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Measuring Students' Engagement in Learning Volumes of Revolution when Using Advanced Visualization Media in an Active Learning Environment

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Abstract

The growing adoption of active learning strategies is changing teaching practices in many disciplines. In particular, mathematics instructors are increasingly using active learning methods to engage students in the classroom and reduce achievement gaps. In this study, the researchers present a pilot-study implementation of an active learning task in a Mathematics course. The task was modeled as a problem-solving group activity utilizing visualization systems in order to promote increased student engagement with relevant course content. The pilot study consisted of a one-group pre-test / post-test experimental design. To assess the effects of the activity, the team evaluated several engagement dependent variables, such as self-efficacy, perceived usefulness, effort regulation, and task-attraction. The students in the experimental group were then exposed to an independent variable, i.e. type of learning activities, with two levels of treatment, group-based visualization activity versus traditional classroom with a group-based activity. The visualization equipment used was an 18’ Hoylu^{TM} Huddlewall projection system designed to facilitate teams in performing design and problem-solving processes. The research team was able to collect data from 15 participants. The participants were students enrolled in a Calculus 2 class at CSU East Bay. A paired-samples T-Test was used to determine whether there was a statistically significant mean difference between the students’ self-efficacy, task attraction, perceived usefulness, and effort regulation when they participated in the visualization activity compared to a traditional classroom. The analysis of the results showed a significant difference between the students’ self-efficacy, task attraction, and perceived usefulness, but not for effort regulation. These results support the researchers’ initial hypothesis that such an activity would stimulate the students’ engagement. The significance of these results contributes to the growing research on the use of visualization media and active and group-based learning in Mathematics courses.

1. Introduction

The Department of Mathematics at the California State University is a Phase 2 partner in the Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL) project funded by the Association of Public and Land-grant Universities and the National Science Foundation. The SEMINAL project at CSU East Bay aims to encourage and support the coordinated use of active learning in Mathematics classes within the Science, Technology, Engineering, and Mathematics (STEM) pathway.

In the pursuit of these goals, the SEMINAL project at CSU East Bay has capitalized on a rich tradition of interdisciplinary collaboration within the University. In particular, during the grant-funded period, the Mathematics department has worked in close partnership with the Engineering department at CSU East Bay in order to utilize visualization, media, and collaborative technology tools available within the Automation and Visualization Lab (AVL). These tools have been leveraged in the design, implementation, and delivery of a novel, group-based active learning task aimed at Calculus 2 students. In a joint effort, members of the SEMINAL leadership team from these two departments have come together to create a classroom activity with the stated goal of helping improve students’ self-efficacy and effort regulation as it relates to course content. The design and execution of the group task have also aimed at maximizing student levels of perceived activity usefulness and task attraction during participation. With these goals in mind, the SEMINAL team at CSU East Bay developed statistical instruments which were used to track the students' relative changes in these four characteristics. The results from a preliminary data analysis are promising and point towards a robust, positive student impact in a subset of these four characteristics. If the data generated through future implementations of this activity provides further evidence of student benefit, this pedagogical approach could potentially be scaled by adapting the active learning task so it can be facilitated by instructors teaching in a typical physical classroom setup at CSU East Bay. Assessing the effectiveness of the developed tasks also helps create a feedback loop that will inform the design and future implementation of other active learning tasks developed at CSU East Bay.

2. Literature Review

2.1. Active Learning in Mathematics

Though active learning has no definite origin and no unanimously accepted definition, it has become synonymous with transforming students from mere passive receivers of information to engaged and analytical scholars [1]. Bonwell and Eison associated methods such as writing activities, presentations, and debates with the term "active learning" [1]. Each of these pedagogical techniques seeks to draw attention away from passive listening and redirect it towards active engagement. Popular implementations of active learning include, but are not limited to, "group problem-solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course designs" [2]. On the other hand, the work of Freeman et al. [2] has established that the inclusion of active learning techniques in STEM disciplines is associated with a statistically significant increase in examination performance and a decrease in course failure rates. Since STEM fields have historically struggled with low retention and success rates [2], active learning has been proposed as a means to shift pedagogy towards increased student achievement. In the case of Mathematics pedagogy, one effective active learning approach involves having the instructor demonstrate how an expert would solve a series of challenging problems and, after a short group discussion, having the students immediately work on a set of problems of similar type [3]. This type of active learning places emphasis on the cognitive apprenticeship practice in which students are all part of an instructional group that solves complex problems together [3]. Thus, leveraging the benefits of group-based active learning can be an effective way to increase student performance and to increase their engagement.

