ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022

Paper ID #37572

Recommended Pedagogies to Achieve Fundamental Theorem Learning and Software Integration in Statistical Data Analysis Course (Work in Progress)

Tara L Ippolito

Mckenzie Landrum (Lecturer)

Austin Hayes

Sanaz Motamedi (Dr.)

Recommended Pedagogies to Achieve Fundamental Theorem Learning and Software Integration in Statistical Data Analysis Course

Abstract

This research aimed to explore different pedagogical methods for integrating software into engineering courses. This is a follow-up study to a preliminary study that was conducted during the previous semester on a quality control course. The preliminary study implemented two pedagogical methods: a traditional Instructor-Guided method and an active-learning Think-Pair-Share method. The study resulted in no statistically significant differences between the two methods. Therefore, for this study, we modified the traditional method, identified as Modified Instructor-Guided, and added two new active-learning methods, Flipped Classroom and Problem-Based Learning, in place of Think-Pair-Share. This study was conducted on an application focused statistics course, ESI3215C: Data Analysis for Industrial Applications. This is the first statistics course that students are required to take in the Industrial and Systems Engineering (ISE) program at the University of Florida. This course focuses on analysis of data encountered in ISE applications including system reliability, demand forecasting and inventory control, simulation, and quality control. Computational tools, specifically RStudio, are implemented to carry out various data analysis techniques. The first, modified pedagogical method is the Modified Instructor-Guided method in which the instructor conducts a cycle of mini-lectures and in-class exercises. The second pedagogical method is the Flipped Classroom method in which students watch short lecture videos before class and work in groups on in-class exercises. The third method is the Problem-Based Learning method in which the instructor presents a case study to be completed in groups to reach a solution, then conducts a mini-lecture at the conclusion of the case study. For each method, self-efficacy surveys and computational assessments were given to analyze student performance and comprehension. The results from this study indicate that Flipped Classroom and Modified Instructor-Guided outperform Problem-Based Learning in terms of computational understanding. However, Problem-Based Learning tends to result in higher RStudio self-efficacy, while Flipped Classroom tends to result in higher Theoretical and Statistical self-efficacy.

Introduction

With rapid changes in technology comes the increased need to integrate newly developed software programs into engineering education. It is critical for students to be exposed to software in order to be competitive in the job market and utilize it in their career. Programs, such as RStudio, are implemented in both classrooms and industry settings, and allow for problems to be solved more efficiently and reduce the possibility of computational errors.

Instructors are facing difficulties in finding the right balance and means of integration when introducing these technologies. It is important for instructors to focus on teaching the fundamental theories of the course, while using software as a means for efficiency and exposure to real-life applications. Currently, most engineering courses are still utilizing the traditional method of instruction, in which the instructor will use lectures to deliver the course material and assign practice problems for the students to complete outside of the classroom. A modified version of this pedagogy will be utilized as the control group for this research study, and it can be identified as the "Modified Instructor-Guided" method.

The traditional lecturing method tends to introduce software while students are still trying to grasp the theory, allowing the possibility for students to become dependent on it. If the instructor does not place high importance on understanding the theoretical concepts of the course, students are at risk for developing a weak theoretical foundation, which could negatively affect their performance in future courses and in their career. Students can memorize how to input data into the software, using it as a calculator to solve the problem for them, as opposed to fully understanding the mathematical methods behind the software and the values the program returns as a result. The goal of this study is to find a pedagogy that allows the instructor to introduce the material in a manner that does not lead to dependence.

To address this issue, different pedagogical methods have been identified to study in an engineering-based statistics course at the University of Florida (UF). In an effort to solidify students' theoretical foundation, we wanted to focus on selecting methods that provide students with sufficient exposure to solving both theoretical and software-based questions. At the conclusion of this study, we hope to find out whether different pedagogical methods impact student understanding and course perceptions.

Background

With the rise of technology in the engineering industry, software has been increasingly integrated into the engineering curriculum. Students are given a limited amount of time to learn important, and often, difficult theoretical concepts, while also using analytical thinking and problem-solving skills to develop software algorithms that are based on those theoretical concepts. When software provides more efficient problem-solving and reduces the possibility of computational errors, it becomes easier for students to rely heavily on the software to give them the correct answer, rather than having a deep understanding of the course material. With this in mind, the research question of this study is as follows:

- Which teaching method is most conducive for students to master the theory and be proficient with software?

Preliminary Study

A preliminary study was conducted in the Spring 2021 semester on an Industrial Quality Control course at UF. The results showed no statistical significance between the two methods that were implemented, which were a traditional lecture method, identified as the Instructor-Guided method, and the Think-Pair-Share method [1]. Even though there were no statistically significant differences between the two methods, it was found that the Think-Pair-Share Method resulted in slightly higher RStudio self-efficacy [1]. On the other hand, the results for the computational assessment presented a higher mean of correct answers for the Instructor-Guided method [1].

The literature review for the preliminary study primarily focused on how the use of calculators in high school mathematics courses affected student performance in introductory college calculus courses. Although learning software is more complex than learning how to operate a calculator, the risk of student dependence on calculators is still prominent. It was found that putting restrictions on calculator use for previous courses was positively correlated with student performance in future courses [2]. Therefore, we had reason to believe that applying restrictions to software in the form of course structure and teaching methods could result in a more balanced integration of software and theory. We want to find a teaching method that introduces the software at a specific point during the learning process that will not result in a dependency.

Due to varying results from the methods in the preliminary study, this literature review was focused on finding additional methods to implement in the classroom as well as updating the methodology of some of the current methods. We were particularly interested in studying Flipped Classroom and Problem-Based Learning, due to their learner-centered nature and ability to implement active-learning techniques. Creating a learner-centered environment was important for this study because it allows students to be more actively engaged in the learning process and develop higher-order thinking skills, such as analysis, evaluation, and creation [3]. We were also looking into how to modify the traditional Instructor-Guided method to incorporate aspects of mini-lectures to further break down how the material was delivered.

Modified Instructor-Guided Method

The Modified Instructor-Guided method was our control group for this study. But instead of implementing the traditional lecture method, where the in-class time is only spent on lecturing, we decided to modify it in a manner that allows more room for an active-learning experience. Baumgartner [4] recommended a laboratory-alternating approach that allowed for more frequent exposure to high-level concepts. This model was deemed most useful where the linkage between underlying theories and practical applications must be taught linearly, in other words, the concepts continuously build upon each other [4]. The original model consists of a cycle of mini-lectures and mini laboratory tasks. We decided to modify this model with in-class exercises replacing the lab tasks and, instead, having a singular, independent laboratory session.

