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Effect of PhET simulations and YouTube videos on polytechnic students' conceptual understanding in fluid mechanics

Jean D'Amour Iradukunda, Lakhan Lal Yadav
African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science,
University of Rwanda-College of Education, Rukara Campus, Kayonza, Rwanda

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ABSTRACT

Fluid mechanics is an important branch of engineering and science with various technological and scientific applications. However, students often struggle to develop a solid conceptual understanding of related concepts due to their abstract nature, which involves invisible forces and complex scientific phenomena. This study investigated the effect of physics education technology (PhET) interactive simulations combined with educational YouTube videos on students' conceptual understanding in ten areas of fluid mechanics. Using a quasi-experimental pre-test and post-test design, 168 construction technology students from two Rwanda Polytechnic (RP) colleges were assigned to the experimental group (n=81) and the control group (n=87). The experimental group got instruction using PhET interactive simulations and YouTube videos, while the control group was taught using traditional methods. A validated test assessed students' conceptual understanding before and after the intervention. Descriptive and inferential statistics analyses of the study show that the students in the experimental group demonstrated far enhanced conceptual understanding in different areas of fluid mechanics than those in the control group. Results using different measures (normalized learning gains and effect sizes, using different approaches) show that the experimental group gained significantly greater improvement in their level of conceptual understanding compared to that of the control group. For example, Cohen's *d* for the post-test scores for the two groups was found to be 1.85; ratios of Hake's normalized learning gains and Cohen's *d* for post- and pre-test for the experimental group to the control group were respectively 2.2669 and 2.1623. Based on these findings, the study provided actionable recommendations for educational policy and practice for polytechnic colleges.

Corresponding Author:

Jean D'Amour Iradukunda
African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science
University of Rwanda-College of Education (UR-CE), Rukara Campus
Kayonza, Rwanda
Email: ijdamour2015@gmail.com

1. INTRODUCTION

Fluid mechanics is a critical branch of physics with real-world applications across various science and engineering fields. Despite its contribution to modern technological advancements, students often face difficulties in understanding basic fluid mechanics concepts [1] due to the content's abstract and complex nature, and involvement of mathematics and reasoning [2]. Such difficulties in conceptual understanding often result in students' low academic achievement and failures. For example, at California Polytechnic

University, a student's high failure rate was observed in the fluid mechanics course [3], which consequently hindered students' progress in subsequent academic levels [3], [4].

Despite global recommendations for technology-enhanced learning for all education systems [5], polytechnic students in developing countries continue to struggle with fluid mechanics concepts due to limited exposure to practical and technology-based teaching tools [6]. Thus, science, technology, engineering, and mathematics (STEM) students need to learn fluid mechanics concepts through innovative and interactive methods. The latter promotes a deep conceptual understanding necessary to build essential competencies for academic success and lifelong learning. Effective learning of fluid mechanics equips polytechnic students to develop the necessary competencies for effectively applying fluid mechanics principles to solve real-world challenges in sectors such as aerospace, automotive, environmental engineering, medicine, and life sciences [7], [8]. Recent research indicates that traditional teaching methods often fail to promote a deep conceptual understanding of abstract concepts in physics [9], particularly in fluid mechanics [10], [11]. For example, students taught through traditional teaching and learning approaches struggle to understand fundamental concepts such as Bernoulli's principle, Archimedes' principle, and surface tension.

Previous research consistently shows that STEM students often struggle to conceptualize the mechanisms of fluids, as related content deals with invisible forces and complex phenomena in gases and liquids. As a result, fluid mechanics is regarded as a challenging topic [11]–[13]. For example, a study conducted in the USA [14] showed that students had serious difficulties in applying Archimedes' principle. Many students failed to recognize the importance of considering displaced volume in finding the buoyant force. Students' issues with understanding hydrostatic pressure and related fluid mechanics concepts have been documented in various contexts [15]. In the area of fluid dynamics, Suarez *et al*. [16] found that students often fail to relate the continuity equation to Bernoulli's principle. These findings highlight that helping students to understand fundamental concepts related to fluids is not an easy task. It appears that the most critical learning barriers in fluid mechanics occur when students fail to develop a solid understanding of the relationship between the dynamics and kinematics of moving fluids.

According to Diyana *et al*. [15], for students to effectively apply fluid mechanics concepts in solving real-world problems and explaining natural phenomena, they must fully understand how fluid mechanics concepts connect with one another and with other areas of physics. Samsudin *et al*. [17] show that when students fail to conceptualize basic fluid mechanics, they risk developing strong misconceptions that may be difficult to correct. To address the challenges related to students' learning in fluid mechanics, researchers around the globe have explored various pedagogical approaches and technologies that could be used as instructional tools to enhance students' learning in fluid mechanics [18], [19]. Much effort has been invested to make the topics of fluid mechanics more accessible, as evidenced by various contributions in research publications and other initiatives, such as the availability of various textbooks and the development of related concept inventories [20]–[23]. However, its abstract nature continues to pose barriers to understanding the key concepts for students from technical colleges, who have not chosen it as their career of study. The students' interest in learning physics modules may also be impeded by some other factors, such as limited access to technology tools, inadequate knowledge of the use of information and communication technology (ICT) tools, and false beliefs about science education, that it is hard to learn. All these need much effort to change the existing situation, whereby technology-enhanced instruction on polytechnic students' understanding of key concepts in fluid mechanics can be helpful.

