the handouts.

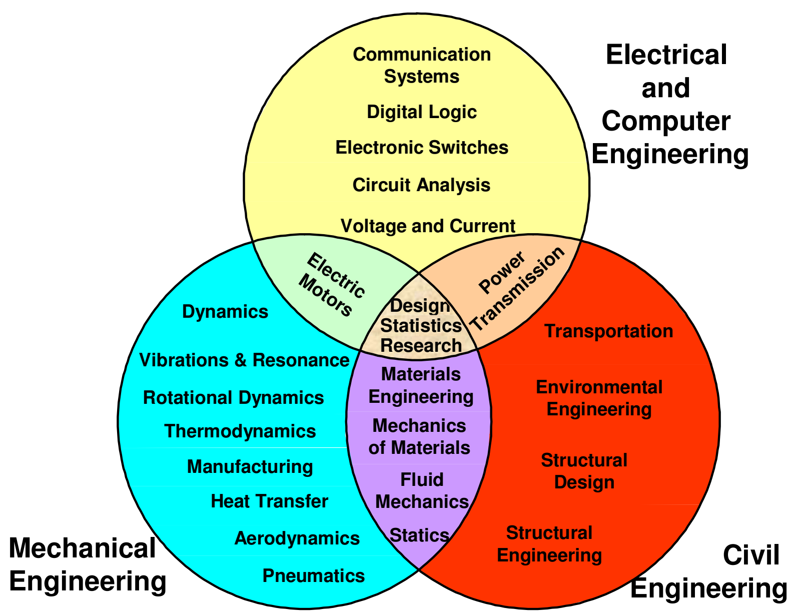


Figure 1. GE 100 Concept Map

On Tuesday and Friday, the class meets for a laboratory experience related to the topic. Laboratory spaces from all of the disciplines are used which gives the students an opportunity to see some of the equipment they will be using in later semesters. The labs are short enough to be completed in 50 minutes. Some labs require formal lab reports and some only include some analysis and answering a few questions. Most of the labs are done in groups of 3-4, but some require larger groups. The group work gives students an opportunity to get to know all of the students in their class very well.

In addition to the 26 modules, there are two design projects, a short one at midterm and a longer final project. For the midterm project, the students all complete the same project in groups of four. Projects are selected to use several of the topics from the first part of the semester. The final design projects are more discipline specific (digital clock, pneumatic cannon, manila folder bridge, etc.) and the students have an entire week to complete them. These final design projects are the highlight of the semester for most students.

There are four exams for the course, three during the semester and one during final exam week. Because so much material is covered in the course, each exam tests only the previous 6-7 topics and CSIs. The exams are primarily short problems, with some true/false and multiple choice questions and are given in a common period.

4. Fluid Mechanics Module

Fluid mechanics is one of twenty-six modules in the Fundamentals of Engineering course. It was chosen for assessment and reporting because it is a typical module in the middle of the course and because the concepts can be rather difficult for first-year students. A description and partial content of each part of the fluid mechanics module is provided in the following discussion.

The lecture is provided in PowerPoint format for each instructor. The lecture is designed for a 50-minute class period and includes learning objectives, topical information, worked examples, and in-class exercises. For this module, objectives include describing Bernoulli's equation in words, utilizing Bernoulli's equation, applying the Continuity equation, and determining velocity and flow rate discharge for a pipe. PowerPoint files are placed on a course website for student use in completion of the homework and laboratory assignments.

The in-class exercise (ICE) is used to introduce students to engineering calculations in each module. For the fluid mechanics module, students learned to apply Bernoulli's and Continuity equations to perform calculations. In the PowerPoint presentation, the ICE problem statement is revealed. Students are given a computation sheet with the problem statement and asked to solve the problem, based on the discussion and examples shown earlier in class. Students are allowed to work in pairs on the ICE. The instructor moves through the room, assisting where needed. After a set period of time, the instructor discusses the problem with the students and reveals the solution to the exercise. A sample ICE problem is given in Figure 2.