Flipped Classroom Method

The Flipped Classroom (FC) approach is relatively standardized when applied in the classroom. It is characterized by short lecture videos that students watch before class and exercises or homework assignments to be done in class. The optimal video length for FC lecture videos was found to be approximately 10 minutes, but no longer than 20-30 minutes [5]. However, due to varying course difficulty and length, lecture videos can range from 5-15 minutes per individual concept [6, 7, 8, 9, 10]. In many cases, a pre-assessment quiz will be assigned to students to take after watching the lecture videos and before class [6, 7, 9, 11]. This is beneficial for the students to test their understanding of the material, and for the instructor, who can use this information to tailor the next class towards what students struggled most on [9, 11].

When it comes to comparing student achievement between traditional teaching methods and the Flipped Classroom method, there are some discrepancies. Some have found no statistically significant differences between the two methods; however, it has been found that with a FC methodology, there are fewer students with lower grades, and generally students obtain better grades when frequently attending laboratory sessions [8].

The success of FC tends to heavily rely on the course type. Courses that are more content-based, as opposed to design-based, have been found to perform better [11]. For example, when a FC method was applied to a high school advanced placement chemistry course, the flipped group scored higher on all assessments compared to the traditional method [9]. The Flipped Classroom method also develops life-long skills in students. When applied in a software engineering course, it was found that problem-solving ability was significantly higher for the Flipped Classroom than the traditional method [3].

Problem-Based Learning Method

Problem-Based Learning (PBL) has proven to be effective in many different engineering education environments due to its ability to expose students to large and complex problems that mirror problems they will likely face in their careers [12]. PBL is mostly characterized by its focus on collaboration and group work to solve a complex, open-ended problem. Typically, the instructor should develop the problem to be solved by all students. If students are allowed to choose their own topic, this would increase intrinsic motivation, but would make it difficult for the instructor to ensure consistent knowledge between all students [13].

When PBL was applied in an undergraduate electrical engineering course, it was found to result in significantly higher conceptual understanding compared to the traditional lecture method [14]. To ensure individual student participation, fairness, and accountability, many studies incorporated peer evaluations [15, 16]. PBL also has positive results on student perceptions. For example, when PBL was implemented on an Administration Theory course, students felt that PBL promoted their technical skills and attitudes [17]. In other studies, students have felt PBL fostered a productive learning environment, provided awareness of real-life problem types, and experienced an increase in motivation and personal satisfaction [16, 18].

Challenges

Although Flipped Classroom and PBL result in significant benefits for engineering students, there are challenges to implementing both methods. Both methods take more time on the instructor's end to implement than the traditional lecture method [17, 19]. Specifically, Flipped Classroom can produce a significant time constraint for instructors when developing and editing lecture videos [19]. The upside to this challenge is that after the first implementation, the FC videos and PBL problem can be re-used for future classes. Students also commonly face challenges with the flipped format of learning new material and not being able to ask questions during the lecture [9, 19]. This challenge can be mitigated by including a brief discussion at the beginning of class and answering any questions students have [6, 7, 20].

Methodology

Participants & Background

The participants of the study include the students registered for ESI3215C: Data Analysis for Industrial Applications course. This is a required course within the ISE curriculum at UF, and for some students, it may be their first course on statistics.

This research was conducted with Institutional Review Board (IRB) approval under IRB202003092. As this research is included as part of the normal course delivery, the only portion of this research requiring consent from the students was direct quotations or direct answers. There were 59 students in the course who agreed to allow for direct quotations to be included in this paper. However, there were 70 students total who responded to the Background Survey. Of these students, 50% were male and 50% were female. Figure 1 below shows the ethnic makeup of the sample.

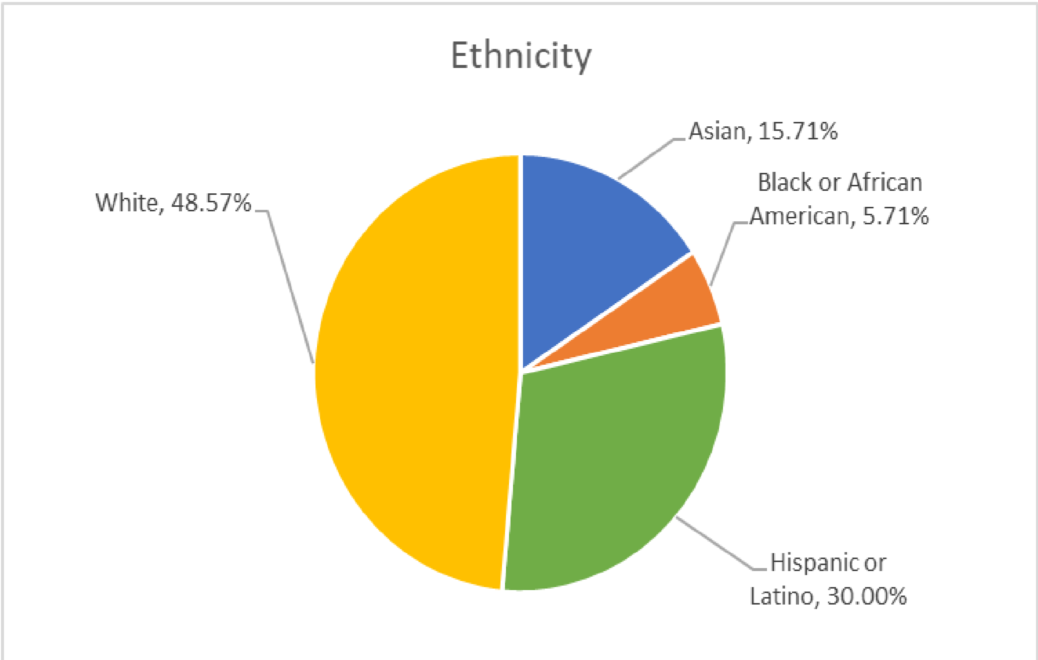

Figure 1: Ethnic Makeup of Sample

The majority of participants were juniors in college (78.57%), 17.14% were seniors, and 4.29% were sophomores. 88.57% of students attended high school in the United States and 11.43% attended high school in another country. While in high school, 47.14% took a statistics course and 52.86% did not.

There are no statistics prerequisite courses for this course, yet 42.66% of students have previously taken a statistics course in college and 57.33% have not. This is most likely due to a curriculum change and may not be the case for future studies. Figure 2 below shows the self-reported average grade in the students' previous statistics courses.