Researchers in science education recommend the use of interactive engagement approaches for the development of a strong conceptual understanding of fluid mechanics concepts. In this approach, the instruction emphasizes demonstrating to learners the inconsistencies in their reasoning in different situations and guiding them through a variety of activities to reshape their understanding in line with correct scientific reasoning [9], [24]. While the learning scope of fluid mechanics is very vast with wide applications, more efforts are needed for interdisciplinary dialogue for its teaching at all levels and in different disciplines [8]. Following the rapidly growing trend in technology use in education to enhance students' learning, there is a large body of recent work that highlights the positive impact of physics education technology (PhET) simulations and YouTube videos in addressing various issues relating to physics education [25], [26]. Several studies from Rwanda and outside highlight the positive effect of PhET simulations alone on students' learning in physics [27]. Some of the current studies suggest that PhET simulations can serve as a valuable connection that links classroom instruction with hands-on laboratory experiments in physics courses at higher education levels. This can promote a learner-centered learning approach as strongly advocated by the constructivist theory of learning.

In education settings, YouTube videos are not only used for leisure and entertainment but also serve as supplementary resources that enhance classroom instruction by offering visual explanations, real-world applications, and interactive demonstrations [26]. In teaching science subjects, educational YouTube videos help simplify complex concepts and illustrate experiments with expert explanations. The ability of YouTube videos to combine audio and visual elements aligns with multimedia learning principles, which makes them effective in improving students' conceptual understanding and engagement in physics education.

A recent study conducted by Nyirahabimana *et al*. [28] showed that the Rwandan students expressed a strong preference for the use of computer simulations, animations, and YouTube videos as interactive approaches suitable for quantum physics instruction. They also reported that lessons incorporating visualization techniques were more engaging and enjoyable compared to those delivered without such methods. Despite the documented benefits of PhET simulations and YouTube videos separately or combined with other learning approaches in some branches of physics, there are still gaps in research concerning their combined use to enhance the conceptual understanding among students at polytechnic colleges. That is, while some studies have explored the effect of each of these instructional tools on students' learning separately, current research that specifically targets their combined effect is limited, particularly regarding fluid mechanics learning in Rwanda Polytechnic (RP) colleges. In response to this gap, this study investigated the potential of integrating PhET simulations and well-chosen YouTube videos as interactive and visual learning tools to improve students' conceptual understanding in fluid mechanics. By exploring the combined effect of these technologies, the research aimed to bridge the existing gap and provide insights into effective instructional strategies tailored to the polytechnic colleges in the Rwandan context. In this study, we addressed this research question: how do PhET simulations and YouTube videos influence RP students' conceptual understanding in different areas of fluid mechanics compared to traditional teaching methods?

2. METHOD

2.1. Research approach

Being grounded on the post-positivist paradigm, this study followed a quantitative approach in which numerical data in terms of students' test scores were collected and analyzed from administered fluid mechanics conceptual understanding tests.

2.2. Research design

This study used a quasi-experimental design with pre- and post-tests. This type of design was adopted as there was no random selection of participants and allocation into groups, as they were chosen from existing colleges following certain selection criteria. It enabled the comparison between control and experimental groups to investigate the influence of the treatment on students' conceptual understanding of various areas of fluid mechanics in a natural setting. Students in both groups learned the same content, which aligned with specific fluid mechanics concepts as prescribed in the RP curriculum for level 6. The main covered content was related to: Pascal's and hydrostatic principles, the use of Archimedes' principle and capillarity in the study of static fluids, Bernoulli's principle, viscosity, and Stokes' law of fluid behavior. The intervention lasted six weeks, using 6 hours per week as per the university curriculum and calendar, integrating PhET interactive simulations and well-selected YouTube videos for the experimental group, while the control group learned through a traditional lecture-based approach. However, the participants could neither see the questions on the test before administration, nor be told which group (experimental or control) they belonged to. They also did not interact with each other to avoid bias and side effects. The participants signed an informed consent after explanations about the aim, ethical issues, mitigation of risks (such as confidentiality of data), and benefits of the study.

During the intervention, lesson plans were developed for the experimental group, and the teacher received training to ensure effective implementation. The physics facilitator was trained to integrate PhET simulations and selected YouTube videos, follow a structured lesson sequence, promote interactive learning, and address students' misconceptions in fluid mechanics. The lesson plans were first piloted at another RP college to refine the approach before full implementation. Teacher training, feedback from the pilot, and regular discussions with the experimental group teacher ensured a shared understanding, minimized bias, and standardized instructional procedures to reduce variations that could affect the study results. Each intervention session followed a structured sequence: a brief concept introduction, guided student exploration using PhET simulations or relevant YouTube videos (for topics not available on PhET, such as surface tension, capillary action, hydrostatics applications, Pascal's principle, and some Bernoulli applications), and concluded with group discussions and reflection focused on real-life applications and correcting common misconceptions. Some examples of simulations used from the PhET website are: Density, under pressure, fluid pressure, fluid flow, and Buoyancy (all are accessible via the link: filter - PhET simulations). The educational YouTube videos were selected by the two researchers and the teacher who taught the experimental group, based on the need and their usefulness according to the curriculum. Some examples of the YouTube videos used include: some applications of hydraulics and Pascal's principle (accessible at: https://www.youtube.com/watch?v=DdZnknku8b8), adhesion and cohesion (accessible at https://www.youtube.com/watch?v=XAnICnJ_-80), and surface tension (accessible at: https://www.youtube.com/watch?v=pmagWO-kQ0M). The physics teacher facilitated students' inquiry by encouraging predictions, guiding exploration, and requiring students to explain their reasoning. This structure promoted a learner-centered environment through active engagement and peer interaction, and addressing students' common errors and misconceptions to promote conceptual understanding of fluid mechanics concepts.