2.2. Group Problem-Based Learning

One facet of active learning that has received much attention is the concept of problem-based learning, which was shown by Schmidt et al. to increase pedagogical effectiveness [4]. Developed during the 1960s for the advancement of medical pedagogy, problem-based learning introduced the novel concept of active learning via small groups in order to facilitate "greater effectiveness for the acquisition of basic knowledge" [5]. According to Drăghicescu et al. [6], problem-based learning involves presenting students with problems designed to evoke critical thinking, planning, and communication. Problem-based learning encourages students to further involve themselves in the process of developing results, as it allows each other to be accountable and support when a road-block arises [6]. Steps such as the interpretation and researching of information yield an increase in critical and creative thinking [7]. One benefit of problem-based learning, as a pedagogical method, is that it can be applied to any discipline. In mathematics, students tend to have an outlook based solely on computation, focusing on obtaining an answer from an already given problem as opposed to heuristic educational development [8]. However, by using problem-based learning activities, students' focus can change from rote computation to heuristic educational development [8]. When problem-based learning is paired with visualization, Wang et al. [9] found that the learning process can be further enhanced. Visualization allows many critical thinking problems to be further understood by students as some problems can then be solved by leveraging spatial reasoning and geometric intuition.

2.3. Visualization and Media Learning

Constructivism epistemology [10], [11], has been the base for several learning theories like experiential learning [12], [13], situated learning [14], [15], constructionism learning [16], [17], and problem-based learning [4]. Such theories aim at engaging the learner in active learning environments where they gain knowledge and skills through carefully designed experiences. Because of the benefits of constructivist epistemology, instructors must make an effort to leverage the methods and tools developed by these theories. For example, in constructivism learning theories, visualization is an essential tool for students to learn in an active and engaging environment [18]. Card et al. [19] and Mazza [20] define visualization as the mental cognitive process that is supported through the interaction with various types of representations such as computer-generated visual data [21]. According to Kuljis et al. [22] visualization is a necessary tool and process for successful decision-making and problem-solving. Visualization has documented potential in various STEM disciplines to improve both problem-solving and knowledge retention [23]–[25]. Because of the value that visualization has in the learning process, there is research potential in investigating the impact that it has on mathematics education.

3. Research Goal and Question

In the literature review, the study's background was framed in the research areas of group problem-based, active, and media learning. Through this review, the authors identified a potential area of research. Furthermore, the research team is interested in evaluating the impact that the intersection between problem-based, active, and media learning can have in a classroom environment. Therefore the goal of this research study was to design, implement, and evaluate a group problem-based activity that included visualization and interactive media in a mathematics class. In particular, the team wanted to evaluate how the designed activity would support students' self-efficacy and effort regulation, perceived activity usefulness and task attraction, and their user-experience with the visualization system (dependent variables). To achieve the set goal, the team set the following research questions:

1. *Does participating in a group problem-based activity with visualization media yield higher students' self-efficacy in mathematics class when compared to a lecture with a group-based activity in a traditional classroom setting?*
2. *Does participating in a group problem-based activity with visualization media yield higher students' effort regulation in mathematics class when compared to a lecture with a group-based activity in a traditional classroom setting?*
3. *Is the students' perceived activity usefulness and task attraction higher in group problem-based activity with visualization media when compared to a lecture with a group-based activity in a traditional classroom setting?*
4. *Is the students' user-experience positive when using visualization media in a group problem-based activity?*

The first question will test for the null hypothesis that **(1) students' self-efficacy will be the same between the group problem-based activity and a lecture with a group-based activity in a traditional classroom setting**. The second question will test for the null hypothesis that **(1) students' effort regulation will be the same between the group problem-based activity and a lecture with a group-based activity in a traditional classroom setting**.