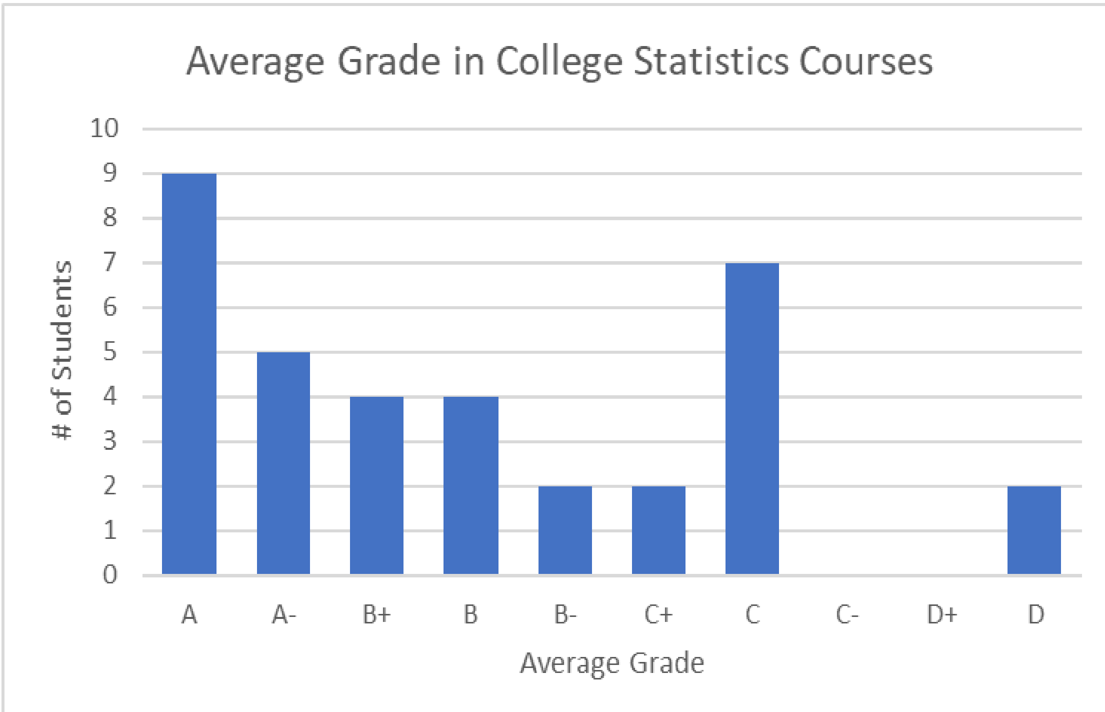

Figure 2: Self-Reported Average Grade in College Statistics Courses

Before this course, 90% of students had no previous experience with RStudio, 8.57% had minor experience, and only 1.43% had significant experience. Furthermore, 91.43% of students had no internship experience applying the topics taught in this course, but 64.29% plan to in the future or during their career.

Course Overview

The course we decided to focus on for this study is an introductory applications-based statistics course. It is a foundational statistics course that includes heavy theoretical concepts as well as the use of the software RStudio. The class meets three times a week. Two of the sessions are 100 minutes long, while the third session is 50 minutes long. Of the weekly class time, approximately four hours are spent on instruction and approximately one hour is reserved for a lab session. Due to COVID-19, this course was delivered in a HyFlex format, meaning in-person attendance was optional. Students could choose to watch the class live online or watch a recording later. If students choose to not attend class or the lab session, there is no penalty to their grade.

Success in this course is not only necessary for future courses within the curriculum, but it is also necessary within the ISE industry. Statistics can aid manufacturing companies in making better informed decisions that are backed by data as opposed to guesswork. It is crucial for students to have a solid foundation of the topics in this course while also having confidence that they can apply these topics in RStudio. Given these characteristics, this was an ideal course to utilize for data collection. In particular, the research focused on topics related to Statistical Intervals, Hypothesis Testing, and Statistical Inference with Two Samples.

The topics discussed in Statistical Intervals include confidence intervals on the mean of normal distribution, confidence intervals on variance and standard deviation of normal distribution, confidence intervals on population proportion, prediction intervals for future observation, and tolerance intervals for normal population. This topic also teaches students the difference between one-sided and two-sided confidence bounds, the t distribution, and how to calculate and make decisions regarding sample size. This chapter takes approximately 4 hours (2 days) to teach in the classroom.

The topics discussed in Hypothesis Testing include hypothesis testing on means of normal distribution, tests on the variance and standard deviation of normal distribution, tests on population proportion, goodness of fit tests, and calculating p-values. This topic also teaches students how to compute probability of type I and type II errors, the difference between one-sided and two-sided hypothesis tests, and the connection between confidence intervals and hypothesis testing. This chapter takes approximately 5 hours (3 days) to implement in the classroom.

Statistical Inference of Two Samples discusses topics related to inference on the difference of means of two normal distributions, nonparametric tests on the difference of two means, paired t-tests, inference of variance of two normal populations, and inference on two population proportions. Along with these topics, students should be able to compute power, type II error probability, and make sample size decisions for two sample tests on means, variances, and proportions. This chapter takes approximately 5 hours (3 days) to implement in the classroom.

Teaching Methods

The purpose of this research is to identify whether the mode of instruction affects student understanding of the course material and whether one method in particular helps reduce dependency on software programs. All students in the study were exposed to the same methods for the same chapter, and all chapters were taught by the same instructor.

We are implementing three pedagogical methods that were randomly assigned to three chapters within the course. Statistical Intervals was taught using Flipped Classroom, Hypothesis Testing was taught using Modified Instructor-Guided, and Statistical Inference of Two Samples was taught using Problem-Based Learning. The basics of RStudio were taught at the beginning of the course and for each method a brief, high-level overview of the necessary functions was given by the instructor as well as direction to additional resources.

- **Flipped Classroom:** Students watch short lecture videos that are broken down by topic and take a brief pre-assessment quiz before class on what was covered in the videos. The pre-assessment quiz had a low-risk effect on the students' grade and the goal of the quiz is so the instructor could use the results to tailor the first 10-15 minutes of class to discuss the topics students seemed to struggle with. For the rest of class, students worked in groups or individually on a set of theoretical practice problems meant to be solved by hand. Students will then solve the same problems from class as their homework assignment, but in RStudio.

- **Modified Instructor-Guided:** This is a modified version of the traditional lecture method. This method includes a cycle of mini-lectures, theoretical in-class exercises solved manually, and then a wrap-up discussion. The same in-class exercises will then be solved as a homework assignment in RStudio. The timing of this method is shown in Table 1 below.

