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Virtual Simulations to Support Applied Fluid Mechanics Course: A Pilot Implementation Overview

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Abstract

Laboratories serve as controlled environments to link engineering theories to practical applications, and consequently they are crucial to engineering education. The impact of technological advancements on laboratory-based learning is, arguably, mixed: while we have advanced laboratories to support learning, education is also becoming time and location independent. With online classes, as an example, students can complete classes without meeting their instructors or ever stepping into a classroom. Laboratory based learning has to adapt to similar shifts. This study explores the use of virtual simulations as a means to conduct experiments designed for laboratory-based learning in online settings. A set of online simulations have been designed and developed to support the sophomore level Applied Fluid Mechanics course in a 4-year accredited state college. This paper provides an overview of the development process for the modules, the pilot implementation details, and the assessment results of the pilot implementation.

Introduction

Traditional engineering education set-ups combine theory and practice components in their curriculum; theory components are carried out during traditional lectures and practical components are carried out during traditional laboratory settings. In a traditional lecture environment, the professor teaches in-class, in-person and supports the lecture materials with textbooks, and lecture notes. In a traditional laboratory environment, the students conduct experiments, collect data and report their results under the guidance of their professor. These traditional approaches have proven to work very well to educate engineering students. However, with the continuously increasing student enrollment, many educational institutions can't find adequate laboratory space and equipment to meet the demand. In addition, students are increasingly interested in online learning components to be implemented to their courses, pushing institutions to offer hybrid and fully online engineering courses. Educational platforms such as Angel, Blackboard and Moodle provide a great environment for educators to set-up their online and hybrid courses; however, sharing laboratory materials and providing students with the accessible laboratory experience out of the traditional laboratory setting remains a challenge.

In an effort to overcome these aforementioned challenges, educators who teach hybrid and online courses, have supplemented their teaching by adopting different styles of teaching, such as: video-based teaching, slide-based teaching, voice-recording, online office hours, discussion boards, and teleconference office hours, etc. These methods have proven to be successful, since they provide the feel of the in-class learning environment and a certain degree of interaction with the professor. The challenging part is to have the same interaction and learning environment for the online applied courses. Over a 30 year time period, the laboratory setting started to slowly move from the traditional set-up to a computerized, remote, online, and finally a virtual setting. In the late 1980s and early 1990s, the existing computer-based systems that were developed for engineering experiments had some limitations: they had "inflexible and unfriendly programming structure", were "usually not compatible with the existing experimental systems", the "hardware generally contained small-scale testing devices", and "usually housed behind a panel that prevented the students experiencing the real-life devices and the visual benefits of direct experimentation"[1]. As the capability of the computers, hardware-wise and software-wise, increased, engineering educators were able develop better-integrated and interactive visualization components to support the theory in their courses. Educators developed and adopted technologies to create remote laboratories, and virtual platforms to provide students with the application experience. Although some of these set-ups were developed to support the online courses, many of the set-ups support the traditional courses and make the laboratory environment available to students anytime and anywhere.

A comparative literature review[2] of the hands-on, simulated and remote laboratories shows that out of the 60 articles that was reviewed; 11 of them provided a hands-on methodology to teach the subject matter while 13 of them provided a simulated methodology, and 15 of them provided a remote methodology to teach the subject matter in engineering education; while the rest of the articles were not engineering related[2]. The results of the comparative literature review[2] show the increased implementation of simulation and remote methodologies employed by engineering faculty to provide students an extensive laboratory experience. The applications of virtual, remote and simulation methodologies are developed for a variety of engineering majors. In Electrical Engineering: electrical machines, drives, electronics, circuits, and microcontroller experiments are among the many virtual, interactive and game-based online environments that are developed to support a variety of electrical engineering and electrical engineering technology courses. [1,3-7] In Chemistry, Chemical and Biochemical Engineering: process control, process operations, biochemical engineering, process systems, chemistry and organic chemistry laboratories are few examples of the many interactive and virtual laboratory applications that are developed to support chemistry, chemical and biochemical engineering courses. [8-13] In Civil Engineering: geotechnical engineering, strength of materials, behavior of mechanisms, material testing, and kinematics are among the many virtual, interactive and game-based online environments that are developed to support a variety of civil engineering and civil engineering technology courses. [14-18] In Mechanical Engineering: machine dynamics and mechanisms, thermodynamics, fluid mechanics, materials science, and gear design are among the many online, virtual and game-based laboratories and experiments designed to support the mechanical engineering and mechanical engineering technology courses.[19-26] As the traditional hands-on role of undergraduate engineering laboratories[27] transfer to interactive, virtual and remote environments; the availability of the education and the opportunities provided to students increase as well.