2.3. Participants and data collection procedure

The study was conducted during the study period of the first semester of the academic year 2024-2025. The study had a population of 304 students who took fluid mechanics during the period of this study. However, after applying other inclusion criteria, 168 students were selected as the sample from two separate colleges, as per their enrolments. In educational research, sampling more than half of the available population is considered appropriate, particularly when the total population is relatively small [29]. Therefore, this research study involved 168 year-one, level 6 (first year of university at RP) students who had registered for the option of construction technology at two purposively selected RP colleges (out of the eight colleges that make up RP). The selection of colleges also used other inclusion criteria: the college should offer the option for students to learn a physics module, and the physics teacher should possess a master's degree in physics education with at least five years of teaching experience. Following these requirements, only two colleges could satisfy the criteria. Both colleges had the same level in terms of infrastructure and resources, such as internet and computers, necessary to conduct this study to allow all students in each class to be involved. The sample was adequate for this study; however, has a limitation for generalizability of the study, as discussed in limitations and recommendations for future research.

The participants were divided into experimental (n=81) and control (n=87) groups, where each group was chosen from a separate college. The allocation of each college into its group followed a convenience sampling [30] based on the availability of computer labs in the college. The procedure consisted of identifying the number of available computer labs with computers that could accommodate all students who would be involved in the experimental group. The choice of these students depended on the fact that the two classes had their physics module in the same teaching round. Normally, modules in RP colleges are delivered in different rounds. Each academic year has two semesters, and each semester has two rounds. Therefore, the students of year one, construction technology at both RP colleges, coincidentally had to take their physics module in the same first round, and advantage was taken to collect data from both groups in the same period. The participants had similar characteristics in both groups, so there was no significant issue with allocating one as the experimental group and the other as the control group.

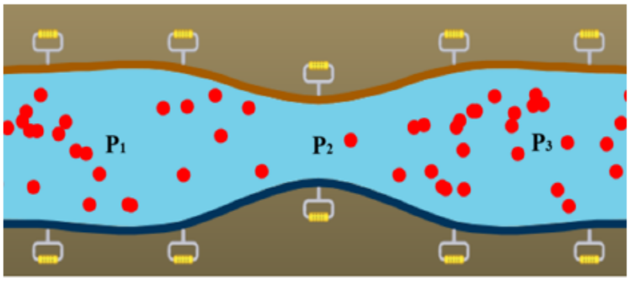
A pre-test was administered to the students of both groups before teaching began to assess their baseline understanding of fluid mechanics. The students' pre-test results of the experimental group were compared to those of the control group. The students in both groups were taught the same content related to different areas of fluid mechanics. The physics teacher in the control group used traditional lecture-based methods with verbal explanations and static diagrams using markers on the whiteboard. However, the teaching and learning in the experimental group incorporated some practical activities that students performed from PhET interactive simulations and watching well-selected educational YouTube videos. Thus, students manipulated the simulations by doing the assigned practical activities and were involved in watching the selected videos from YouTube while solving some embedded conceptual understanding problems. After the instruction, the same test was given as a post-test to both groups to measure students' conceptual learning achievement.

2.4. Data collection instruments

The data collection instrument utilized in this study was a two-tier test instrument. According to Septiantini *et al*. [23], a two-tier test is a diagnostic assessment tool consisting of two parts. The two-tier test employed comprised 22 items and was used as an assessment tool designed to diagnose students' conceptual understanding. Each question of the test consisted of two parts. The first tier consisted of four multiple-choice sub-questions that assessed students' scientific knowledge or direct understanding of fluid mechanics concepts. The second tier consisted of four follow-up options (A, B, C, and D) that required students to justify their choice. Among the four options, one was the correct justification for the correct answer in part 1, while the other three options were distractors. This test format enabled the researchers to discover students' reasoning.

Some test items were adapted from earlier works of [21], [22], [31], [32], and others were adapted from the PhET website, as per the content and learning outcomes of the RP curriculum for fluid mechanics. Only 22 questions relating to the contents of the RP curriculum were finally adapted by the researchers, taking into consideration the RP curriculum as per different topic areas, after several stages, working at an individual level, and three rounds of intensive discussion among the researchers. Then, the test items were checked for both reliability and validity. The validity of the instrument was assured by passing the questionnaire to three physics lecturers to check whether it addressed the intended concepts and related applications as per the RP curriculum and learning objectives, and the appropriateness of the language used. The Cronbach's alpha value for internal consistency was found (α=0.83). A sample of the two-tier test items in this study is shown in Figure 1, and the whole test is available and can be provided upon request.

Consider the picture of a constricted pipe.



1. At which point(s) does the fluid experience the lowest pressure?

A) Point P_1, P_2, and P_3

B) Point P_1 and P_3

C) Point P_1

D) **Point P_2**

2. What should be the reason for the chosen answer above?

A) Pressure is independent of the cross-sectional area of the pipe.

B) Pressure is directly proportional to the velocity of fluid flow.

C) **The higher the speed, the lower the pressure.**

D) The pressure at all points on the pipe is the same.