Table 1: Timing for Modified Instructor-Guided Method

Introduction lecture	20 mins
Mini-lecture on specific theory/concept	15 mins
In-class exercise	15-20 mins
Wrap-up discussion	5 mins

- **Problem-Based Learning:** The first 25 minutes of class will be spent presenting a complex case study requiring RStudio and answering any clarification questions the students may have. In the subsequent class time, students will work in pre-assigned groups of three to develop the knowledge necessary to reach a solution. Including the introduction lecture, the students will have two additional class days to work on the case study. In addition to submitting a solution, groups will also submit peer evaluations. The last class will include a 25-minute mini-lecture which briefly covers the main topics of the problem.

A conceptual flowchart visualizing the overall methodology of this study and each teaching method can be seen in Figure 3. Because this is an overall methodology, the sequence of implementation may vary.

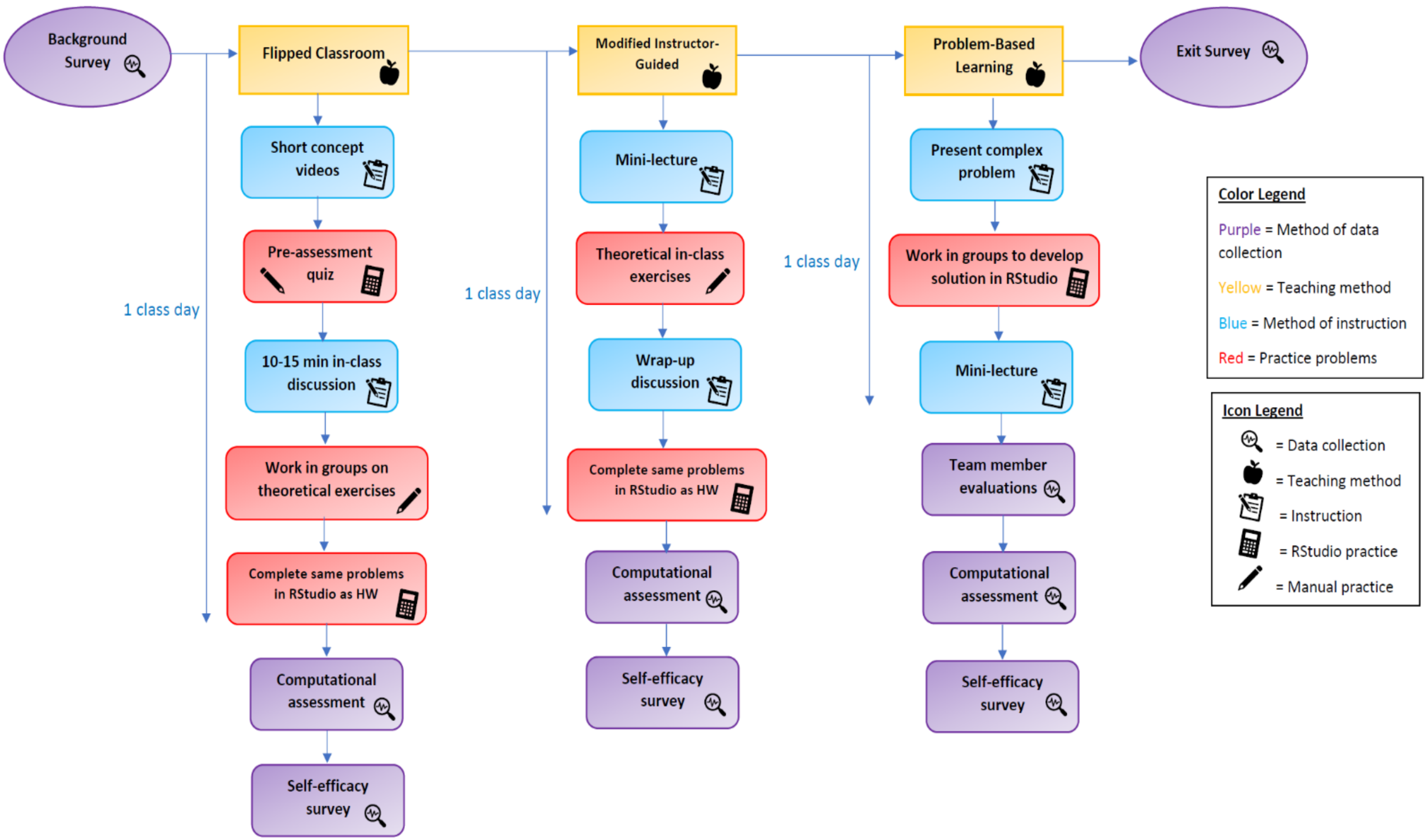

Figure 3: Methodology Flowchart

Data Collection Tools

This research implements five types of data collection tools. A background survey was used to collect identifying characteristics of the research participants, a self-efficacy survey to examine student confidence for each chapter and how it changes across teaching methods, a computational assessment that analyzes student understanding and performance in the course, an exit survey to gauge students' experience with changing modalities, and active measures to gauge student participation.

1. **Background Survey:** The background survey asked the participants for their name and other identifying characteristics, such as gender and ethnicity. This survey was used to gauge the participants' experience with statistics and RStudio, and whether they have previously or in the future, plan to explore job opportunities related to this course.

2. **Self-Efficacy Survey:** The self-efficacy survey targeted student confidence on three aspects of the course: *Statistics*, *RStudio*, and *Theory*. Because this is a foundational statistics course, it is crucial to measure how well students are understanding the statistics concepts, and because the goal of the study is to compare theoretical and software understanding across different teaching methods, it is important to measure students' confidence for each.

    a. **Statistics Self-Efficacy:** The survey asked questions gauging the student's comfort level with statistics and whether they are interested in learning more about the topic or pursuing it in their career.

    b. **RStudio Self-Efficacy:** The survey asked questions related to the student's confidence with working in RStudio. The questions include whether the student can write syntactically correct statements, understand, identify, and correct errors, correctly interpret output, and understand basic problem-solving approaches within RStudio.

    c. **Theory Self-Efficacy:** Separate from Statistical self-efficacy, this survey asked questions related to students' confidence with specific theoretical topics from each chapter. The questions involved statements such as how confident the students feel they can learn the material related to that topic, whether they are interested in or have enjoyed studying the topic, and whether they are able to identify different problem types.

The self-efficacy survey contains 13 content-related statements, all with a 5-point Likert scale with one being "strongly disagree" and five being "strongly agree." The statements have not been modified since the preliminary study and were adapted from multiple sources.