The third question will test for the null hypothesis that **(2) students' perceived activity usefulness and task attraction will be the same between the group problem-based activity and a lecture with a group-based activity in a traditional classroom setting.** In the last question, the researchers were interested in understanding if the students' user-experience was positive or negative, and therefore will be testing for a reported user-experience against a baseline set in the analysis section. The last hypothesis will test if the **(3) students' user-experience was neutral.**

4. Methodology

4.1. Participants

Participants were 20 undergraduate students attending a Calculus II class at CSU East Bay. The students were in their second or third year. IRB consent was given to the research team to collect and use the data by the participants.

4.2. Measurement Instrument

An assessment instrument was developed to evaluate a broad range of dependent variables necessary to answer the research questions. The instrument was developed by utilizing several validated questionnaire instruments. The total number of questions for the instrument was 20, 8 for self-efficacy, 3 for task attraction, 4 for perceived usefulness, 3 for user-experience, and 2 for effort regulation. The instrument was administered at the end of the different treatments. In addition to the following questions, the research team asked the participants for demographic information such as age, grade point average, gender, and current year of study.

The questions that measured the students' self-efficacy, perceived usefulness, and effort regulation were based on the instrument developed by Boekaerts [26] titled the OnLine Motivation Questionnaires. These instruments included questions such as: "*How do you feel just after finishing the activity?*; "*How well do you think you are at visualizing volumes of revolution?"; "How useful do you consider this activity (on volumes of revolution)?"*, "*How important do you find it to do well on volumes of revolution?";* etc.

In addition to the previous questions, to measure the students' perceived activity usefulness and task attraction the research team utilized question items based on the validated instrument Student Response to Instructional Practices (StRIP) developed by DeMonbrun et al. [27]. These instruments included questions such as: *"I tried my hardest to do a good job"; "I participated actively (or attempted to)"; "I saw the value in the activity",* and *"I felt the time used for the activity was beneficial"*.

Similar to the self-efficacy and effort regulation, the questions of the instrument for the user-experience when using the visualization media were based on the instrument developed by Boekaerts [26] the OnLine Motivation Questionnaires. The usability of the media was measured by asking the students to rate their experience in using the system elements (pens, patterned paper, and projection screens). These items included three questions: "*How engaging was the Smartboard equipment (pens, board, and special paper)*"; *"How easy was it to use the Smartboard equipment (pens, board, and special paper)?"*; and *"How was your overall experience with the Smartboard equipment (pens, board, and special paper)?"*.

4.3. Equipment

The participants in the experimental group were asked to use the Automation and Visualization Laboratory (AV Lab) from the School of Engineering. The AV Lab is equipped with a variety of visualization solutions, on the group or individual level. For large groups, the AV lab is equipped with an 18' Hoylu™ Huddlewall projection system designed to facilitate integrated and high-performing teams in performing design and problem-solving processes, see Fig. 1. For individuals and smaller groups, the AV lab is equipped with high definition virtual reality and augmented reality headsets, such as the Oculus Rift, HTC Vive, and HoloLens. The Hoylu™ Huddlewall is capable of projecting students' handwritten work. The system uses camera-enabled pens and paper with a pixelated pattern.