Figure 1. Sample two-tier test item

2.5. Data analysis

Version 25 of IBM SPSS statistics was used for data analysis. The pre- and post-test scores were analyzed with appropriate statistical tests using both descriptive and inferential statistics, after running the normality test. The test items were grouped into different areas of fluid mechanics. This enabled researchers to analyze students' level of conceptual understanding in different areas of fluid mechanics.

After arranging the pre-test for both control and experimental groups, the frequency of students' choices per question was recorded for the pre-test and post-test for both groups in a table. Students' responses were arranged according to topic areas in fluid mechanics, in two categories: correct responses and wrong responses, for both control and experimental groups. This enabled the researchers to find the average number of students who responded correctly and who responded wrongly in different areas of fluid mechanics (considering all questions in each area, e.g., for applications of Pascal's principle, two questions) and put it in a tabular form to do a deeper analysis of the performance of students. A similar analysis was done for both groups after the post-test. For the correct and wrong answers, respectively, 1 and 0 marks were assigned to find the scores and to determine the conceptual understanding of students in different areas of fluid mechanics. To make sure that the observed changes were due to the applied intervention and not by chance, the students' normalized gains in both groups were analyzed and compared using different approaches, such as the normalized gain in terms of the standard deviation of the control group [33], Cohen's *d* for the post-test scores for the two groups and for pre-and post-tests for: the control group and the experimental group, and the quotient effect size, q [34] and Hake's normalized learning gain g and the average of gains, $\bar{g}$ calculated from individual learning gains for each student [35], [36].

3. RESULTS AND DISCUSSION

3.1. Analysis from descriptive and inferential statistics

After running the normality test, sufficient evidence showed that both the control and experimental groups' pre- and post-test results appear to follow a normal distribution, as the obtained p-values are greater than the common alpha level of 0.05. This permitted the researchers to use a parametric test, namely an independent samples t-test, for comparing the mean scores of both groups. Table 1 presents students' pre- and post-test results in both groups regarding their level of conceptual understanding.

Table 1. Comparison between students' pre-test and post-test scores in both groups

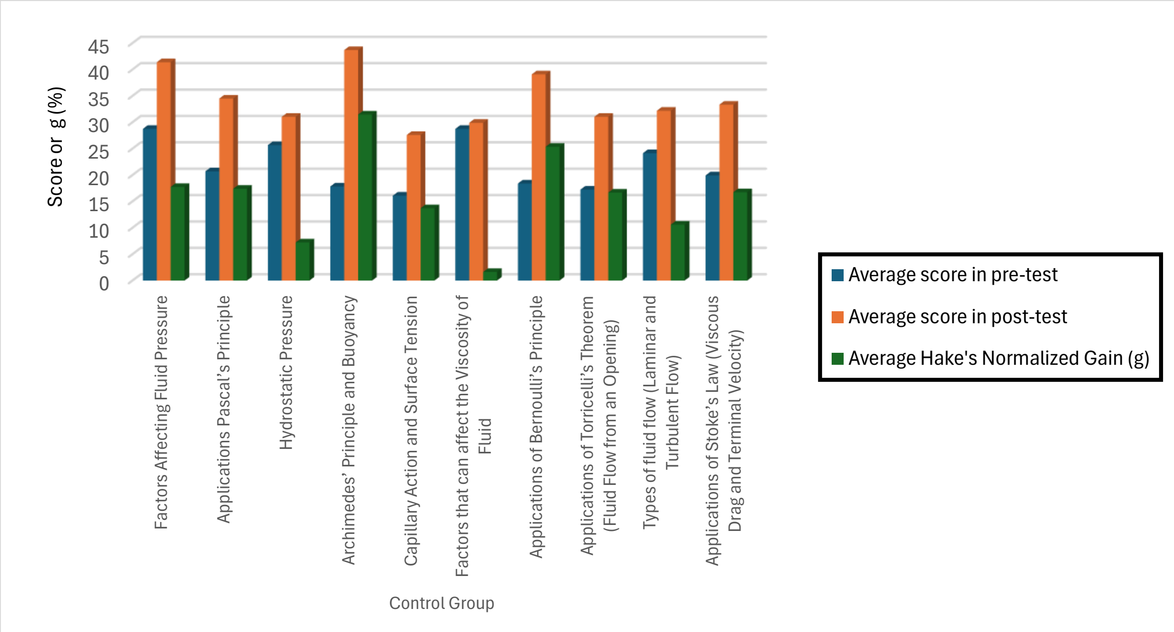
Group test	N	Minimum	Maximum	Mean	Std. Deviation
Control pre-test	87	4	14	8.85	2.855
Experimental pre-test	81	4	16	9.53	3.417
Control post-test	87	6	22	14.23	4.037
Experimental post-test	81	13	28	21.46	3.742

The analysis of the descriptive statistics in Table 1 showed that the difference in pre-test mean scores and standard deviations between the two groups was not significant according to the inferential statistics. The statistical test was performed using an independent samples t-test, and the alpha value was (α=0.162). On the other hand, the independent samples t-test performed on post-test scores shows that the difference in mean scores between the experimental and control groups of 7.23 is statistically significant, as there was a t-statistic of 12.009 with 166 degrees of freedom (df) and a significance value (Sig. 2-tailed) of 0.000. This significance value (also known as the p-value) is less than the typical significance threshold of 0.05, which shows a statistically significant difference between the two groups. Furthermore, the 95% confidence interval of the difference ranges from 8.415 to 6.039, suggesting that the true mean difference lies within this range with 95% probability.