Table 2: Survey Statements by Question Type

Question Type	Statement	Reference
Statistics	I can learn the statements taught in my statistics course.	[1]
	I am interested in learning new topics in statistics related to ISE.	[1]
	I have enjoyed studying statistics in school.	[21]
RStudio	I like trying to solve new problems related to … in R.	[21]
	I can write syntactically correct statements in R.	[22]
	I can identify and correct errors in my R code.	[1]
	I am confident I can explain how to approach ... problems in R to my classmates.	[23]
	I can correctly interpret the outputs of my code in R.	[1]
	The use of R helped my understanding of …	[24]
Theory	I can learn the content related to …	[25]
	I am interested to learn more about …	[1]
	I have enjoyed studying …	[21]
	I can identify when a problem requires the use of ...	[1]
	I like trying to solve new problems related to … by hand.	[21]

3. **Computational Assessment:** The computational assessments were aimed at testing student understanding after they have been taught the theoretical material and have had practice in RStudio. The assessment focuses on two question types: *Theoretical* and *RStudio*. There are seven questions total: three are theoretical-based questions that must be solved manually, three must be solved in RStudio, and the last question asks the students how they felt about the mode of instruction.

Table 3: Distribution of Computational Assessment Question Types

Question #	Flipped Classroom	Modified Instructor-Guided	PBL
1	Theoretical	Theoretical	Theoretical
2	RStudio	Theoretical	Theoretical
3	Theoretical	RStudio	RStudio
4	RStudio	Theoretical	Theoretical
5	Theoretical	RStudio	RStudio
6	RStudio	RStudio	RStudio

4. **Exit Survey:** At the end of the course, an exit survey was given to the students to inquire about the teaching methods implemented and the changing modality of the course throughout the semester. This survey consisted of 17 questions gauging which teaching method and chapter the students preferred most and whether the students feel

that changing modalities of instruction impacted their experience or understanding of the material within the course.

5. **Active Measures:** Due to the course being delivered in a HyFlex format, there is no grade penalty for students who do not attend class. Therefore, it is crucial to measure whether students are actively participating in the teaching methods being implemented. For the Flipped Classroom method, we monitored the number of students who completed the Pre-Assessment Quiz after watching the lecture videos. For the Problem-Based Learning method, we assigned a peer evaluation to be completed after the case study.

Data Collection Procedure

Randomized and unique identifiers were utilized to maintain confidentiality of the survey and assessment results. This identifier remained constant throughout the semester and for each survey/assessment. With IRB approval, the instructor of the course, who is also a part of the research team, is the only member who had access to the survey results and assigned random identifiers to each student before distributing the results to the rest of the team.

Data was collected at multiple points throughout the semester. Students take a Self-Efficacy Survey and Computational Assessment for each chapter a different teaching method is implemented, which totals three times throughout the semester. The survey and assessment for each chapter were taken at the same time at the end of each chapter. The Background and Exit Survey were both distributed after all teaching methods had been implemented. The main goal of the Background Survey was to gauge student experience prior to the course, while the Exit Survey was to gauge student experience at the conclusion of the course.

Results

For this study, we analyzed five types of data. The first dataset was the Background Survey. The second dataset consisted of the Pre-Assessment Quiz implemented in the Flipped Classroom method. The third dataset focused on students' conceptual understanding of each chapter under each teaching method and was collected through computational assessments. The fourth dataset focused on students' self-efficacy that was broken down into three sections: *Statistics*, *RStudio*, and *Theory* and was collected through self-efficacy surveys. The fifth and final set of data was the Exit Survey that focused on gauging student perception of each teaching method, the chapters they were applied to, and the overall experience switching teaching methods throughout the semester.

Computational Data Analysis

The first part of our data analysis was to analyze the correctness of the Computational Assessments for each method and the Pre-Assessment Quiz for the FC method. For each method, a computational assessment was given at the conclusion of the chapter. Each assessment consisted of six questions, three were theory-based and three were RStudio-based. The Flipped Classroom method had an additional assessment, the Pre-Assessment Quiz, and was taken after watching the lecture videos and before class. Once this was completed, we calculated the average number of questions each student got correct under each method.

A. Flipped Classroom Method

a. **Pre-Assessment Quiz:** The pre-assessment quiz was completed by 75 students. This assessment offered partial credit, so the student could receive a score anywhere between a 0, a 0.5, and a 1 for each question. On average, students got 5.62 out of the 6 questions correct, which corresponds to a 93.6%. Figure 4 shows the percent of students who received a certain number of points on the pre-assessment quiz. As shown in the figure, 62.67% of students answered all 6 questions correctly.

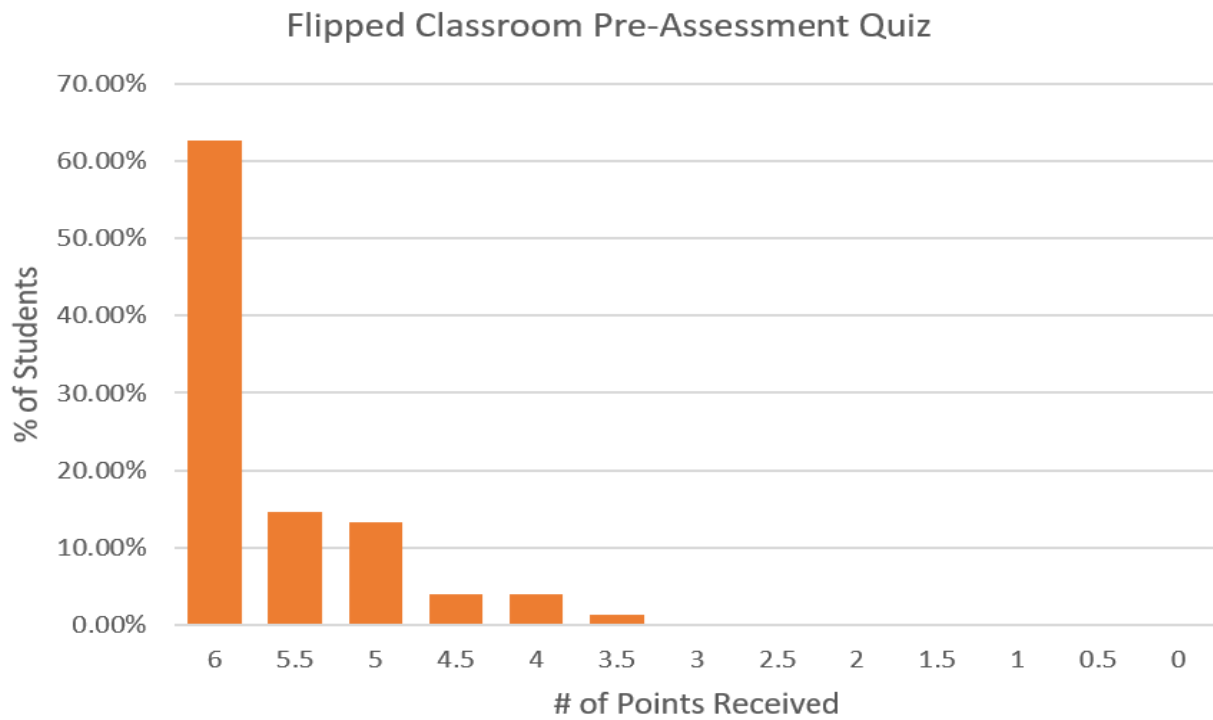

Figure 4: Flipped Classroom Pre-Assessment Quiz Results

b. **Computational Assessment:** The assessment for FC was completed by 75 students. For scoring, if the question was answered correctly, the student received a 1 and if it was answered incorrectly, the student received a 0. On average, students got 3.44 out of the 6 questions correct. Figure 5 shows the percent of students that got a specific number of questions correct. From the figure, 4% of students got 0 questions correct and 13.33% of students got all 6 questions correct.

