The Effectiveness of Virtual Environments for Increasing Engagement in Engineering Technology Courses

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Abstract

The paper describes a learning activity design and data gathering methodology for use in forecasting student achievement via a survival analysis approach. Survival analysis is a methodology to predict the probability of survival based on a medical treatment procedure. In this paper, it is tailored for an academic program by defining learning activities, treatments, and measuring the effects of selected treatments. Selected treatments in this case are virtual laboratories applied in an undergraduate fluid mechanics course. Usage data is gathered to assess student engagement. A qualitative review is performed to assess student learning outcomes related to the learning activity. Finally, data from a student survey is gathered to assess their perceived value from the virtual laboratory treatment. This enables an assessment of the effect from the selected treatment on the resulting skill and knowledge demonstrated.

1. Introduction

The measurement of student engagement in educational activities has gained increasing attention in educational research and practice [1]. Effective student engagement is associated with improved learning outcomes, increased retention rates, and enhanced overall educational experiences. Thus, the assessment and understanding of student engagement have become critical in shaping pedagogical strategies and educational policies.

Measuring student engagement, and resulting skill development, provides educators and institutions with valuable insights into the effectiveness of their teaching methods and curriculum design. It helps identify students at risk of disengagement and allows for timely interventions. Additionally, it aids in assessing the impact of pedagogical innovations and educational technologies on learning outcomes. It is also a feedback mechanism for students to assess their own engagement and skill development required to successfully complete their program. The goal of this research is to establish a framework from which to measure the effectiveness of a learning activity as well as informing students of their progress toward achieving student outcomes.

The proposed framework to achieve this goal is based on survival analysis (SA), a methodology to predict the probability of survival based on a medical treatment procedure. It is a statistical method to analyze time-to-event data, such as the time until a patient's death or the failure of a medical device. An example framework is given by the Kaplan-Meyer equation shown below [2]. It calculates the survival probability as a series of successes. For interval i, letting t_i be the start time and q_i be the conditional probability of failure (death), the survival probability to t_i or beyond is:

$$S(t_i) = \prod_{j=1}^{i-1}(1 - q_i) \qquad \text{Eq. 1}$$

In this project, a learning activity is analogous to a medical treatment. We apply this approach to predict students' success.

This versatile analytical tool has found applications in various domains, including education. In this literature review, we explore the use of survival analysis for educational purposes. One of the primary applications of survival analysis in education is the assessment of student retention and dropout rates. Researchers have used survival analysis techniques to model the probability of students remaining enrolled in a program over time. By identifying critical points at which students are most likely to drop out, educational institutions can implement targeted interventions to improve retention rates. Studies [3-7] applied survival analysis to understand the factors influencing student persistence in higher education, laying the groundwork for subsequent research in this area. It has also been implemented to analyze the time it takes for students to complete their academic programs. This can help institutions identify factors that contribute to prolonged graduation times and develop strategies to accelerate student progress. In other studies, researchers used survival analysis to examine the time-to-degree for college students and found the impact on graduation rates [8, 9].

Forecasting learning achievement with survival history (FLASH) is based upon the concept of SA. This is accomplished by tailoring the concept for an academic program by defining variables for failure, success, treatments, and the engagement time. This enables measurement of activity engagement of a treatment and the resulting skill and knowledge demonstration as the success criterion. For example, each individual element in Equation 1 could represent how many students passed a course. The probability of program completion can be established once the series is complete. The unique goal of this work is to dive deeper to better assess what traits (i.e., knowledge and skills) successful students have demonstrated.

This research is focused on the effectiveness of the virtual lab as a treatment to enhance students' engagement. This study will lead to applying FLASH to identify and track performance metrics that can predict student success in engineering programs. While the long-term goal is to integrate this approach into entire curricula, the ERAU-WW campus's fluid mechanics course is selected as the pilot to demonstrate this idea to be immediately followed by application of FLASH to thermodynamics courses.

The framework for the approach revolves around selecting treatments, designing learning activities, and creating the data gathering instruments to answer the following questions:

- How can treatments be measured using SA to evaluate student learning outcomes and support the prediction of student success?
- What are some of the most effective methods for integrating the selected treatment into the program?

- What are the impacts of the selected treatments on the students cognitive, psycho-motor, and affective skills? How will the student's engagement be affected?

In the following section, the methodology to design and implement the treatments are discussed. An analysis plan describes how the effectiveness of the treatments are measured.

2. Methodology

The methodology used for the current research is summarized in Figure 1. The methodology is described in more detailed below:

Fig. 1. A flowchart of methodology and design process.