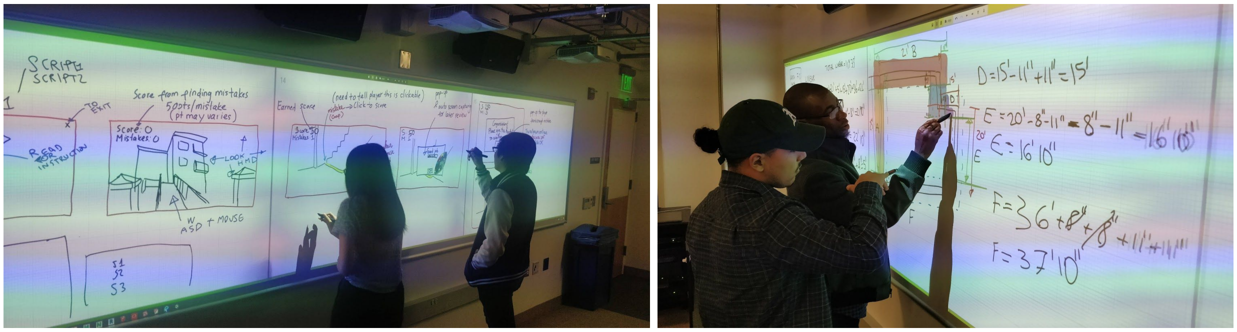

Figure 1: AV Lab's 18' Hoylu™ Huddlewall Projection System

4.4. Design and Procedure

The research group developed a pilot study to assess the impact that the activity had on mathematics students. The pilot study consisted of a one-group pre-test / post-test experimental design, which assessed the dependent variables described in the measurement instrument, see Fig. 2. This design method was selected to directly see the within-subject differences of the sample. Based on this design, 20 students from a Calculus II class of 40 students were randomly assigned to the experiment. The students that were not participating in the experiment were prompted to perform the group-based activity but with another instructor, in a traditional classroom setting, and without the aid of the Hoylu™ Huddlewall. The students in the experimental group were then exposed to an independent variable, i.e. type of learning activities, with two levels of treatment, visualization activity versus traditional classroom. The treatments were administered during the Calculus II class time with a day difference and at the same time. On the first day, the students got to listen to a lecture on the topics of volumes of revolution and solve problems with a group-based activity without visualization technology. The second day of the experiment, the students we prompted to participate in the group-based visualization activity. At the end of both treatments, the students were given time to complete the questionnaire of the measurement instrument. As mentioned in the measurement instrument, the study aimed at evaluating differences in self-efficacy and effort regulation, perceived activity usefulness, task attraction, and their user-experience with the visualization system. The dependent variables were compared in a paired-sample T-Test. The user-experience dependent variable was analyzed through a single-sample T-Test.

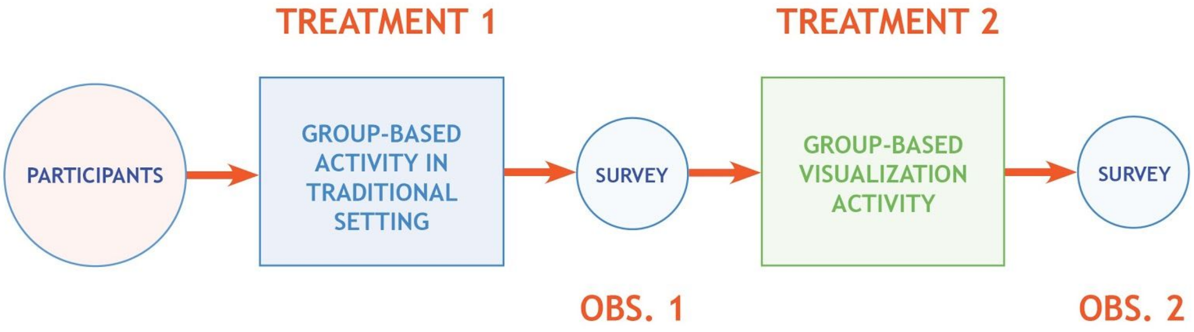

Figure 2. Experimental procedure

During the group-based visualization activity, the students in the experimental group were asked to group into fours, see Fig. 3. After the groups were made the students were trained on how to use the Hoylu™ Huddlewall pens. The groups were then given a refresher lecture of 10 minutes on the topics of volumes of revolutions, see Fig. 4. After the lecture, the groups were given activity packets with three problems on volumes of revolutions and they were asked to work together and set up the solution integrals, see Fig. 5. As they wrote on the activity packets their handwriting was projected on the Hoylu™ Huddlewall. Additionally, as the students were working on the activity they were shown on the Hoylu™ Huddlewall the 3D models of the problems. The students were given 45 minutes to set up the integral for the provided problems.

In the last part of the class time, the groups had to present the written solutions as they were projected on the Hoylu^{TM} Huddlewall, Fig. 6. As the groups were presenting, the instructor of the class added to the students' presentation as he/she saw fit. Before the class was dismissed the students had 10 minutes to complete the questionnaire described in section 4.2.