Development and implementation of the online laboratories, interactive simulation-based experiments and use of game-engine platforms not only increase the learning experience, but also provide solutions to limited laboratory space and equipment challenges. As these virtual platforms become more common, the need to compare these platforms to identify and implement the platform that will serve students the best is researched by engineering educators; such as virtual laboratories vs. remote laboratories[28] and which one to adopt. Educators can benefit from the availability of the vast examples in virtual experiments, game-based laboratories and online collaborative learning environments, and decide to implement the most appropriate one that fits their students' needs. Although many of the existing virtual learning platforms are designed to support the traditional in-class learning environments, it is a great addition to the online engineering courses or courses without the application (laboratory) component.

One of the challenges of developing virtual laboratories or experiments is to have access to the proper hardware and software to develop the virtual environment. This may present a challenge for many educators, as they may not have access to these tools. In an effort to address these challenges, a free and easy-to-use software, Scratch[29], developed by the Lifelong Kindergarten Group at the MIT Media Lab is used to develop virtual simulations for the sophomore level Applied Fluid Mechanics course[30]. This paper will provide a detailed review of how these simulations are developed, implementation of these simulations to the course, and assessment of the pilot implementation. The analysis of the assessment results will discuss students' preferred learning styles and their attitude towards virtual laboratories.

General Course Description

The Applied Fluid Mechanics Course (MET 212) is a 3-credit sophomore level course offered in the Mechanical Engineering Technology Department at Farmingdale State College, State University of New York. Applied Fluid Mechanics course is a required course for Mechanical Engineering Technology – BS, and Facility Management Technology – BS programs. The Applied Fluid Mechanics course covers nature of fluids, forces due to static fluids, buoyancy, conservation of energy and Bernoulli's equation, Reynold's number, laminar and turbulent flow, flow measurements, drag and lift, and flow of air in ducts, blowers and compressors subjects. During the fall semesters, the course is offered in-class, and during the spring semesters, the course is offered online. The in-class offerings the course meets once a week for 2.5 hours, has a designated textbook, and all the course materials (slides and weekly homework assignments) are shared through the course's online learning platform. The in-class offering has weekly homework assignments, 2 quizzes, a midterm and a final exam. The online offering of the course is built on a module basis. Each module has the learning content (the course material), the additional learning content (support material), a homework assignment, a quiz, a module review question, and a class interaction activity. In addition to the module assignments, the online course has a midterm and a final exam.

Pilot Implementation

During the Fall 2014 semester, three virtual simulations have been implemented to the Applied Fluid Mechanics Course as extra credit modules. Each module carries 1% extra credit weight, and students will receive 1% extra credit upon successful completion of each module. Students who successfully complete all three of the extra credit modules will receive 3% extra credit. During the Fall 2014 semester, each module is shared on the course's online learning platform, Angel. Figure 1 shows the online folder where the extra credit assignments are shared. In this folder, students are provided with the IRB (Institutional Review Board) consent document, an overview of how the extra credit modules will be completed, and a separate page for each extra credit module. The available dates and the due dates for modules are also provided under each module's title.