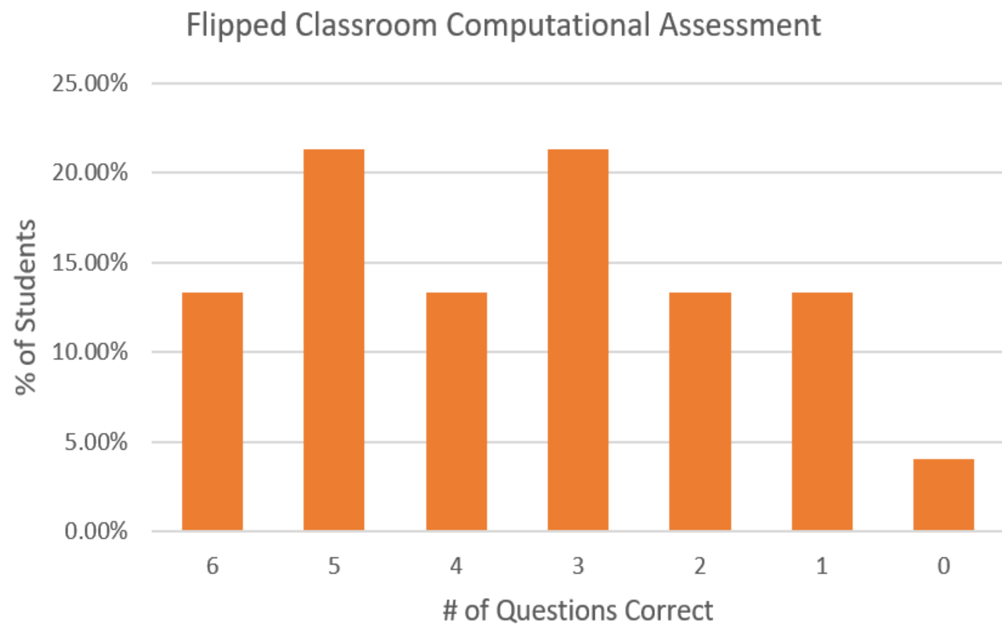

Figure 5: Flipped Classroom Computational Assessment Results

B. **Modified Instructor-Guided Method:** The assessment for the Modified Instructor-Guided method was completed by 70 students. On average, students got 3.85 out of the 6 questions correct. Figure 6 shows the percent of students that got a specific number of questions correct. From the figure, 17.14% of students got all 6 questions correct, 2.86% got 0 questions correct, and the majority, at 30%, got 3 questions correct.

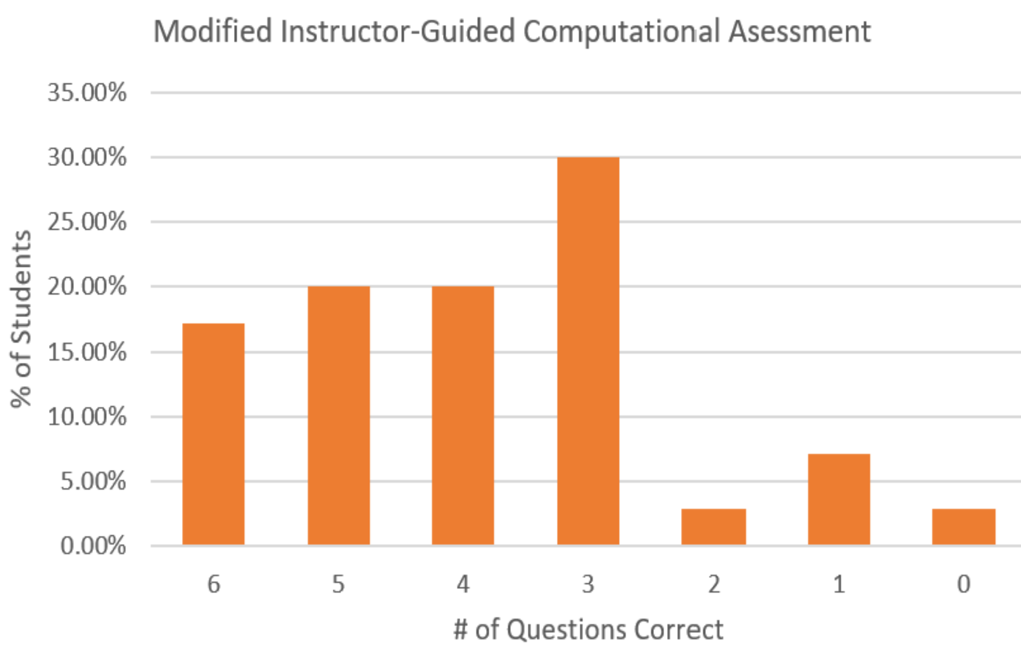

Figure 6: Modified Instructor-Guided Computational Assessment Results

C. **Problem-Based Learning Method:** The assessment for the PBL method was completed by 66 students. On average, students got 2.02 out of the 6 questions correct. Figure 7 shows the percent of students that got a specific number of questions correct. From the figure, 1.52% of students (one student) got all 6 questions correct, 18.18% got 0 questions correct, and the majority, at 25.76%, got 2 questions correct.