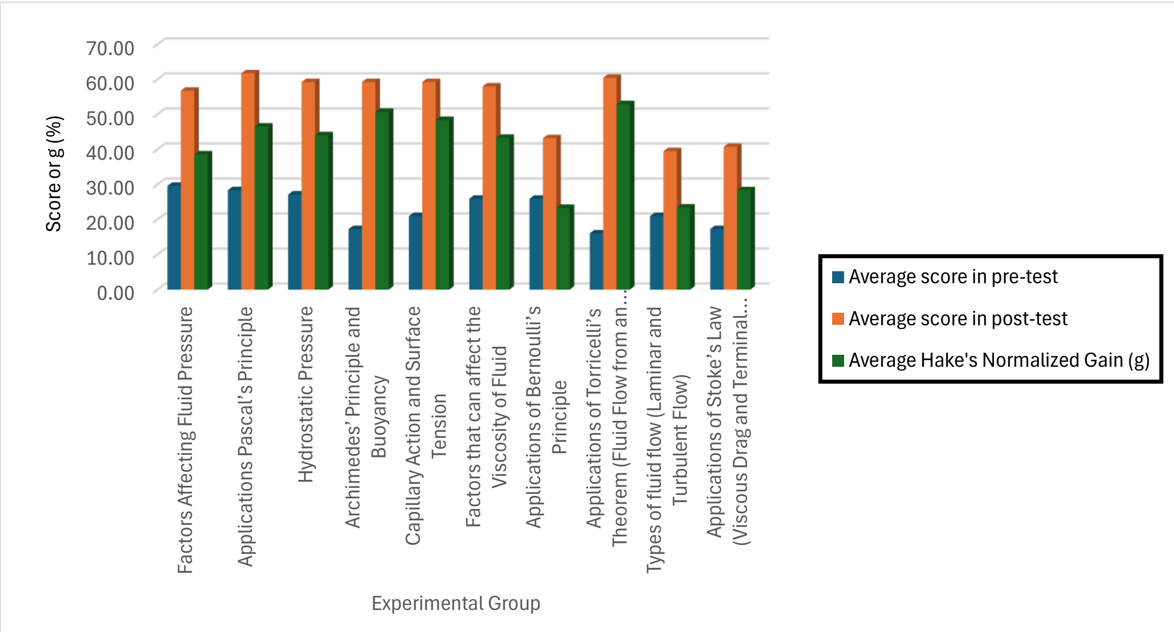
The statistically significant difference in improvement between the two groups suggests the experimental group's intervention has a positive effect on improving students' conceptual understanding compared to that of the control group. Similar results were found by Dewi *et al.* [31] and Thahir *et al.* [37] that the treatment group performed better than the control group. However, their studies involved a different intervention and classified students in four different categories according to their level of conceptual understanding (sound, partial, alternative, and no understanding). Also, better improvement was observed in the treatment group compared to that in the control group [23], but their study was conducted solely on fluid statics, not fluid mechanics as a whole. Furthermore, Samsudin *et al.* [17] found similar changes in conceptual understanding. However, their study involved a peer teaching model as a treatment technique for fluid dynamics rather than the whole branch of fluid mechanics.

The bar charts shown in Figure 2 represent the level of students' conceptual understanding in each topic area of fluid mechanics during the pre- and post-tests, showing correct responses in pre-test and post-test, and the average Hake's normalized gain [35]. The bar charts for the control group are shown in Figure 2(a), while those for the experimental group are shown in Figure 2(b). From Figure 2, it can be noted that at the beginning of instruction (blue bars on the left, for each topic area), both groups exhibited a significant lack of conceptual understanding of fluid mechanics concepts. It is evidenced by the consistently low percentage of correct responses for each topic, which is commonly less than 30% across both groups. This shows that all students from both groups had almost the same low level of conceptual understanding in almost all areas of fluid mechanics before any instruction. The figure also show that, after the post-test (represented by the orange bars in the middle, for each topic area), the average number of students who responded correctly in both groups increased for each area of fluid mechanics.

However, it is imperative to note that the average number of correct responses increased significantly for the experimental group (Figure 2(b)) compared to the control group (Figure 2(b)) in each area of fluid mechanics. It can be noted that the number of correct responses for each topic area in the control group is quite below 45% after the post-test (Figure 2(b)), while that for the experimental group is significantly higher than that percentage in the majority of areas (Figure 2(b)). For example, for the control group, in the area of "factors affecting fluid pressure", average percent scores of pre-test and post-test are respectively 28.74 and 41.38, and hence, the corresponding normalized learning gain is 17.74%. Similarly, for the experimental group, for the area of "factors affecting fluid pressure", the average pre- and post-test scores are 29.63 and 56.79, respectively. Applying (1), the corresponding normalized learning gain is 38.60%.