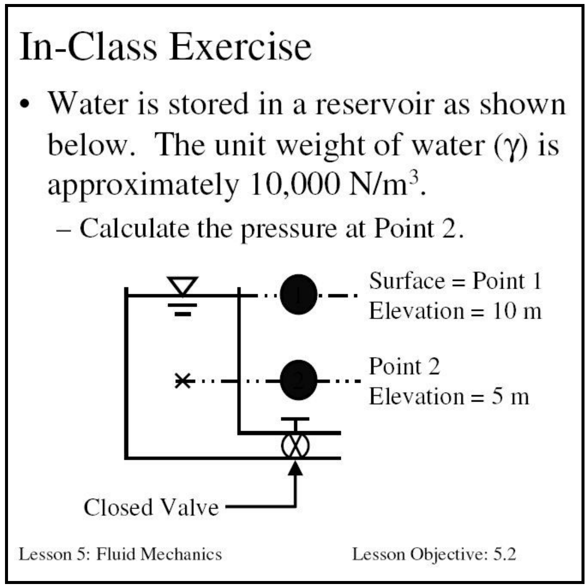


Figure 2. In Class Exercise (ICE) for Fluid Mechanics Module

The homework assignment reinforces the concepts learned by the lecture and ICE problems. Homework problems are similar in content to those in the lecture and ICE. The homework and ICE are turned in the next day at the start of the laboratory period. Students have access to instructors and peer tutoring prior to submittal of the homework assignment so that they may seek additional assistance with the new concepts if needed.

The laboratory assignment further reinforces the module concepts by hands-on experience. For the fluid mechanics module, students learn to how to estimate the flow rate (volume per time) of water out of a hole. Three methods are utilized: 1) Bernoulli's equation and flow rate, 2) volume of water and elapsed time, and 3) particle dynamics and flow rate. Figures 3 and 4 depict a schematic of the test apparatus and a photograph of the test, respectively. Students are required to write a comprehensive laboratory report that includes a cover page, executive summary, objectives of the test, experimental method, results and discussion, and appendix with raw data and calculations. The results and discussion section demonstrate student understanding of the experimental method, calculations, conclusions, and possible errors for the laboratory exercise.