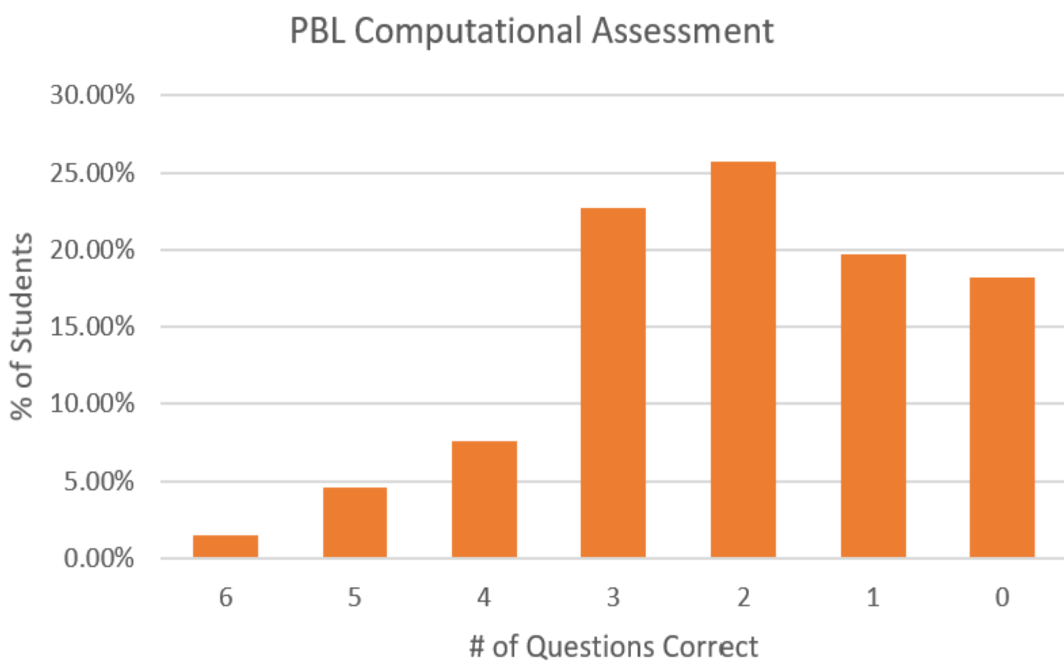

Figure 7: PBL Computational Assessment Results

Computational Comparison

Each computational assessment was composed of Theoretical and RStudio questions. For each method, we ran paired t-tests on the theoretical questions, the RStudio questions, and the overall assessment. The results from the analysis of the difference in means between the Flipped Classroom method, Modified Instructor-Guided method, and PBL method can be seen in Tables 4-6 below. Nine separate analyses were done to analyze the results for Theory, RStudio, and a combination of both between each of the three methods. The test statistic (t_0) and p-value were calculated using the RStudio software. We used a significance p-value of 0.05 to determine whether there were any statistically significant differences in means.

As seen in Table 4 below, comparing Flipped Classroom and Modified Instructor-Guided, there was a statistically significant difference in means for Theory, but not for RStudio or Combined.

Table 4: Results of Inference for a Difference in Means Between Flipped Classroom and Modified Instructor-Guided

	Analysis					
	Theory		RStudio		Combined	
	Flipped Classroom	Modified Instructor-Guided	Flipped Classroom	Modified Instructor-Guided	Flipped Classroom	Modified Instructor-Guided
n	75	70	75	70	75	70
mu	0.5467	0.6619	0.6000	0.6238	0.5733	0.6429
sigma	0.3225	0.3185	0.3635	0.3256	0.2916	0.2590
t_0	-2.1630		-0.4144		-1.5140	
p-value	0.0322		0.6792		0.1322	

As seen in Table 5 below, comparing Flipped Classroom and Problem-Based Learning, there was a statistically significant difference in means for Theory, RStudio, and Combined. All three favored Flipped Classroom over PBL.

Table 5: Results of Inference for a Difference in Means Between Flipped Classroom and Problem-Based Learning

	Analysis					
	Theory		RStudio		Combined	
	Flipped Classroom	PBL	Flipped Classroom	PBL	Flipped Classroom	PBL
n	75	66	75	66	75	66
mu	0.5467	0.2727	0.6000	0.3990	0.5733	0.3359
sigma	0.3225	0.2737	0.3635	0.3319	0.2916	0.2437
t_0	5.3982		0.4750		0.8530	
p-value	2.8308E-07		0.000845		6.7789E-07	

As seen in Table 6 below, comparing Modified Instructor-Guided and Problem-Based Learning, there was a statistically significant difference in means for Theory, RStudio, and Combined. All three favored Modified Instructor-Guided over PBL.

Table 6: Results of Inference for a Difference in Means Between Modified Instructor-Guided and Problem-Based Learning

	Analysis					
	Theory		RStudio		Combined	
	Modified Instructor-Guided	PBL	Modified Instructor-Guided	PBL	Modified Instructor-Guided	PBL
n	70	66	70	66	70	66
mu	0.6619	0.2727	0.6238	0.3990	0.6429	0.3359
sigma	0.3185	0.2737	0.3256	0.3319	0.2590	0.2437
t_0	7.6222		3.9867		7.1096	
p-value	4.0759E-12		0.00011		6.2749E-11	

Self-Efficacy Analysis

A. **Statistics Self-Efficacy:** We assessed statistics self-efficacy with three statements. As shown in Figure 8 below, students were most confident in their ability to learn statistics and were most interested in learning new topics with the Flipped Classroom method. However, students enjoyed studying statistics most with the PBL method.