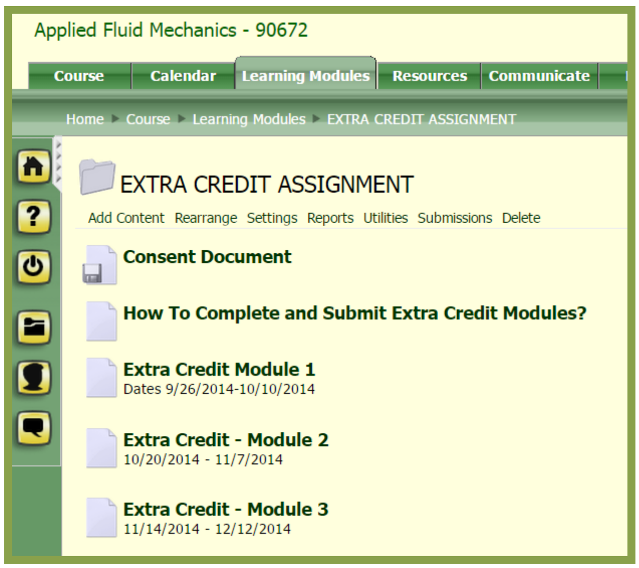


Figure 1. Extra Credit Assignment Overview

Each module includes step-by-step instructions on how to access the virtual simulation, how to run the simulation, concepts pertaining to the simulation along with the assignment for the module. The virtual simulations are available to students 24/7, and students can access and run the simulation as many times as they need. In order to receive the extra credit grade, students are asked to complete an assignment based on the virtual simulation. Figure 2 provides an overview of the extra credit modules implemented during Fall 2014 semester.

Figure 2. Presentation of each extra credit module

Overview of the Modules

The modules are created using MIT's Scratch [1] – a programming language developed by MIT Media Lab[29]. Scratch is free programming software; users can use Scratch to develop their custom animations, interactive art, and simulations. Three virtual simulations have been developed and implemented to the Applied Fluid Mechanics course during Fall 2014 semester. Table 1 provides an overview of the modules and their associated learning concepts.

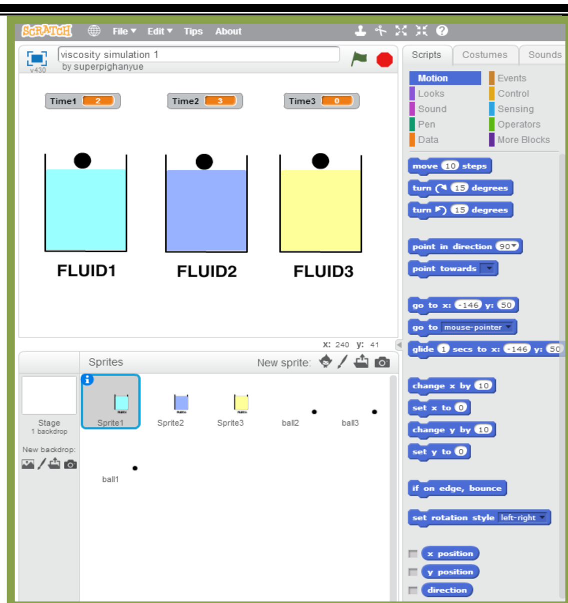
Table 1. Animation based modules for the experiments and the concepts covered by each module

Module	**Concept**
Module 1 [31] Falling Ball Viscometer	Reviews the viscosity concept of viscosity through Falling Ball Viscometer.
Module 2 [32] The Continuity Principle	Reviews the continuity principle concept with a pipe with different diameters
Module 3 [33] Pressure in Fluids	Reviews the pressure management concept in fluids through a manometer set-up.

[1] Scratch is developed by the Lifelong Kindergarten Group at the MIT Media Lab. See http://scratch.mit.edu

Module 1 – Falling Ball Viscometer

The first module reviews the concept of viscosity through a falling ball viscometer setup. In this set-up, three fluids in three different containers are examined. Simulation shows three identical balls being dropped at the same time into the three containers. The counters located on top of each container show the time duration the ball takes to reach the bottom of the container for each fluid. Students can run the simulation as many times as they need. In order to receive the extra credit, students need to successfully complete the Module 1 assignment. The assignment provides specific gravities for each fluid, height of the fluids, along with the diameter measurement for the steel balls. In this assignment, students are asked to compute the viscosities of each fluid. Students will use the falling ball viscometer equation to compute the viscosity of each fluid. The simulation set-up and the Module 1 assignment are shown in the Figure 3 below.



Module 1 Assignment:

Using the falling ball viscometer equation, determine the viscosities of fluid 1, fluid 2, and fluid 3.