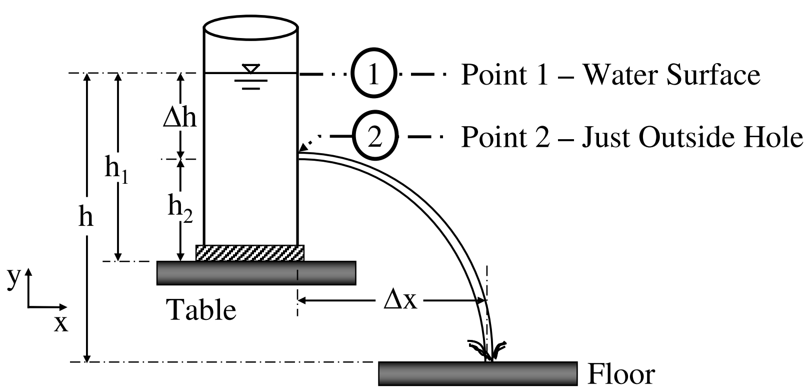


Figure 3. Schematic of Laboratory Test Apparatus

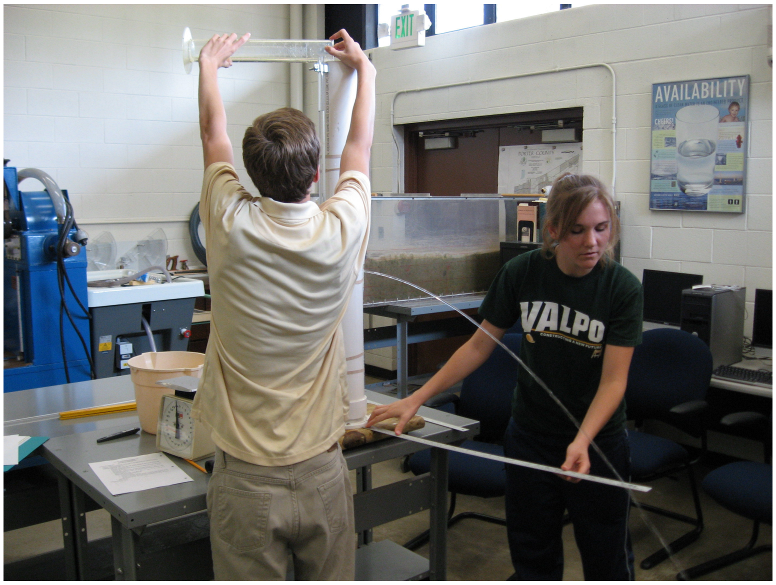


Figure 4. Students Performing the Experiment in a Collaborative Setting

Fluid mechanics was fifth of the twenty-six modules and was covered on the first of the four course exams. Two comprehensive problems were on this exam, the first covering the concept of continuity and the second involving use of Bernoulli's equation to find the velocity of water at the discharge point of a tank exposed to atmospheric pressure. A single professor graded exam questions related to fluid mechanics for approximately 140 students to ensure uniformity in scoring. The results are assessed in the following section of this paper.

5. Assessment of the Fluid Mechanics Module

The assessment of the fluid mechanics module included two tools, (1) a survey that provided an indirect assessment of the module's effectiveness and (2) exam questions, which provided a direct assessment. This assessment effort included seventy-five students from four sections of the course during the fall 2007 semester. Each of the two tools is described in more detail within this section.

The survey was split into two parts. The first part was given to the students as a pre-test before they began the module. It included a question asking whether or not they had seen fluid mechanics topics in any of their high school classes. This was followed by four questions asking the students to rate their ability to accomplish the module's learning objectives:

1. I can write Bernoulli's equation in sentence and mathematical form.
2. Given pertinent information at one location in a fluid, I can use Bernoulli's equation to solve for the pressure, velocity, or elevation at another location.
3. I can apply the continuity equation to calculate the velocity, area, or flow rate.
4. I can measure relevant distances and, using the principles of particle motion, calculate the velocity and flow rate discharging from a pipe.

The students were asked to respond to these questions using a five-point semantic differential scale with "No, Not at All" and "Yes, Definitely" as the antonyms to anchor the "1" and "5" responses, respectively.

After completing the module, the students were given the second part of the survey as a post-test. In this part, the students again rated their ability to accomplish the module's learning objectives using the same four questions. They were then asked to rate how the five components of the module (lecture, in-class exercises, homework, laboratory, and laboratory report) helped them to achieve the learning objectives. With these ratings, a ten-point semantic differential scale was used with "Did Not Help" and "Helped Greatly" as the antonyms to anchor the "1" and "10" responses, respectively.

The following three figures summarize the results of these two surveys. First, Figure 5 illustrates the students' responses to the four learning objective questions before and after the module was completed.