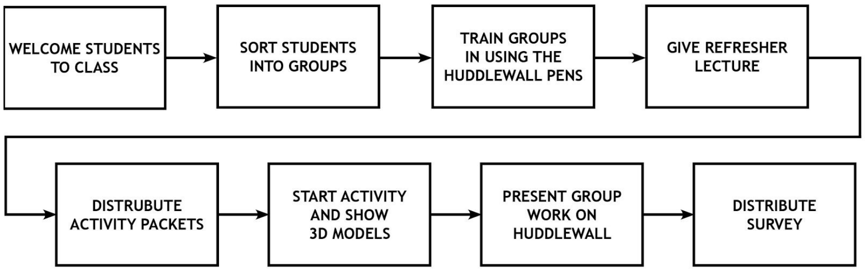

Figure 3. Group-based visualization activity procedure

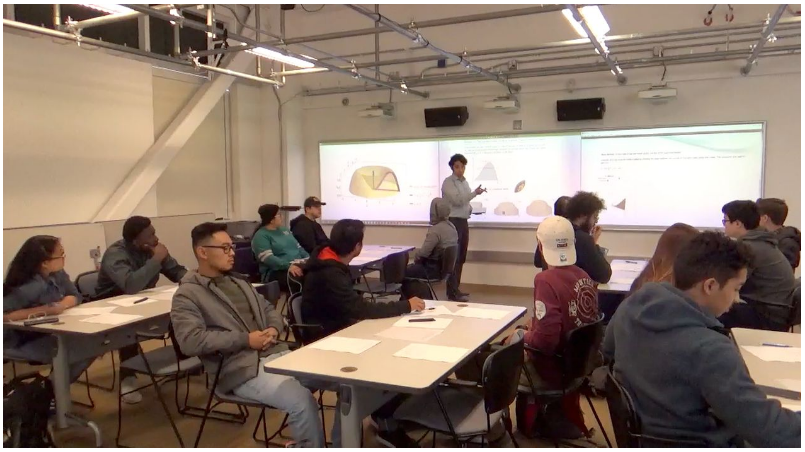

Figure 4. Refresher lecture with the volumes' 3D representation on the Huddlewall