Identify Suitable Activities

The first step involves careful selection of learning activities based on established learning objectives and anticipated outcomes. Activities are chosen with a clear focus on enhancing student engagement, with consideration given to the alignment of measures for evaluating their effectiveness. Fluid Mechanics is the first course selected to implement this approach. It is a required course in 3 undergraduate engineering programs and provides a sample size of 120 students per year from whom to gather data. There are three basic types of activities to choose from. They are traditional problem solving, discussions, and experimental assignments. As a first attempt, a discussion based on experiments is selected. This results in an interactive and engaging activity that also contains a measurable cognitive component in the form of data analysis and presentation.

Define Measures

In this step, measures are defined to assess student engagement. Cognitive measures, involving practical assessments, are designed to gauge the acquisition of knowledge and skills. Psycho-motor measures assess usage and engagement, capturing how students interact with the learning activities. The measures include discussion scholarly engagement, pre and post lab quizzes, the student's ability to demonstrate the theory application. Furthermore, the midterm exam grade, particularly those questions related to the treatment are used as the measure of success for current students, meaning that, survival of the two individual activities will be a prediction indicator for survival of the overall midterm in addition to specific related questions on the midterm. This direct measure supports the added impact on the students' learning performance, particularly on their cognitive skills, and includes the following ABET performance indicators. The students should be able to a) apply appropriate dimensional units; b) record and represent data in an appropriate format (tables, plots, presentations, etc.); and c) draw conclusions from scientific investigations.

Identify and Develop Treatment

Selection of a treatment is a critical component. Recent studies show that pedagogical use of virtual environments (VEs) may enhance learner outcomes by raising improved feelings of learning achievement and by enhancing learning performance [10], [11], thus suggesting VE's are good treatments to improve the student's success. VEs are also important for engineering majors in an online, asynchronous education modality because they offer a more immersive learning experience than traditional lecture-based courses. VEs allow students to not only observe the results of experiments and simulations, but also to interact with the environment and gain a simulated version of hands-on experience. This can help students understand engineering concepts more deeply, allowing them to apply their knowledge in real-world contexts.

Three virtual environments have been implemented for this purpose. They are shown in Figures 2-4. The first one is related to measuring viscosity of fluids using a virtual rotary viscometer. The second lab focuses on measuring pressure as a function of altitude for different layers of atmosphere, and the third one discusses the application of conservation of mass, linear momentum, and Bernoulli's equation to propeller a water jetpack device in steady state operation. All these labs have the capability to control experimental parameters and enable gathering and therefore interpretation of data.

Data Gathering and Analysis Plan

The effectiveness of the VE as a treatment on students' performance is evaluated through direct and indirect measures on the students cognitive, psycho-motor and affective skills. Data collection from the VE is performed, utilizing Unity Analytics and Power BI to gather insights. The measures defined in step 2, define measures, are employed to evaluate student engagement. The data from previous activities without the VEs are compared to the same activities with the VE. Insight into student satisfaction and engagement levels is gathered via surveys, allowing informed decisions about future VE development and any required support strategies and affective skills. A qualitative analysis is used to evaluate the students' performance using Table 5. The micro-surveys show up after the activity and at the course evaluations to gather feedback from students about a variety of topics, including the VE contents to the instructions provided.