Given Information:

Diameter of Steel Ball = 1.2 mm

Specific Gravity for Fluid 1 = 0.94

Specific Gravity for Fluid 2 = 0.88

Specific Gravity for Fluid 3 = 0.85

Specific Weight of Steel = 77kN/m3

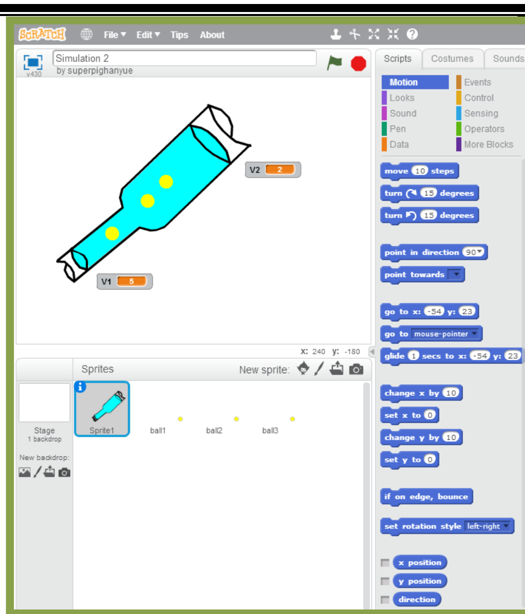
Falling Height = 300 mm

Calculate the viscosities of Fluids 1, 2 and 3.

Figure 3. Module 1 – Viscosity of the Fluids and the Module 1 assignment

Module 2 – The Continuity Principle

Module 2 provides an overview of the concept of the continuity principle through a virtual simulation of a pipe with two different diameters. The yellow balls are used to show the changing velocities of the fluid. On each side of the pipe there are two counters that display the changing velocities. In the Module 2 assignment, students are asked to compute either one of the diameters of the pipe by employing the continuity equation. The interactive simulation set-up is flexible enough for the course instructor to select a diameter for either side of the pipe. In addition, the simulation doesn't specify use of a unit system, so the course instructor has the flexibility to set-up the question in either metric or US unit system. The simulation set-up and the Module 2 assignment are shown in the Figure 4 below.



Module 2 Assignment:

Using the Continuity Principle and the continuity Equation, please calculate:

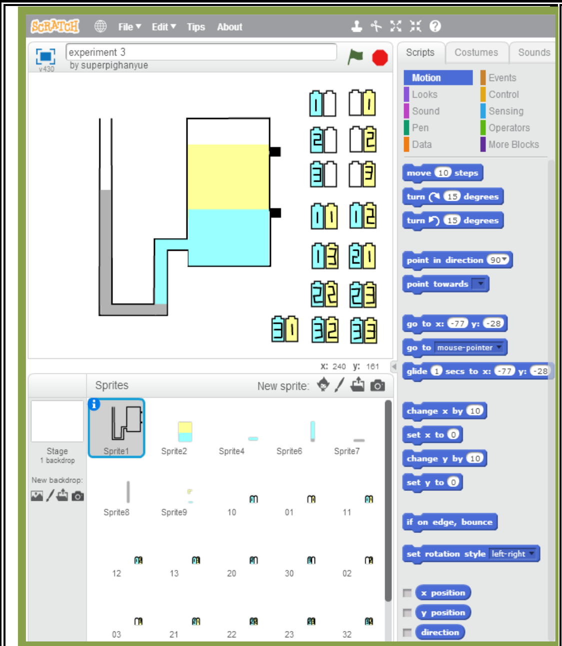
a) What is the Di diameter, if the D2 diameter is 15 cm, V1 velocity is 5m/s and V2 velocity is 2m/s.

b) What is the D2 diameter, if the D1 diameter is 10 cm, V1 velocity is 5m/s, and V2 velocity is 2m/s.

Figure 4. Module 2 – The Continuity Principle and the Module 2 assignment

Module 3 – Fluid Pressure Measurement & Manometers

Module 3 reviews the concept of fluid pressure calculation in systems with manometers. For the simulation setup, a well type manometer is used. The simulation is set-up in a way so that it is interactive and students can select a combination of oil and water to add to the system to monitor changes in the fluid heights and to calculate the fluid pressure. Module 3 assignment provides students with a combination of oil and water, and requires students to calculate the pressure at a certain point in the manometer using the manometer pressure equations. The assignment component of the module is very flexible; the instructor can set-up the assignment by changing height of the fluids as well as by changing the fluid pairs added to the system to adjust the complexity level of the question. In addition, the simulation doesn't specify use of a unit system, so the course instructor has the flexibility to set-up the question in either metric or US unit system. The interactive simulation set-up and the Module 3 assignment are shown in the Figure 5 below.