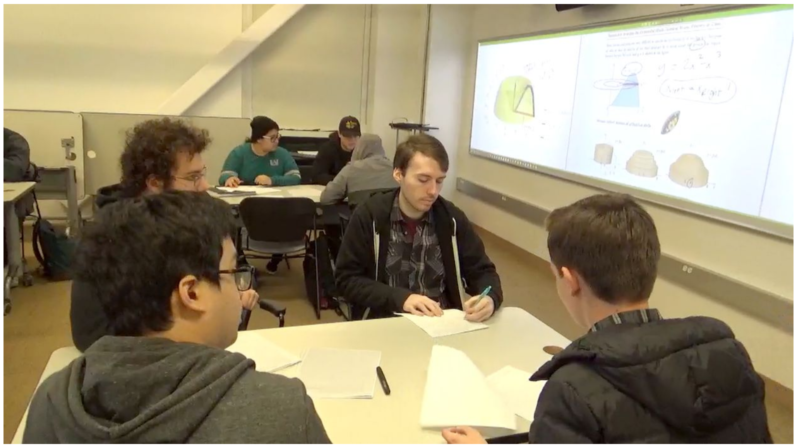

Figure 5. Students working in groups and using the Huddlewall's projection pens

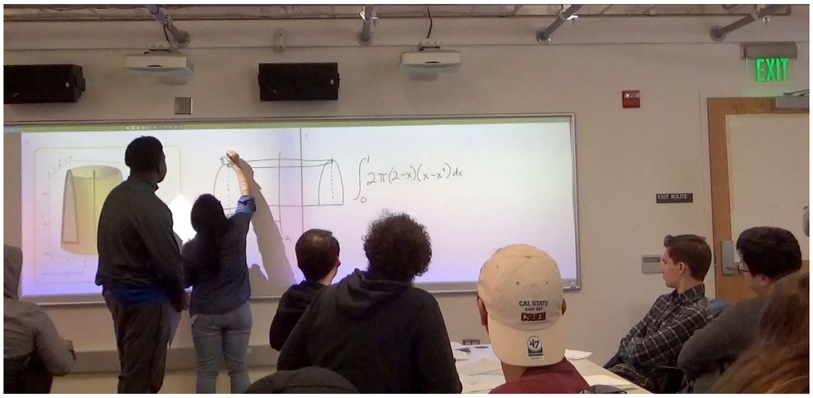

Figure 6. Students presenting their work on the Huddlewall

5. Results And Analysis

The research team was able to recruit 20 participants for the experiments, out of which 5 dropped out of the experiment. These participants were students registered to a section of Calculus 2 class at CSU East Bay. IRB consent was given to the research team to collect and use the data by participants. The participants included 12 self-identified males and 3 self-identified females. Only 10 reported their grade point average for an average of 3.61. The sample included 3 freshmen, 7 sophomores, 2 juniors, 2 seniors, and 1 graduate student, with a minimum value of 2.70 and a maximum value of 4.00. The average responses for the dependent variables were obtained by taking the average of the questions related to the dependent variable. The descriptive statistics of the students' responses can be found in Table 1 and a graphical representation of the results can be found in Fig. 7.

Table 1. Results from the Questionnaire

DEPENDENT VARIABLES	**N**	**MEAN**	**SD**	**MIN**	**MAX**
Self-Efficacy Post Lecture	15	3.3893	0.29288	2.93	3.86
Self-Efficacy Post Activity	15	3.6500	0.34684	3.14	4.29
Task Attraction Post Lecture	15	3.0660	0.64435	1.67	4.33
Task Attraction Post Activity	15	3.8887	0.65117	3.00	5.00
Perceived Usefulness Post Lecture	15	4.000	0.46291	3.00	5.00
Perceived Usefulness Post Activity	15	4.1441	0.67871	3.40	5.00
Effort Regulation Post Lecture	15	4.4667	0.58146	3.50	5
Effort Regulation Post Activity	15	4.3333	0.64550	3.50	5.00
User-Experience	15	4.4000	0.56625	3	5.00

A series of paired-samples T-Tests and one single-sample T-Test were used to determine whether there was a statistically significant mean difference between the students' self-efficacy, task attraction, perceived usefulness, and effort regulation when they participated in the visualization activity compared to a traditional classroom. Data are mean ± standard deviation unless otherwise stated. The outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of their values did not reveal them to be extreme and they were kept in the analysis. Furthermore, the team decided to keep the outliers as this is a pilot study. The assumption of normality was assessed by Shapiro-Wilk's test and they were violated ($p < 0.05$) for the self-efficacy, usefulness, effort regulation data from both the lecture and activity. The data was not modified to deal with the violation of normality as the paired-samples T-Test is fairly robust to deviations from normality.

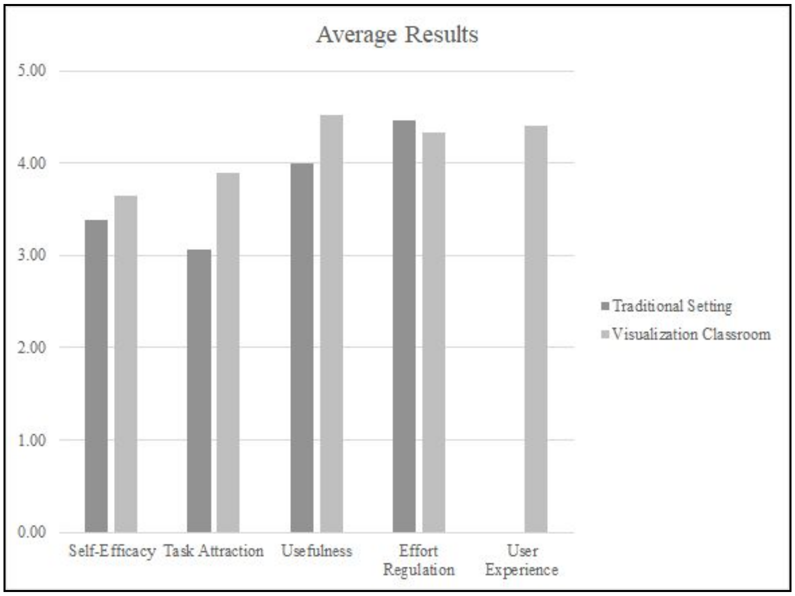

Figure 7. Average Results for the Visualization Activity and Lecture In Traditional Classroom Interventions