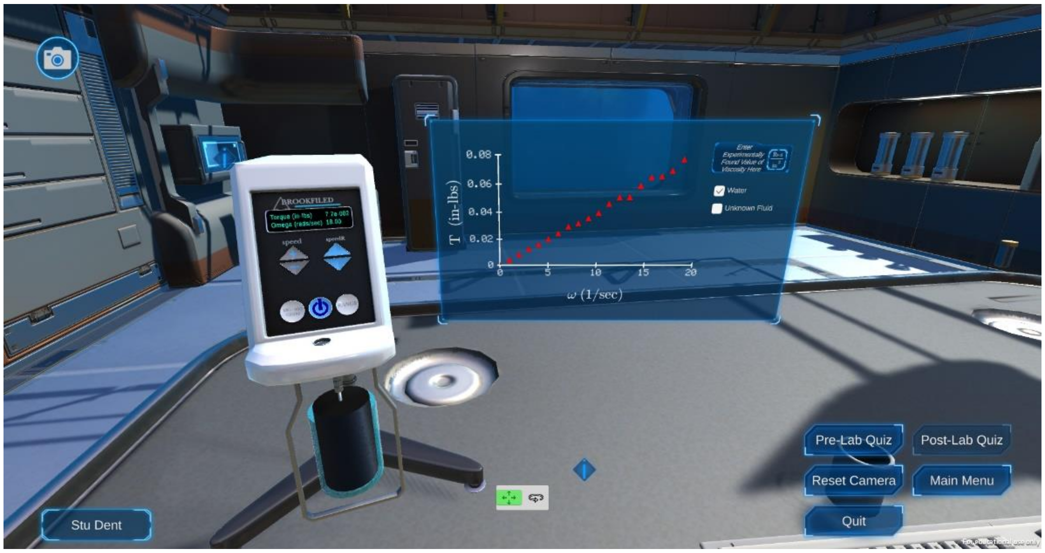


Fig. 2 Virtual viscosity laboratory image.

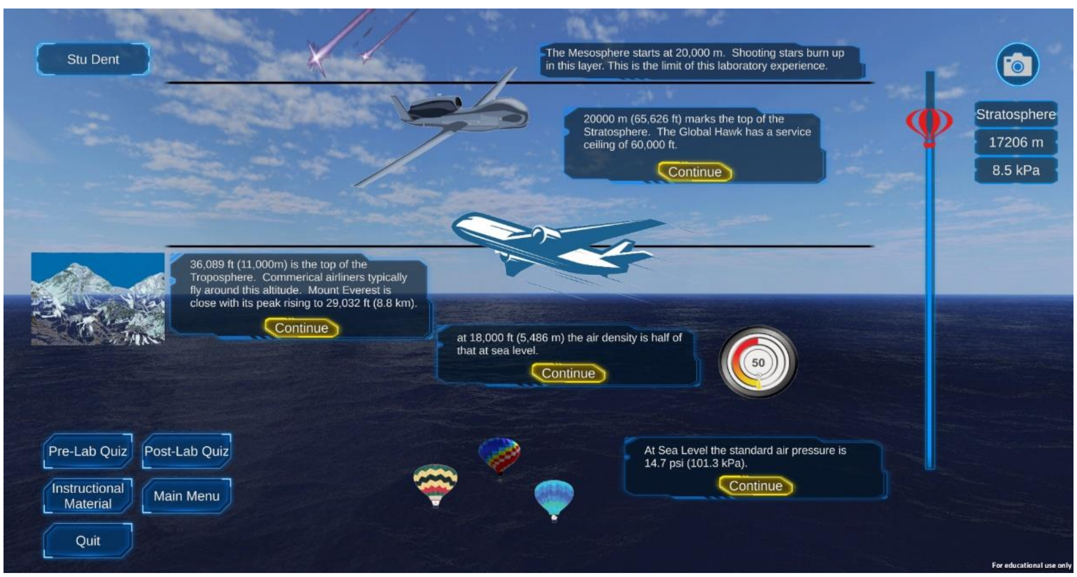


Fig. 3 Virtual atmospheric laboratory image.

Fig. 4 Virtual momentum laboratory image.

The data gathered above culminates in a statistical analysis to evaluate the performance of the students and their level of engagement. By designing different environments with different levels of required math knowledge, as well as analytical versus visual experiments, a better assessment was developed on the students' engagement pattern and the results are used to optimize the activity design. Assessment results are used to inform and guide future iterations of the VE, ensuring continuous improvement, optimization of the learning experience and creating a prediction tool to identify and flag the students at risk of disengagement or failure.

3. Results and Discussion

As a "treatment" for FLASH, the virtual environment supports the attainment of essential student outcomes that complies with various ABET commission requirements including Engineering Accreditation Commission, Engineering Technology Accreditation Commission and the Applied and Natural Science Accreditation Commission. This includes the ability to apply mathematical and scientific knowledge, conduct experiments, gather, and interpret data, and apply acquired knowledge to solve technical or scientific problems. Here, we discuss the effectiveness of virtual labs from multiple standpoints, aligning with these student outcomes. The evaluation of the effectiveness of the VEs includes both direct and indirect measures.