Module 3 Assignment:

Select one of the combinations of water & oil bottles. As you make a selection, you will see that the levels of oil and water will change.

- In the initial system, the vacuum air pressure in the container (on top of the water) is 200 kPa.
- The height of the water is 10 meters, and the height of the oil is 10 meters.
- Add a water & oil combination to the system and use the necessary pressure equations to calculate the deflection (h) in the manometer.

Figure 5. Module 3 –Pressure Management, Manometers and the Module 3 assignment

The Pilot Implementation of the Virtual Interactive Simulations

The pilot implementation of the virtual interactive simulations was carried out during the Fall 2014 semester. Prior to the implementation process, students were provided with a survey regarding their enrollment (part-time student vs. full-time student) and employment status (part-time employed vs. full-time employed). In addition, the survey also asked the students whether it was their first time taking the Applied Fluid Mechanics course, and which year they are at the program. The course had 22 students and a total of 20 students (n=20) participated and completed the survey. Pilot implementation surveys were carried out anonymously. The course's student population is made up of seniors (15%), juniors (45%) and sophomores (40%). Among the 20 students participated in the survey, 19 of them are taking the Applied Fluid Mechanics course for the first time, whereas 1 student took the course in the past. The students' current employment and college enrollment status is shown in Figure 6 below.

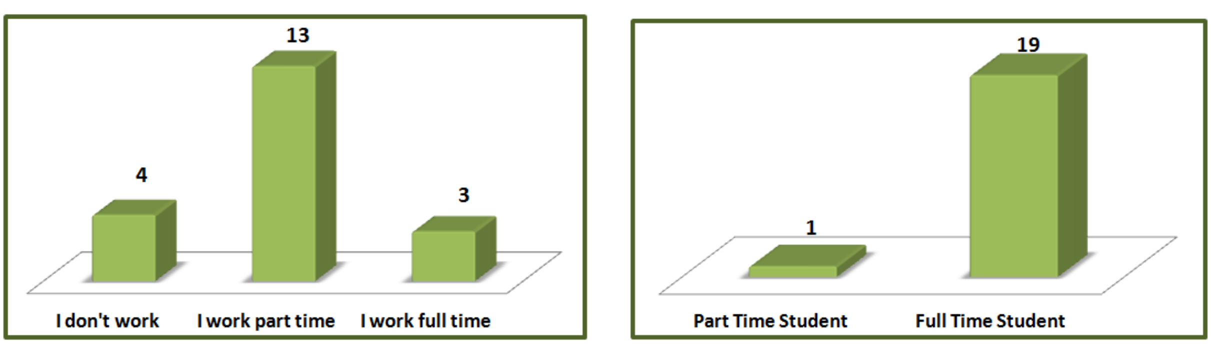


Figure 6. Students' work and college enrollment status

In an effort to measure students' interest in simulations and to understand their preferred learning styles, the following question is asked prior to the implementation of the virtual simulations:

Question: *Please circle the definitions that describe your learning styles the best (Max 3)*

Among the 20 students who took the survey, the majority of the learning styles students preferred were visual, kinesthetic, and logical with 28%, 26% and 25% weights respectively. These top three outcomes were a good indicator that visual and hands-on activities that are supported by the logical principles are preferred learning method for students. This is a good lead for the course instructor as the simulations support visual, hands-on and logical learning principles. The detailed outcome for this question is shown in Figure 7.