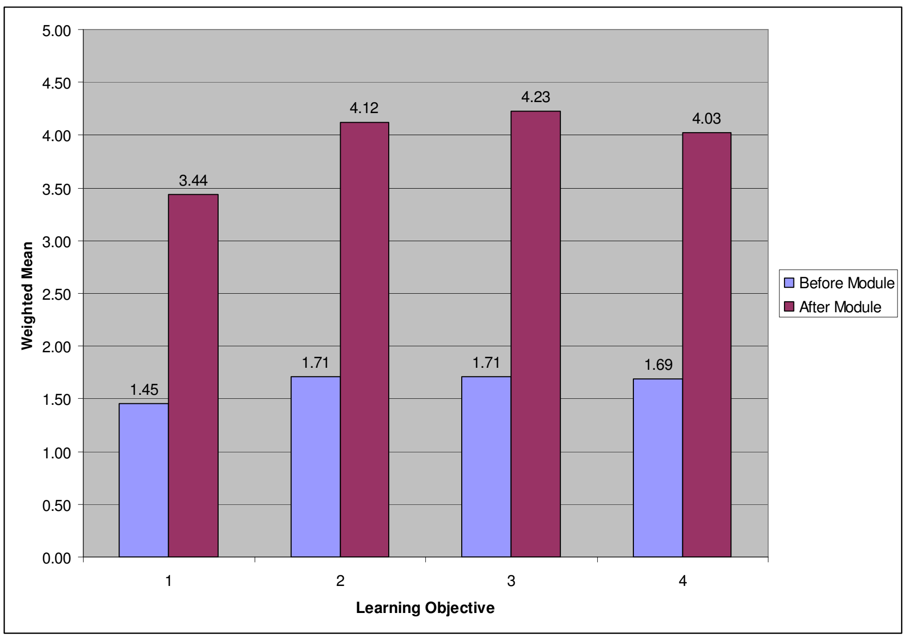


Figure 5. Students' Self-Assessment of Competency

The results show that the students' perception of their ability to meet the learning objectives dramatically increased after the module was completed. A statistical analysis was performed to ensure the results were significant. A pair-wise T-test was performed for each of the four questions, yielding t values that exceeded 15 in all four cases. This corresponds to a p-value for each question that is essentially zero, indicating that the results are statistically quite significant. .

The results of the surveys also illustrated that all five module components were helpful. Figure 6 shows the students' ratings of the different module components and how they aided the students' learning of the material.

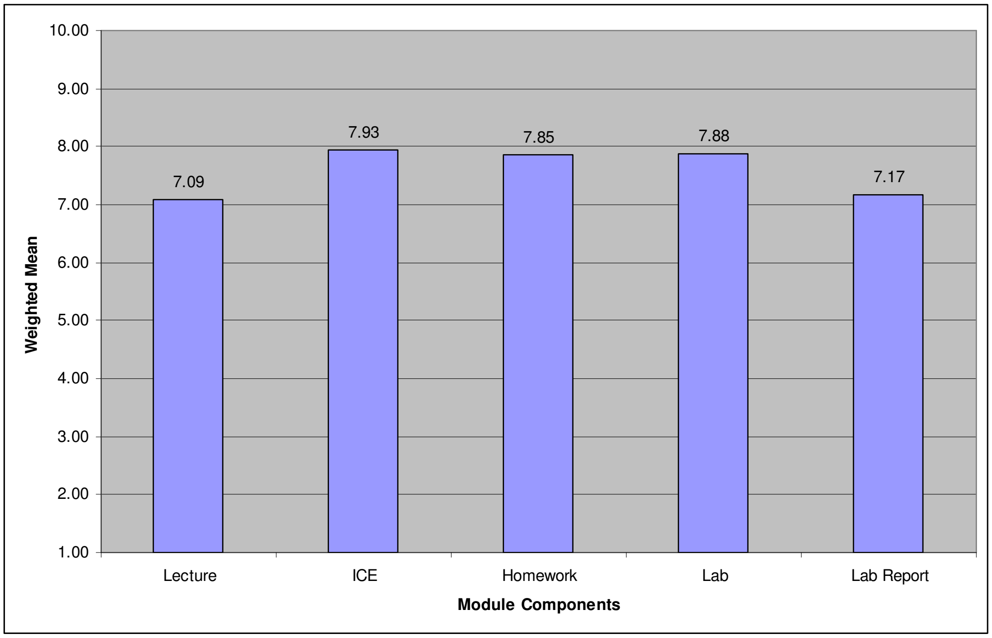


Figure 6. Importance of Module Components to Learning Objectives

The ratings show that all five components helped the students learn the material and that they all helped almost equally. Figure 7 shows the same data set, but broken down to separate those students who had seen fluid mechanics in high school from those who had not.