Engagement As Measured by Time in Virtual Environments

The selection of time of engagement and the number of attempts as criteria to assess students' engagement is grounded in a logical framework that considers the dynamics of online learning environments. These criteria are commonly employed indicators of student engagement due to their relevance in gauging both the quantity and quality of interaction with course materials. The time of engagement serves as a proxy for the depth of student involvement. Longer periods of engagement suggest a more thorough exploration of the content, indicating a higher likelihood of meaningful interaction. Conversely, shorter durations may signal surface-level engagement or potential disengagement. This metric aligns with the premise that the time invested by students correlates with their level of absorption and understanding. Similarly, tracking the number of attempts provides insights into the persistence and effort exerted by students. Multiple attempts suggest a commitment to mastering the material, reflecting a positive engagement pattern. On the other hand, fewer attempts may indicate challenges or disinterest. By utilizing these criteria, we aim to capture both the temporal and effort-related dimensions of engagement, providing a nuanced understanding of students' interactions with the virtual labs.

The analysis of the viscosity virtual lab was used to get preliminary results on the students' engagement. Table 1 and 2 show the lab engagement data for viscosity lab and atmospheric pressure lab, respectively. We defined two levels of engagement in the lab with level 1 including instructions on the interface and the experiment (takes about 3 minutes) as well as the prelab quiz with 8 questions (varies between 1- 5 min based on the time students spend and number of attempts) and level 2 including the experiment, data gathering, and get the resulting value to activate the post lab quiz and finally taking the quiz. The time spent in this level could also vary with the students' ability to perform each step, but an average of 20-30 min is an acceptable time of engagement. As this activity is offered as a discussion, the final steps are curve fitting, data interpretation and analysis.

Table 1. Viscosity lab engagement data, 11 of 24 students.

	Average (min)	Min (min)	Max (min)
Total Time In Level One	10	3	26
Instruction Time	2	2	4
Time Spent On Pre-Lab Quiz	8	1	24
Time In Level Two	47	4	199
Time Spent On Experiment	46	4	194
Time ToTake Post-Lab Quiz	3	2	5
Total Time In Laboratory	57	8	205

Table 2. Atmospheric lab engagement data, 8 of 24 students.

	Average (min)	Min (min)	Max (min)
Total Time In Level One	6	2	14
Instruction Time	2.2	0.2	5.8
Time On PreLab Quiz	4	2	8
Total Time In Level Two	54	6	159
Time Spent On Experiment	52	4	158
Time To Take Post Lab Quiz	2.8	0.4	9.1
Total Time In Laboratory	61	10	167

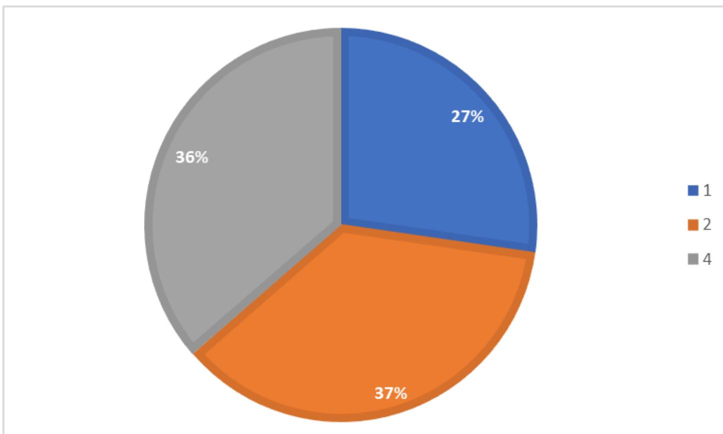


Fig. 5 Times entered virtual environment – viscosity laboratory.

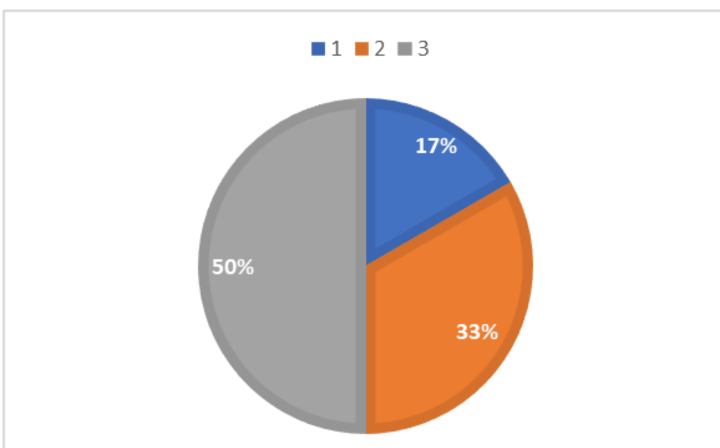


Fig. 6. Time entered virtual environment – atmospheric laboratory 8 students.