(a)



(b)

Figure 2. Bar charts for students' average scores per topic area with corresponding normalized learning gains for (a) the control group and (b) the experimental group

Following Hake [35], the normalized learning gain for each topic area (for both groups) was computed as in (1):

$$g = \frac{average\ posttest\ score(\%) - average\ pretest\ score(\%)}{100 - average\ pretest\ score(\%)} \quad (1)$$

It can be observed that the normalized learning gain, in percentage (green bars on the right, for each topic area), in the control group (Figure 2(a)), is below 20% in most of the areas, where the maximum learning gain of 31.5% occurred in the topic area of Archimedes' principle and buoyancy. The minimum learning gain (1.6%) of the control group occurred in the area of "factors that can affect the viscosity". The topics related to viscosity, types of fluid flow, and Reynolds number, have a variety of applications [7], [38]. Considering the difficulty of students in these topics and their wide applications, the physics teachers should rigorously discuss the related basic concepts, such as Reynolds number, its wide ranges, and relations with types of flow and different phenomena, with examples and applications [7], [38]. In the experimental group (Figure 2(b)), the majority of the values for the normalized learning gain are higher than 35%. For the experimental group, the maximum learning gain (close to 53%) occurred in the area of "applications of Torricelli's theorem", while the minimum learning gain (23%) occurred in the area of "applications of Bernoulli's principle". The differences between the control and experimental groups' post-test results in terms of the number of correct answers and normalized learning gains in each area of fluid mechanics clearly show a significant positive impact brought by the intervention applied to the experimental group.

3.2. Analysis using Hake's normalized learning gain in fluid mechanics

Using data in Table 1, the value of Hake's normalized learning gain, g, for the control group is 0.1727, while that for the experimental group is 0.3915. The normalized gain for the control group falls in the low category, while that for the experimental group falls in the medium effect size category [39]. The average of gains, $\bar{g}$ calculated from individual learning gains for each student, for the control group was found to be 0.1577, while that for the experimental group was 0.3863. The ratios of g and $\bar{g}$ values for the experimental group to the control group are, respectively, 2.2669 and 2.4496, which are very large, indicating that the intervention in the experimental group was more effective than the traditional teaching approach for the control group. It can be noted that for both groups, the values of $\bar{g}$ and g are very close ($\bar{g}$ being a little less than g). This indicates that, on average, the instruction helped to improve students in both groups with low as well as high scores in the pre-test, but students who had achieved lower scores on the pre-test made little more improvements in the post-test than the higher achievers in the pre-test [36].

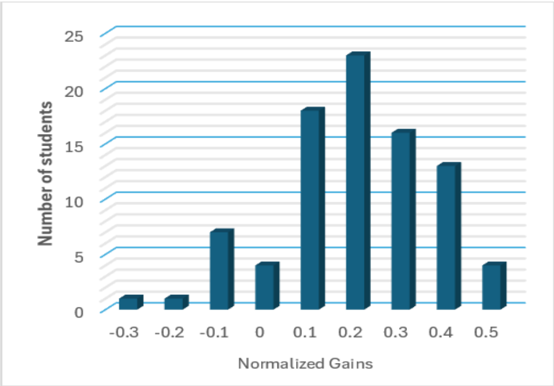
The distributions of the average normalized learning gains for both groups are illustrated in Figure 3, for the control group in Figure 3(a) and for the experimental group in Figure 3(b). The bar chart in Figure 3(a) reveals that the control group's highest frequent gain is close to 0.2, with a total of nine negative values, and four students' learning gains are equal to zero. This indicates that the majority of students in the control group experienced a low category of learning gain, for a few, no improvement, and for some, even a decline in conceptual understanding in fluid mechanics. The minimum learning gain in the control group is -0.33, while the maximum learning gain is 0.49. In contrast, as shown in Figure 3(b), the experimental group exhibits the highest frequency of learning gain, which is approximately 0.4, with all students experiencing positive learning gains, except one student who did not show any improvement after the intervention. The minimum learning gain in the experimental group is 0.00, while the maximum is 0.67. Figure 3 suggests strong evidence that the intervention applied to the experimental group was more effective in promoting individual student learning, which resulted in greater and more consistent improvements in conceptual understanding across different areas of fluid mechanics.

3.3. Cohen's *d* for the effect size of the observed difference between students' post-test scores

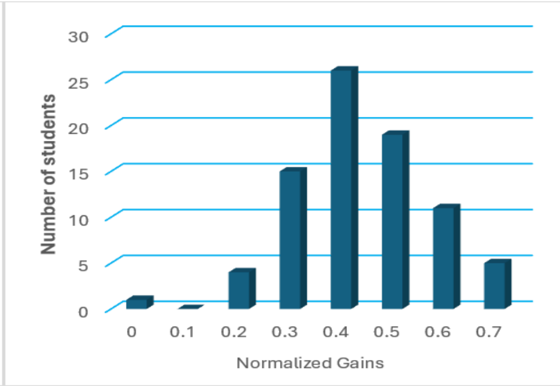
Using data from Table 1 and the equation suggested by Goulet-Pelletier and Cousineau [39], the value of Cohen's *d* for the post-test scores for the two groups was found to be 1.85, indicating a large effect size and a practically significant difference between the control and experimental groups' mean post-test scores. Figure 4 illustrates the interpretation of the effect size of 1.85 as automatically generated using the online tool for Cohen's *d* interpretation by Magnusson [40].

From Figure 4 (which can be regenerated from: https://rpsychologist.com/cohend/ by inserting 1.85 as the Cohen's *d*, with the control group on the left and experimental one on the right), the Cohen's *d* value of 1.85 indicates a large effect size, meaning that the treatment had a strong impact on students' conceptual understanding. Notably, 96.8% of students in the experimental group obtained higher scores than the control group's average score. Regardless of the applied intervention, 35.5% of the students in both groups scored comparable results on the test. However, the treatment group performed better. Additionally, the 90.5% probability of superiority means that if a student is randomly selected from each group, there is a 90.5% chance that the student from the experimental group will have a higher score. Moreover, to have one more favorable outcome in the experimental group compared to the control group, we need to treat 1.55 people on average. This provides strong evidence of the intervention's success.