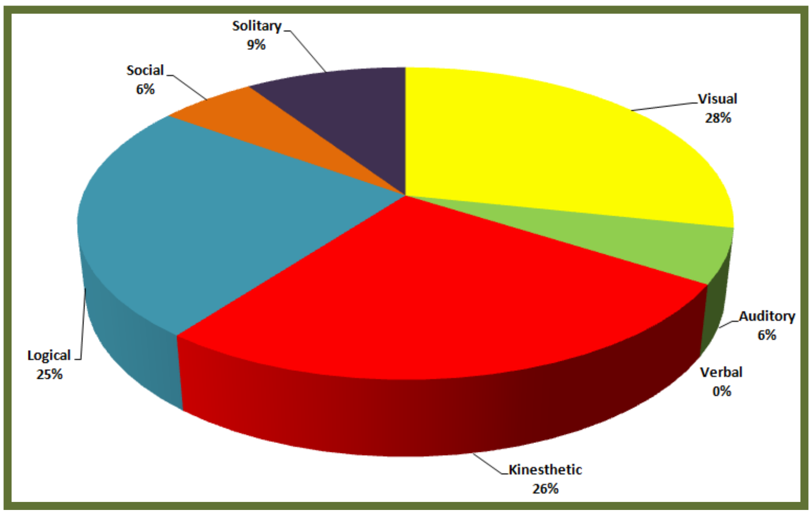


Figure 7. Students' Preferred Learning Styles

Pilot Implementation Assessment and Outcomes

Following the questions regarding the students' work status, college enrollment status and preferred learning styles; students were presented with a set-of questions to analyze their opinion on self-directed learning concepts, and implementation of technology into their courses. The self-directed learning aspect is a part of the simulations. As the students complete the virtual simulations on their own, they will go through the process of self-directed learning. The self-directed learning process will teach students to learn on their own and gain the self-directed learning skill set, which will last them lifelong. The question related to the implementation of technology into their courses aims to measure the comfort level of the students regarding the involvement of the new technologies in their learning process. These questions were presented as Questions 1 through 4, and are listed in Table 2.

Table 2. Survey Questions 1-4

Question Number	Color Code	Survey Questions
Question 1	■	I feel more engaged in courses that have interactive components such as laboratory, hands-on project, use of software or simulation
Question 2	■	Self-directed learning is as effective as in-class or on-job training (internships/co-op)
Question 3	■	I consider myself as a technology-forward person
Question 4	■	I prefer when professors adopt simulations to support the lecture material

Below, the outcome analysis for each of the four survey questions listed in Table 2 are provided in detail.

- ***Question 1:*** *I feel more engaged in courses that have interactive components such as laboratory, hands-on project, use of software or simulation*
  80 % of the students in the course stated that they prefer to have interactive components as a part of their learning activities. Implementations of virtual simulations with interactive components provide students an opportunity to be more engaged in the course.

- ***Question 2:*** *Self-directed learning is as effective as in-class or on-job training (internships/co-op)*
  55% of the students agreed and strongly agreed that self-directed learning is as effective as in-class or on-job training, although 35% of the students were neutral about the statement, this might also be related to the lack of previous exposure to self-directed learning and not knowing the concept of self-directed learning.

- ***Question 3:*** *I consider myself as a technology-forward person*
  90% of the students agreed and strongly agreed with the statement. The course professor expected this, as students were using e-books and also liked that course lecture slides and homework assignments were shared on the course page on Angel.

- ***Question 4:*** *I prefer when professors adopt simulations to support the lecture material*
  90% of the students agreed and strongly agreed that they prefer addition of simulations to their lectures. Additions of the simulations provide students an online environment where the application of the theory is available 24/7 and students can run them as many times as they need.

Graphical outcomes to Questions 1 through 4 are shown in Figure 8.