The students' engagement was also traced based on their number of attempts by tracking the times entered the virtual environment. The pie charts in Figures 5 and 6 depict the time entered the viscosity and atmospheric pressure lab respectively. The results show that more than 70% of the students entered more than once in the viscosity lab. The percentage for the atmospheric pressure lab is more than 80%.

Cognitive performance as measured by direct measures provides quantitative and qualitative data on student performance and engagement. The direct measures in this study include assessment grades (lab reports, prelab and post lab quizzes), as well as engaged and timely contributions in discussions. Prelab and post lab quizzes offer a direct and immediate assessment of the VE's impact on student learning. Prelab quizzes assess students' baseline knowledge and readiness before engaging with the VE while post lab quizzes, administered after the VE experience, evaluate how effectively the VE enhanced their understanding and application of the subject matter. By comparing grades between prelab and post lab quizzes, the extent to which the VE contributed to knowledge acquisition and retention is evaluated.

Table 3. Viscosity lab quiz data.

	Average	Min	Max
Pre-Lab Quiz Attempts	2	1	5
Pre-Lab Quiz Score	78	60	80
Post Lab Quiz Score	40	40	40

Table 4. Atmospheric lab quiz data.

	Average	Min	Max
Pre-Lab Quiz Attempts	3	1	6
Pre-Lab Quiz Score	59	50	60
Post-Lab Quiz Score	33	20	40

The students then posted their findings in a discussion board and made a scholarly conversation with their peers. The results show that the average time spent on level 1 was 9 min with a maximum of 26 min. For level 2, the average and maximum times were 40 min and 199 min, respectively. The average overall grade for this activity was 78/100.

The next measure is the students' engagement through scholarly conversation which serves as a qualitative indicator of the VE's success in promoting critical thinking and deeper understanding among students. Technical review of the discussions is based on the rubric shown in Table 5. Detailed assessment of lab reports and discussions includes evaluating the quality of students' experimental design, data collection and interpretation, the time spent on the lab, analysis, and conclusions which leads us to the first phase of our data gathering for FLASH focusing on the students' ability to collect quality data and conduct experiments.

Table 5. Technical review rubric for the discussions.

	Good	Fair	Poor
Demonstrated Data Gathering	Student gathered enough data points to illustrate data trend	Student gathered some data but not enough to illustrate a trend	Did not show any experimental results
Demonstrated Data Analysis	Student properly analyzed data and obtained the correct answer	Student properly analyzed data but did not obtain the correct answer	Student did not demonstrate a process to analyze the data
Interpretation	74%	17%	9%

Student based indirect measure. Indirect measures are conducted through a micro-survey designed to measure student perceptions and experiences. The first part of this survey focused on assessing the usefulness and preferences regarding the viscometer lab activity while the second survey focuses on the student's success in engagement and application of their knowledge into real experience. The survey questions in part 1 were as follows:

> Q1 - How did the activity help you understand the concepts and principles of fluid mechanics such as viscosity, shear stress and shear strain rate?
> Q2 - How did the activity help you in analyzing and interpreting data?
> Q3 - What was the most challenging issue you encountered while completing the lab?
> Q4 - How successful do you feel you were in completing the viscometer lab experiments?

The responses, as depicted in Figure 7 pie charts corresponding to Q1-4 in part 1 of the micro-survey, a substantial majority of students (63%) expressed their appreciation for the visual representation provided by the lab, indicating that the VE successfully conveyed complex concepts through engaging visuals. Furthermore, the positive response to the visual and hands-on approach of the lab demonstrates that students found the VE to be an effective tool for advancing engagement and practical learning. The majority of students were successful in completing the lab showing that the VE was generally accessible and user-friendly. The feedback also indicates that formulating and interpreting information presented challenges to half of the students underscores the need for ongoing improvements in lab design and scaffolding. Finally, 64% of the students felt they were able to successfully complete the lab. Overall, the survey results indicate that the VE was perceived as a valuable and engaging resource by most students, highlighting its potential in enhancing the educational experience in fluid mechanics.