The first hypothesis stated: **students' self-efficacy will be the same between the group problem-based activity and a lecture in group-based activity in a traditional classroom setting.** Participants reported higher self-efficacy after participating in the visualization activity as opposed to the traditional classroom. A statistically significant increase was found for the self efficacy dependent variable (95% CI, $t_{\text{self-efficacy}}(14) = 2.425$, $p_{\text{self-efficacy}} = 0.029 < .05$, $d = 0.63$). The second hypothesis stated: **students' effort regulation will be the same between the group problem-based activity and a lecture in group-based activity in a traditional classroom setting.** The participants did not report higher effort regulation after participating in the activity as opposed to the traditional classroom. No statistically significant increase was found for the effort regulation dependent variables (95% CI, $t_{\text{effort}}(14) = 1.169$, $p_{\text{effort}} = 0.262 < .05$, $d = 0.3$).

The third hypothesis stated: **students' perceived activity usefulness and task attraction will be the same between the group problem-based activity and a lecture in group-based activity in a traditional classroom setting.** Participants reported higher task attraction and perceived usefulness after participating in the visualization activity as opposed to the traditional classroom. A statistically significant increase was found for the task attraction and perceived usefulness dependent variable (95% CI, $t_{\text{task-attraction}}(14) = 3.477$, $p_{\text{task-attraction}} = 0.004 < .05$, $d = 0.9$; 95% CI, $t_{\text{usefulness}}(14) = 3.841$, $p_{\text{usefulness}} = 0.002 < .05$, $d = 0.99$).

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The fourth hypothesis stated: **students' user-experience was neutral.** Participants reported a user-experience to be higher than the neutral score of 3. A statistically significant positive difference in the user-experience was found to be higher than a neutral score of 3 (95% CI, $t_{\text{user-experience}}(14) = 9.58$, $p_{\text{user-experience}} = 0.0001 < .05$).

6. Discussion and Conclusion

The growing implementation of active learning in STEM disciplines requires the design and development of educational experiences that engage and motivate students to learn. The literature illustrates that such experiences can be supported by the inclusion of group-based activities that integrate visualization learning mediums. To address this growing investigation, in this study, the researchers aimed at evaluating the impact of an active learning group-based experience that leveraged multimedia tools, such as large visualization systems. In particular, the team was interested in evaluating the impact of the activity on mathematics students' self-efficacy, task attraction, perceived usefulness, user-experience, and effort regulation. Based on the analysis results, the team was able to answer the questions set in the research goal section.

The analysis of the results showed a significant difference between the students' self-efficacy, task attraction, and perceived usefulness. They reported that their self-efficacy in developing the integrals for volumes of revolution was higher after participating in the visualization activity than when listening to a traditional classroom. Additionally, they found that the activity's attraction and usefulness were significantly higher than the lecture. This supports the researchers' hypothesis that such an activity would stimulate the students' learning. As the increase in students' self-efficacy is necessary to stimulate their engagement, motivation, and belief that they can be successful in performing and achieving the task at hand, all enhance the learning process. The results related to self-efficacy are further supported by the significant results of task attraction and perceived usefulness. The activity's interactive nature stimulated the students' desire to participate in the activity, which is essential to promote the learning process. Additionally, by designing an interactive and experiential activity, the students found the activity to be useful and of value, further increasing their motivation. The lack of significant differences in the students' effort regulation illustrates that the activity did not tax the students' efforts. These results could indicate that the students can be easily introduced to the activity without feeling overwhelmed by the new technology. This result is furthermore supported the students' positive user-experience with the technology.

The significance of these results contributes to the growing research on the use of visualization media and active and group-based learning. However, these pilot study results require further data before the research team can conclude that the activity that they design had a significant impact on the students' motivation and engagement. While the results illustrated a medium to large effect size, from Cohen's *d*, the collected data's sample size is still not large enough. Furthermore, this first pilot study is an initial step that provides a solid foundation for the research team to continue evaluating the impact of this activity. Lastly, as the team prepares to collect data to evaluate if students are meeting learning objectives, additional experimental procedures, such as mixed designs, will be developed to capture and mitigate for any order effects.

7. Acknowledgements

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