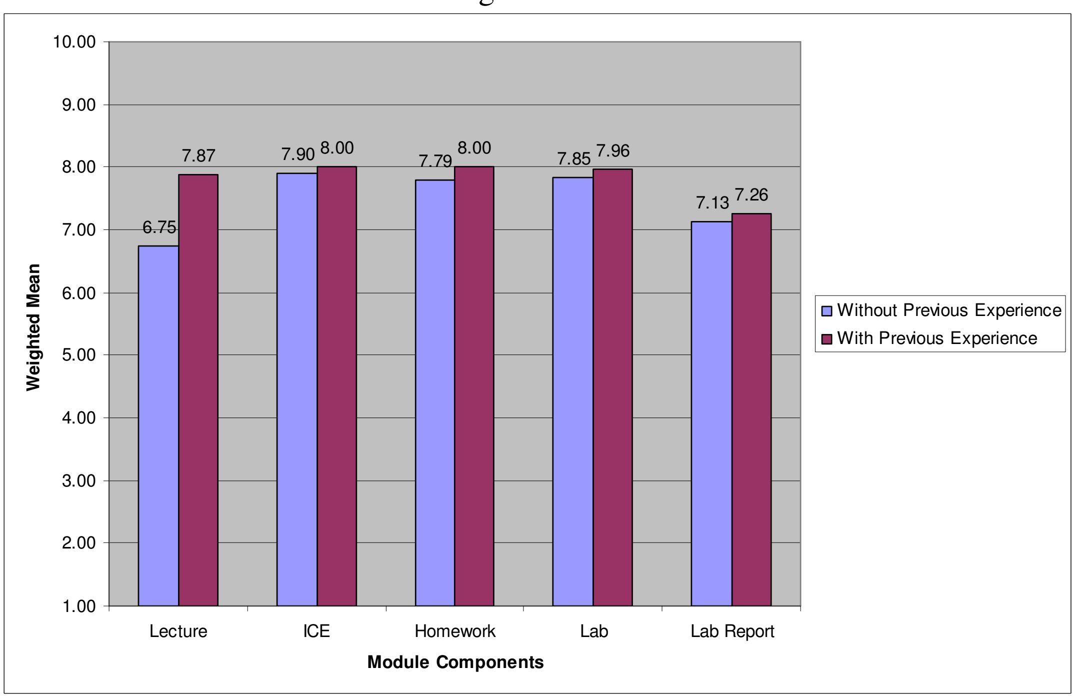


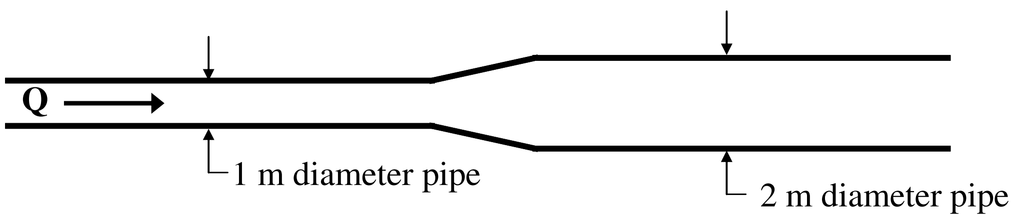
Figure 7. Importance of Module Components to Learning Objectives versus Previous Experience

This figure illustrates that for the in-class exercises, homework, laboratory, and laboratory report, there was no significant difference in value between students who had previously seen fluid mechanics and those who had not. There was, however, a significant difference in the perceived value of the lecture (at a significance level of p=0.024) between students who had seen fluid mechanics and those who had not. It seems that the students who had seen fluid mechanics topics in high school were better able to understand the lecture than those who had not, and therefore they rated it as being more valuable.

The second assessment tool used for the module was exam questions. Two questions on a section exam were developed that could verify whether the students were able to meet two of the four learning objectives associated with the fluid mechanics module. The students were given an equation sheet for the exam that included possible equations that they could use to solve the problems but were not told which equations to use and how to apply them.

The first question involved applying the continuity equation to a water flow problem through a pipe (Learning Objective #3). The actual exam question given was:

> *Water flows from left to right in the pipe below. The velocity in the 1 m section of pipe is 1.4 m/s. Find the velocity in the 2 m section of pipe.*



The students were asked to show all of their work as they completed the problem. The problem was graded on an eight-point scale and the students could receive partial credit. After the students' exams were graded, their answers were tabulated into one of following five categories:

- Correct solution
- Incorrect solution with an arithmetic error
- Incorrect solution with a minor conceptual error
- Incorrect solution with a major conceptual error
- Incorrect solution with little work shown or left blank

Figure 8 shows the students' performance on the first exam question.