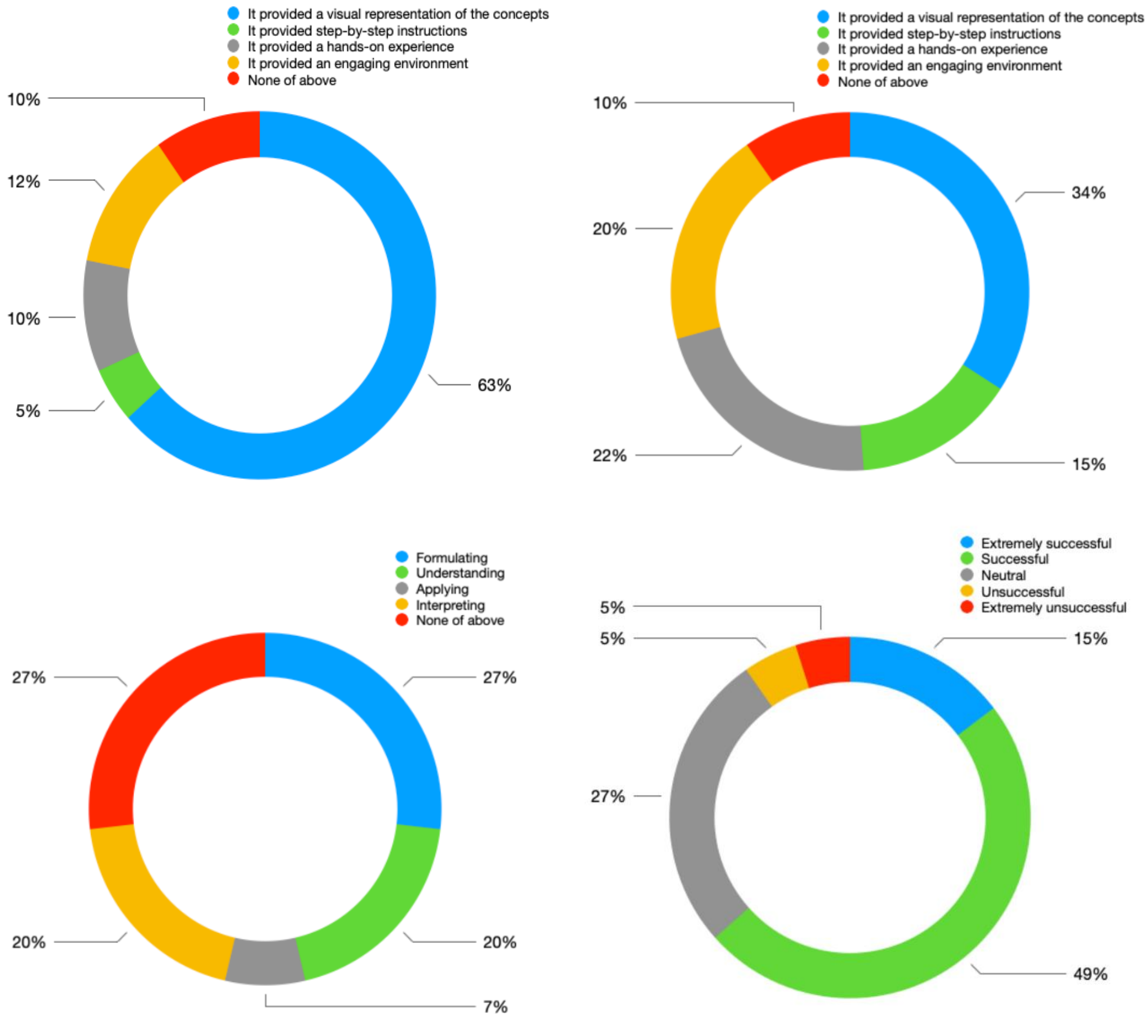
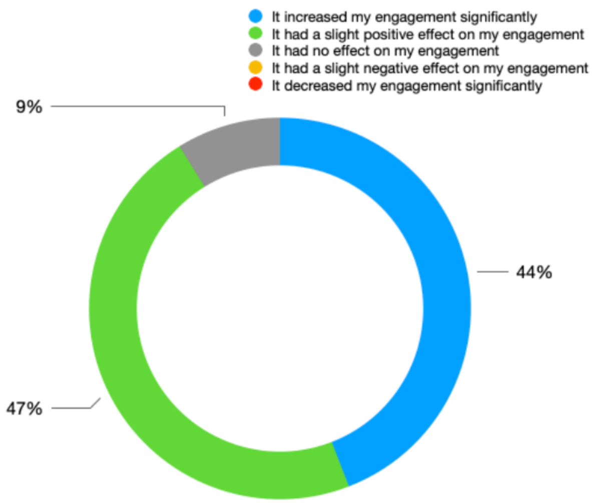
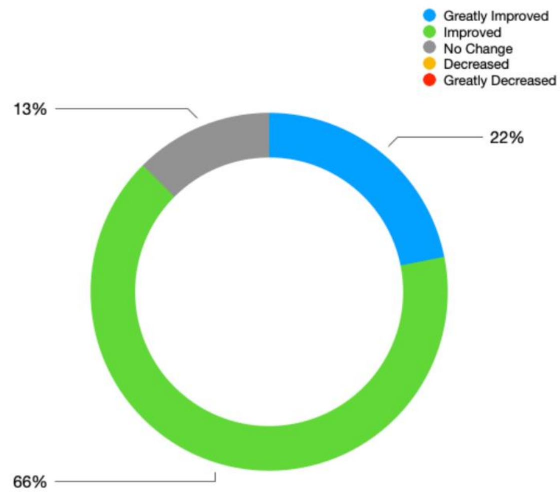