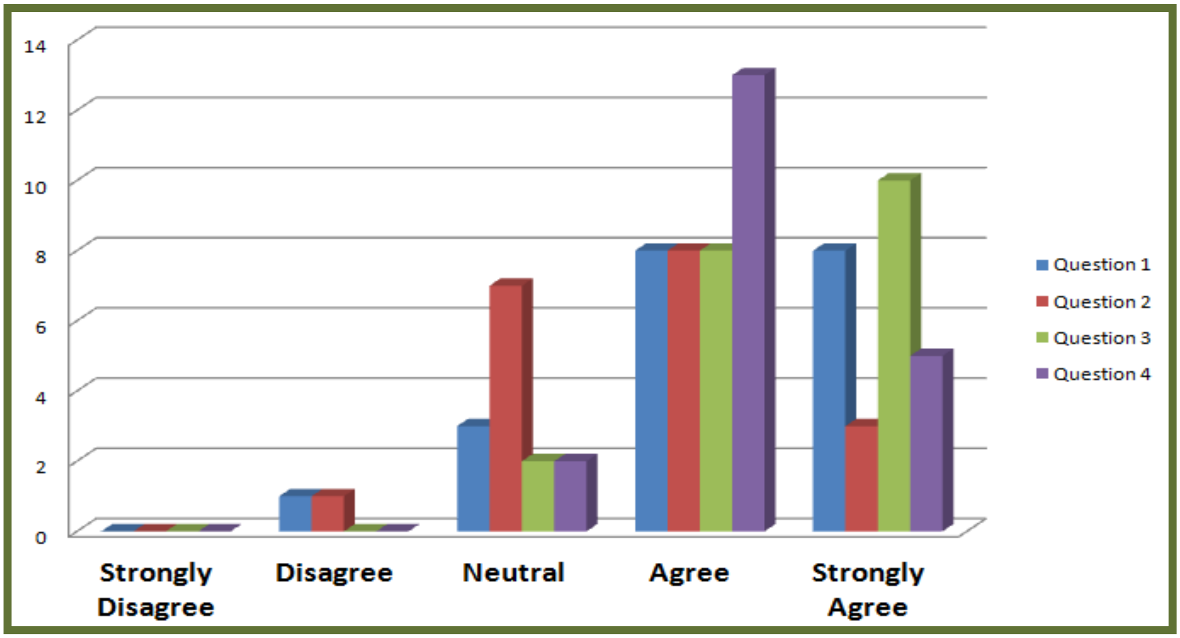


Figure 8. Outcomes to Questions 1-4

Following the pre implementation survey, three modules were implemented to the Applied Fluid Mechanics course. Students who wished to receive extra credit for participating in the virtual simulations were given a question, and asked to solve the question using the simulation set-up. Students' submissions were collected in a coded manner. Each student was provided with a code prior to the implementation of the virtual interactive simulations, and the codes are stored in a password-protected computer. Only the course professor has access to the codes, and codes were solely used to assign the extra credit grades.

Among the 22 students enrolled in the Applied Fluid Mechanics course and among the 20 students participated in the surveys, a total of 7 students completed the extra credit assignments. The participation rate of the overall course is 32%, while the participation of the students who took the initial survey is 35%. Considering the 80% and 90% of the students who preferred interactive learning, and considered themselves as technology-forward, the participation rate to the virtual simulations is lower than expected. Although for a pilot implementation, 100% participation is not expected, there were certain challenges that caused the low participation rate.

One of the challenges is tied to the concept of self-directed learning. Students were not provided with any tutorials or any in-class review of the simulations. They were only provided with the links to the virtual interactive simulations, and the instructions were shared through the course's online page. It was up to the student to read the instructions, learn them and run the simulations. This was a non-traditional approach introduced in a traditional course setting. Another challenge is related to the course load. The Applied Fluid Mechanics course required students to complete 10 homework assignments, 2 quizzes, one midterm and one final exam. The homework assignments were given weekly and collected weekly. Students might not have the extra time available to run the simulations and solve the questions related to the simulations. In addition, although some students ran the simulations and learned from them, they did not submit the assignment. Therefore, they are not included in the participation percentage calculation.

Conclusions and Future Work

This paper provided an overview of the virtual simulations that are developed and implemented to the sophomore level Applied Fluid Mechanics course. In addition to the development of the simulations, the pilot implementation results were discussed.

During the Fall 2014 semester, the simulations were offered in a module format, where students were responsible of reading the online instructions and running the virtual simulations to complete the extra-credit assignments. Although, this approach provided students with the important self-directed learning skill set; it also caused low participation rates. In the future, prior to the implementations of these simulations, an in-class presentation will be given to the students regarding the self-directed learning process. In addition, students will be provided with tutorials to guide them through the simulations.

For the pilot implementation, three simulations were developed to demonstrate the concepts of viscosity, continuity equation and pressure in manometers. For the future implementations, additional simulations will be developed to demonstrate additional concepts. The assessment process will be improved for the future implementations, and will include a post-implementation survey. The virtual simulations with interactive components are a great addition to the traditional Applied Fluid Mechanics course and will serve as a support system for the online offerings of the course.

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