Furthermore, Cohen's *d* for the pre- and post-tests of the experimental group is approximately 3.33, while that for the pre- and post-tests of the control group is approximately 1.54. It can be noted that Cohen's *d* for the experimental group is greater than that for the control group. More importantly, the ratio of Cohen's *d* for the experimental group to that for the control group is almost 2.16, which is also very large.



(a)



(b)

Figure 3. Distributions of students' average normalized learning gains for (a) control group and (b) experimental group

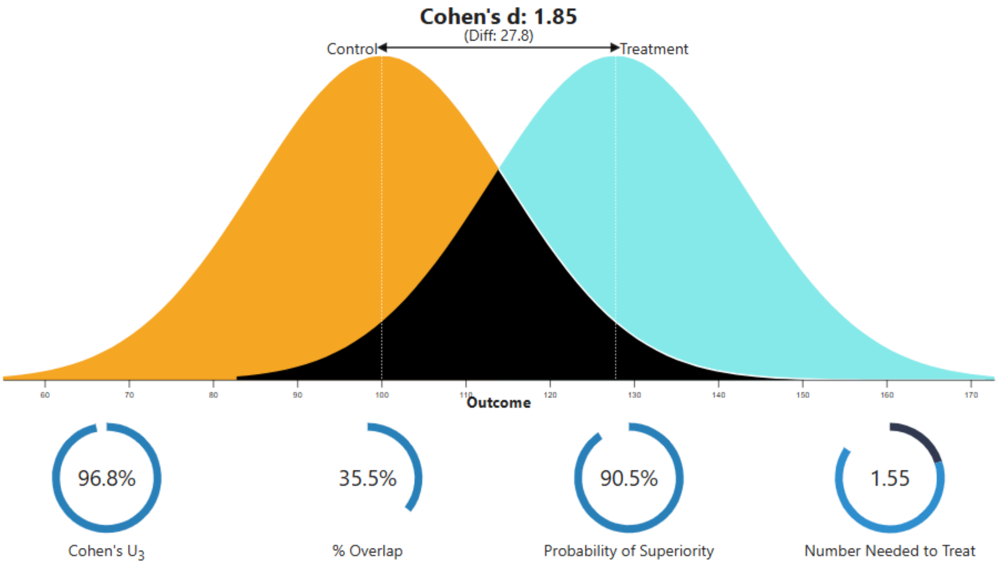


Figure 4. The probability density for the effect size of 1.85 as per Magnusson's online tool

3.4. Analysis using the normalized mean scores and normalized gain in terms of the standard deviation of the control group, and the quotient effect size

To further confirm that the observed changes were due to the applied intervention, we use the analysis of normalized mean scores and normalized gain in terms of the standard deviation of the control group in such a way that the standard deviation and the mean value of the scores of the control group in the pre-test are one and zero, respectively. This approach of measurement was used by Banerjee *et al.* [33] when the initial level of both groups was low. The normalized test score is calculated using (2):

$$Normalized\ test\ score = \frac{Test\ score - Mean\ pre-test\ score\ of\ the\ control\ group}{Standard\ deviation\ of\ the\ pre-test\ score\ of\ the\ control\ group} \quad (2)$$

It is found that after the intervention, the experimental group had a much higher normalized gain (4.179) than the control group (1.884). Most importantly, the ratio of the normalized gains (2.218) for the experimental to the control group and their difference (2.295) are very large [33] and indicate strong evidence for the positive impact of the intervention in enhancing the experimental group's learning compared to that of the control group, which followed the traditional methods.

Recently, Foster [34] has proposed another effect size, the so-called quotient effect size, q, for measuring the effectiveness of an intervention in an educational study. It is defined as the gain score (i.e., the score in the post-test minus the score in the pre-test) for the intervention group, divided by the gain score for the control group. Like Cohen's d and other normalized gains and effect sizes, q is also scale-free. Following Foster [34], we found $q = 2.10$, which is also very large and indicates an effective intervention for the experimental group compared to that for the control group.

Our findings are consistent with Mayer's cognitive theory of multimedia learning, which emphasizes the combination of both visual and auditory components in instructional activities. These activities enhance students' learning by reducing cognitive overload and promoting a deeper understanding of abstract concepts [41]. This is also in line with the fact that auditory and visual aids show promise in enhancing learners' conceptual learning through dynamic, engaging, and visual representations of abstract concepts [32]. The instruction with well-planned simulations and YouTube videos creates a conducive environment of learning, which is consistent with the constructivist view of instruction, which emphasizes the active learning process of learners who interact with a suitable environment and interpret information as per their prior understanding [9]. The findings of our study also agree with several works related to physics learning. For example, Banda and Nzabahimana [42] highlight that the reviewed literature strongly supports that PhET interactive simulations can greatly improve students' conceptual understanding of physics concepts and can be incorporated into various active teaching and learning methods. It is worth noting that these studies used PhET interactive simulations, leaving the educational YouTube videos behind.