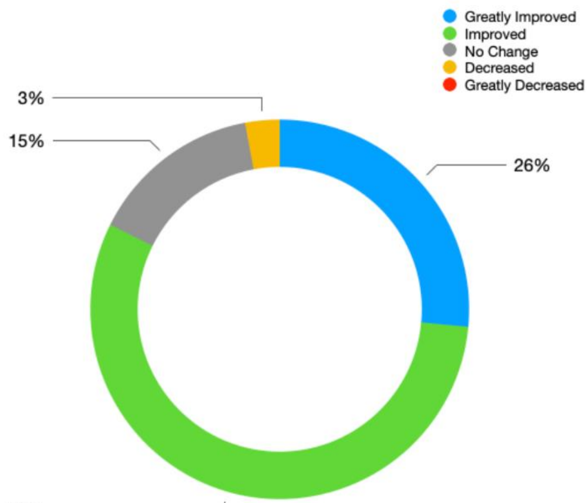
Fig. 7. Microsurvey part 1, Q1-4 results.

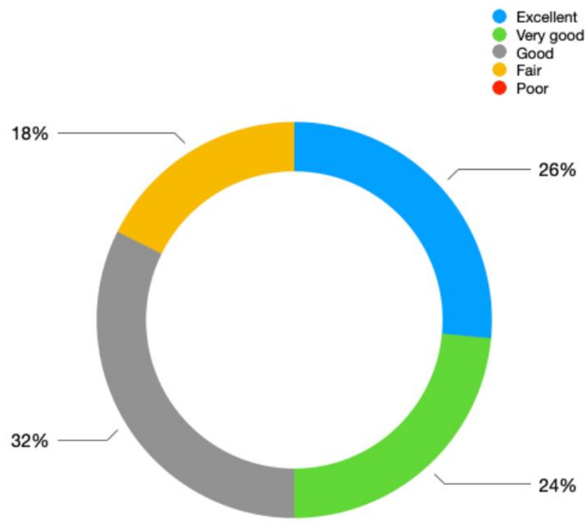
Part 2 of the survey was posted towards the end of term, with survey questions as follows:

Q1 - How did the virtual lab environment affect your engagement with the course?
Q2 - To what extent do you think this activity improved your understanding of the material including shear stress vs. shear strain rate and viscosity concept?
Q3 - To what extent do you think the virtual lab environment improved your ability to conduct experiments and test theories?
Q4 - How would you rate the quality of the instructions provided in the virtual environment for the rotary viscometer lab?
Q5 - How confident are you in your ability to apply the knowledge gained from the viscometer lab experiments in a real-world setting?
Q6 - How would you rate the overall experience of working with the virtual lab environment?


It increased my engagement significantly
It had a slight positive effect on my engagement
It had no effect on my engagement
It had a slight negative effect on my engagement
It decreased my engagement significantly
9%
44%
47%