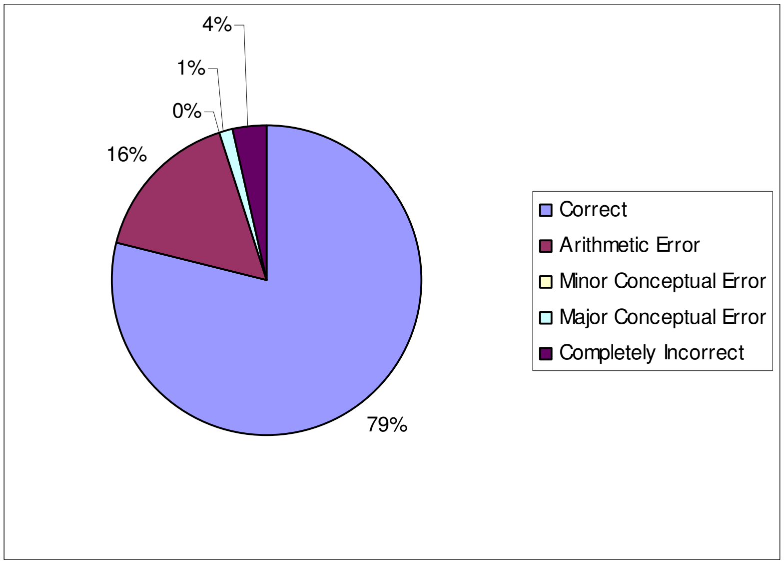
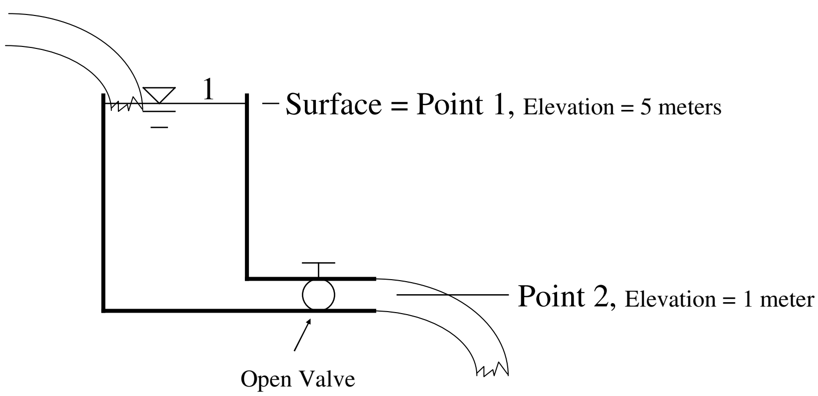


Figure 8. Student Performance on Question #1

Figure 8 illustrates that a large majority of the students (79%) solved this problem correctly. Of the incorrect responses, three-fourths were arithmetic errors, and the rest were minor conceptual errors. These results help verify that the students can meet Learning Objective #3.

The second question, as stated below, involved applying Bernoulli's equation to two points of water stored in a reservoir (Learning Objective #2).

> *If the valve at the bottom of a tank is opened, and liquid is poured in to maintain the height of the surface at Point 1, calculate the velocity of the water just outside the pipe. The unit weight of water is 10,000 N/m^3.*



Again, the students' answers were tabulated and Figure 9 illustrates their performance.