Results similar to our findings were found by Wright *et al.* [19], that simulations can significantly enhance students' achievement of learning outcomes in a fluid mechanics course by integrating simulations into engineering courses. It is, however, worth noting that their study focused solely on interactive simulations in general, with no particular attention to PhET simulations or educational YouTube videos. A study conducted on the use of web-based recitation activities also showed an improvement in Indonesian students' conceptual understanding of fluid mechanics, and the students showed motivation towards this program [15]. A study by Neves [43] on the use of computational modeling in a Modellus environment for Portuguese students showed that they could meaningfully use these models and significantly improved the understanding of concepts related to hydrostatics, a sub-branch of fluid mechanics. Several studies conducted in Africa and Asia also demonstrated that incorporating computer simulations and videos, or only simulations, into learning and teaching improved students' academic performance in optics [25], electric circuits [44], and atomic physics and radioactivity [45].

The physics educators and curricula designers of polytechnic colleges are recommended to plan to use PhET simulations and YouTube videos in a systematic way for a long exposure for students. They should note that PhET simulations follow a layered approach that enables students at various levels to initially explore and develop a conceptual understanding using simplified equipment before progressing to the complexities found in real-world scenarios [46]. They should also note that getting an expertise in complex concepts and principles needs an effective organization of knowledge structures for their easy activation and their applications in a flexible way in different conditions and various contexts, which requires a long exposure of the learner. It is evident from different studies on the cognitive science of physics concepts and problem-solving [47], neural patterns of physics concepts [48], deep learning of neural networks [49], and the neuroscience of scientific concepts [50].

4. CONCLUSION

This study aimed to assess the effect of PhET simulations and YouTube videos on polytechnic students' conceptual understanding in fluid mechanics. To the best of the researchers' knowledge, there was no study conducted prior to this involving the same intervention and instructional resources. The study findings revealed that the experimental group showed far enhanced conceptual understanding in different areas of fluid mechanics compared to that of the control group. Researchers also compared the ratios of different measures (ratio of normalized gains for experimental and control groups and effect sizes using different approaches), which also show that the effect of the intervention for the experimental group is significantly larger compared to the traditional teaching approach for the control group. We compared our findings with some closely related studies on the use of technology-based intervention for the improvement of students' conceptual understanding in fluid mechanics, and also compared these findings with those concerning physics learning at international and national levels.

Despite the limitations due to the study's scope, particularly in terms of the sample size, the use of context-specific videos and simulations, this study significantly adds to expanding knowledge and research regarding the use of effective technology-aided pedagogical strategies in different areas of STEM education, particularly addressed to polytechnic college students. The study procedures and analysis techniques offer a promising direction for future research on interventions aimed at promoting a deeper students' conceptual understanding of fluid mechanics and related fields. This research emphasizes evidence-based, actionable recommendations for educational policy and practice. Particularly for science curriculum developers and physics teachers at polytechnic colleges and other technical and vocational education and training (TVET) institutions, we recommend that they highlight gaps in conceptual understanding and incorporate technology-enhanced instruction into the curricula. Physics teachers are particularly recommended to explicitly teach the concepts of fluid mechanics to their students by employing interactive and visualization tools and emphasizing conceptual problem-solving in fluid mechanics, providing them with long exposures in a flexible way in various contexts, and helping them to remedy their conceptual errors.

The level of conceptual understanding was measured at the level of each group (i.e., by considering the number of students who chose a particular option for a question for the experimental or the control group), in different areas of fluid mechanics. The future studies should use a large sample size and focus on an in-depth analysis of each student to gain more insights into the level of individual students' conceptual understanding of fluid mechanics concepts in all related topic areas, and hence classify the students according to different levels of conceptual understanding, such as those with sound understanding, partial understanding, and those with misconceptions. Future research should also focus on in-depth studies for the identification of students' learning barriers and alternative conceptions in fluid mechanics, using a large population of polytechnic colleges. Future studies should extend this study to other science subjects, such as chemistry and biology, by employing randomized controlled trials to test the efficacy of the approach.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Jean D'Amour Iradukunda	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
Lakhan Lal Yadav	✓	✓		✓						✓		✓	✓	

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

Ethical approval for the research was obtained from the Directorate of Research and Innovation Unit at UR-CE, and official permission for data collection was taken from the principals of the RP Colleges, whose students were involved in this study.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [JDI], upon reasonable request.

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BIOGRAPHIES OF AUTHORS

Jean D’Amour Iradukunda is a master’s degree holder in physics education from the African Centre of Excellence for Innovative Teaching and Learning of Mathematics and Science, based at the University of Rwanda-College of Education. He also holds a bachelor’s degree in physics education from the University of Rwanda-College of Education. He has been serving as an assistant lecturer of Physics at Rwanda Polytechnic-Ngoma College for over 6 years. His research interests lie in promoting interactive multimedia resources in teaching and learning physics. He can be contacted at email: ijdamour2015@gmail.com.

Lakhan Lal Yadav is associated with ACEITLMS, University of Rwanda-College of Education (UR-CE). He had been Head of the Department of Physics and Vice Dean of the Faculty of Science at Kigali Institute of Education, Director of Research, Innovation, and Postgraduate Studies at UR-CE, and Director of the ACEITLMS. He has published many research papers in the fields of Plasma Physics and Physics Education. He is the author/co-author of some modules for the Distance Training Program. The fields of his current interest are nonlinear phenomena in complex plasmas and science education. He can be contacted at email: yadavll@yahoo.com.