Greatly Improved
Improved
No Change
Decreased
Greatly Decreased
13%
22%
66%


Greatly Improved
Improved
No Change
Decreased
Greatly Decreased
3%
15%
26%
56%


Excellent
Very good
Good
Fair
Poor
18%
26%
32%
24%

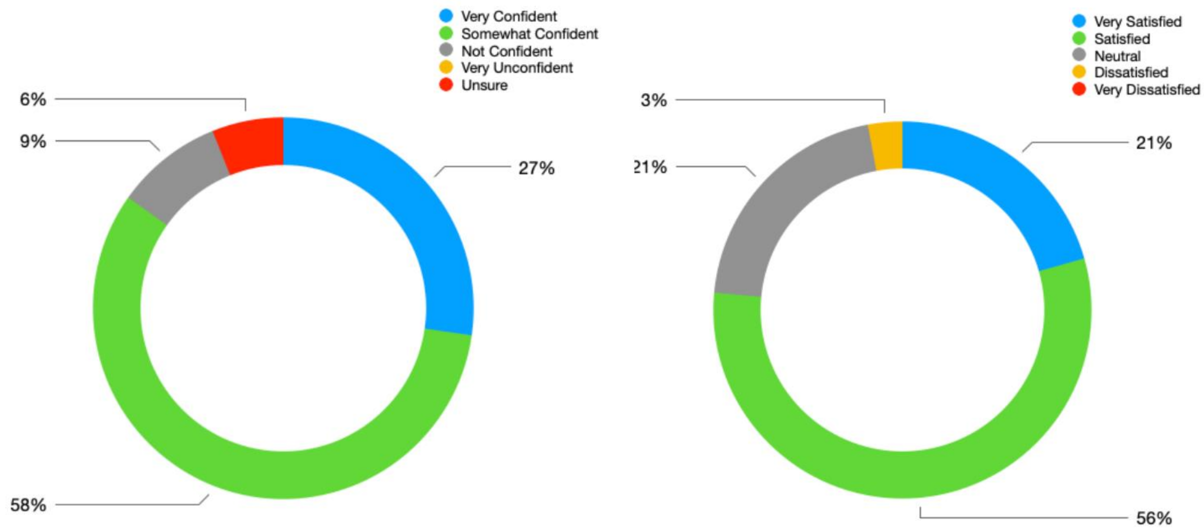


Fig. 8. Microsurvey part 2, Q1-6 results.

The second part of the survey, focusing on student perceptions of the VE and its impact on engagement, understanding, experimental abilities, and confidence in real-world application, provides valuable insights into the effectiveness of the VE in the fluid mechanics lab activity. 91% of the students reported positive effects on their engagement with the course due to the VE. They found the interactive and immersive nature of the virtual lab to be engaging showing that the VE successfully enhanced student engagement, aligning with the goal of making learning more interactive and captivating.

88% of the students indicated that the VE activity significantly improved their understanding of the core material, particularly concepts related to shear stress, shear strain rate, and viscosity. This observation shows that VE served as an effective tool for clarifying complex concepts, demonstrating its potential in facilitating deeper comprehension of fluid mechanics principles. A substantial portion of students (82%) acknowledged that the VE activity enhanced their abilities to conduct experiments and test theories, suggesting that the practical nature of the virtual lab contributed positively to their skills. Moreover, 82% of the students expressed satisfaction with the quality of instructions provided within the VE for the rotary viscometer lab showing that a clear and well-structured instructions within the VE are crucial for student success and were deemed effective by the respondents. 85% of students reported feeling confident or very confident in their ability to apply the knowledge gained from the VE-based experiments in real-world scenarios. The overall experience of working with the VE received positive ratings of satisfied or very satisfied from 77% of the students.

In summary, the VE was generally well-received, indicating that students found it to be a valuable addition to their learning experience in fluid mechanics. The survey results underscore the effectiveness of the VE in the fluid mechanics lab activity. The VE positively influenced student engagement, improved their understanding of complex concepts, enhanced their ability to conduct experiments, and boosted their confidence in applying knowledge in real-world situations. The overall experience was largely positive, indicating that the VE has the potential to continue playing a pivotal role in engineering education, offering a dynamic and immersive learning experience that aligns with the goals of modern pedagogy.

4. Summary and Future Plans

This paper described a derivative application of a survival analysis approach. It is tailored to forecast learning achievement and program success in an undergraduate engineering program. Treatments involved 3 virtual laboratories in a fluid mechanics course. Time-based data indicated satisfactory student engagement. Direct and qualitative measures showed an acceptable level of skill demonstration. Additionally, students had a positive perception of the learning exercises with respect to using the virtual environments, activity instructions, and academic content. Additional data will be available shortly on the third laboratory in this sequence and the data set will increase throughout the academic year.

This study is laying the groundwork for future phases. Once a sufficient amount of data is gathered through the implementation of different treatments, we plan to conduct survival analysis on a broader scale, spanning an entire program. This approach will enable a more comprehensive analysis of dropout and retention rates, providing a deeper understanding of the impact of various interventions on student outcomes.

Our next focus is to implement such treatments in the context of thermodynamics, where the students can engage in interactive activities and experiments related to thermodynamics ranging from phase change of a pure substance during a heat transfer process to modeling and analyzing thermodynamic cycles, such as the Rankine or Carnot cycles to study the efficiency of power generation systems. Students can investigate the effects of varying parameters, such as temperature, pressure, and fluid properties, on the behavior of thermodynamic systems.

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Biographies

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