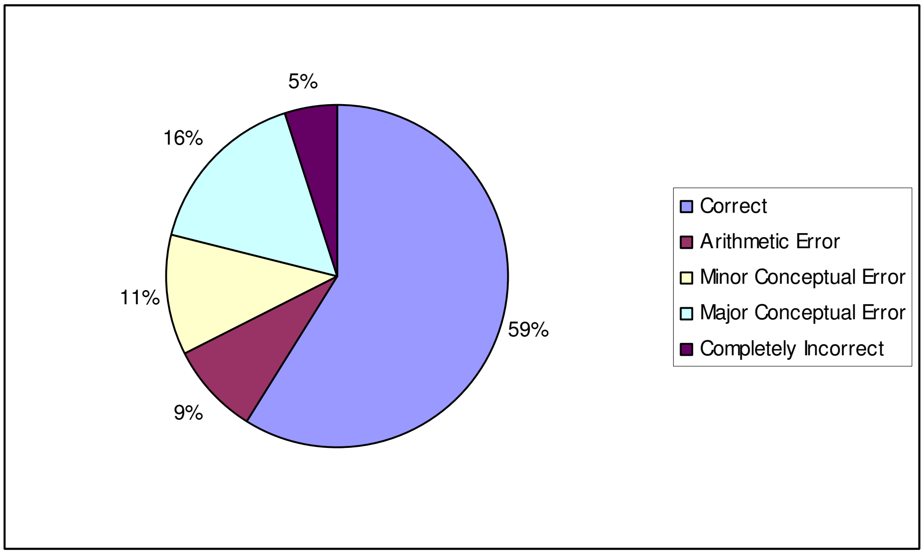


Figure 9. Student Performance on Question #2

This question was more challenging than the first because it involved multiple steps. Students had to realize that the pressure and velocity at Point 1 were zero, then equate the Bernoulli equation at the two points and solve for the velocity at Point 2. Although fewer students arrived at the correct answer, still a majority (59%) was able to calculate the correct answer. If students who either made an arithmetic error (e.g., did not square a term) or a minor conceptual error (e.g., treated the velocity at point 1 as nonzero) are included, then a large majority (79%) either found the correct answer or had a good understanding of the problem and made a minor mistake.

A comparison between results on the exam from this year and previous years is not possible because this is the first year that any assessment was done with the module. Also, students who have taken this course and continued on to become civil or mechanical engineering students have not yet completed the upper-level fluid mechanics course so that no conclusions can be made tying this module to their performance in that course. This assessment will be done next year by surveying students at the beginning and end of the academic term in which the fluid mechanics course is taken.

At the end of the course the students were asked to fill out a survey that rated many aspects of both their instructor and the course. Each question was asked using a five-point semantic differential scale. The weighted mean of each question was calculated, generating a response that ranges from a worst case of 1 to a best case of 5. The responses from 79 of the students to some of the questions from the survey are given in the table below.

"How well did the topics in the course match the learning objectives listed in the syllabus?"	4.30/5.0
"How would you rate the overall quality of this course?"	4.11/5.0
"How would you rate the overall quality of the instructor?"	4.33/5.0
"Did GE100 help you select your major?"	3.48/5.0

Table 1. Weighted Averages for Questions from the Fall 2007 Course Evaluations

The survey results illustrate that the students rated both the quality of the course and their instructor as very good. These results help validate that the modular approach to introducing engineering topics to first year students has been successful at Valparaiso University. While there was a lower rating for the course in helping the students decide on a major, this result is not surprising, because some students begin the class fairly certain of which major that they were going to choose.

6. Conclusions

A module-based approach has been implemented for introducing engineering topics to first-year engineering students at Valparaiso University. In this paper a typical engineering module (fluid mechanics) has been described using this approach. The module included a lecture on fluid mechanics with in-class exercises, a homework assignment, and a hands-on laboratory and report.

The assessment results show that the structure used (lecture, in-class exercise, homework assignment, laboratory experiment, laboratory report, and in-class exams) was very effective at helping both students who had already seen some fluid mechanics and those who had not yet had any exposure to this topic in high school. According to the students, the most valuable of these experiences were the in-class exercises, the homework assignment, and the laboratory experiments, with the lecture experience being rated as the least valuable. This illustrates the great importance of integrating active learning experiences into the course rather than filling all available time with lecture.

Students' self-assessment of achieving the learning objectives for this module increased from an average of 1.64 before the module to an average of 3.95 after the module on a scale from one to five, illustrating that they feel strongly that they can achieve the learning objectives for this module. Even more importantly, direct observation of their performance on exam questions related to this module verified that their self-assessments were accurate.

Future work in this course will involve assessing other modules, studying the differences in the effectiveness of the different modules, and continually seeking ways to improve existing modules and, where appropriate, replacing weaker or obsolescent modules with better ones on different topics. Additional work will address the most effective assessment and evaluation methods to be used in the course, with the possible inclusion of a mastery exam.[29]

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