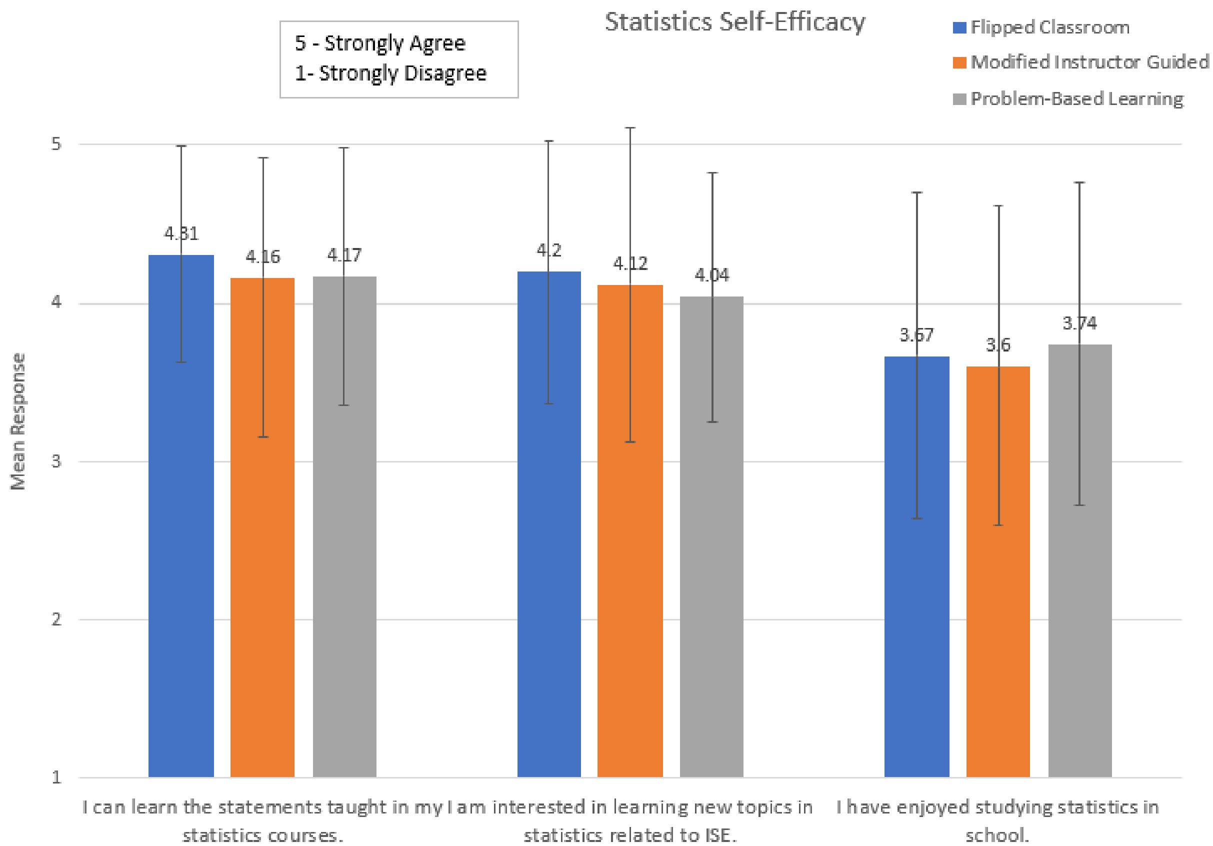

Figure 8: Statistics Self-Efficacy Survey Results

B. RStudio Self-Efficacy: We assessed RStudio self-efficacy with seven statements. The statements were tailored to the topics learned in each chapter. The topic specific aspects of each question have been removed from the analysis. From figure 9, students felt most confident using RStudio with the PBL method and they felt least confident using RStudio with the Flipped Classroom method.

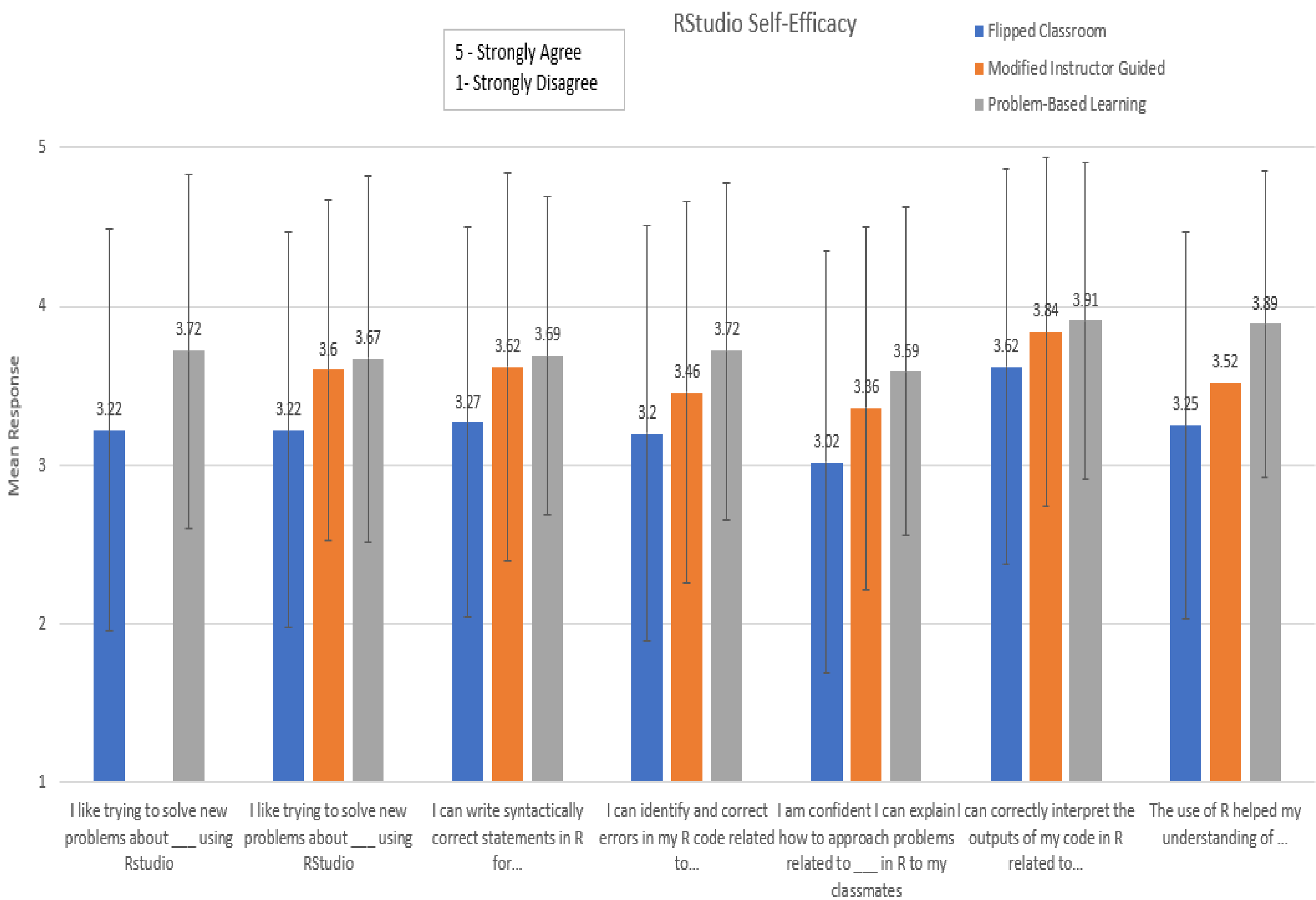

Figure 9: RStudio Self-Efficacy Survey Results

C. **Theory Self-Efficacy:** We assessed theory self-efficacy with six statements. The statements were tailored to the topics learned in each chapter. The topic specific aspects of each question have been removed from the analysis. From Figure 10 below, the Modified Instructor-Guided method resulted in the highest confidence in being able to learn new content and identify the problem-solving approach for each question. Students' level of interest in the topics remained at approximately the same level for all three methods, but students seemed to enjoy studying the most with the Modified Instructor-Guided and Flipped Classroom methods. Regarding solving different topics by hand, both Modified Instructor-Guided and Flipped Classroom produced the highest results.

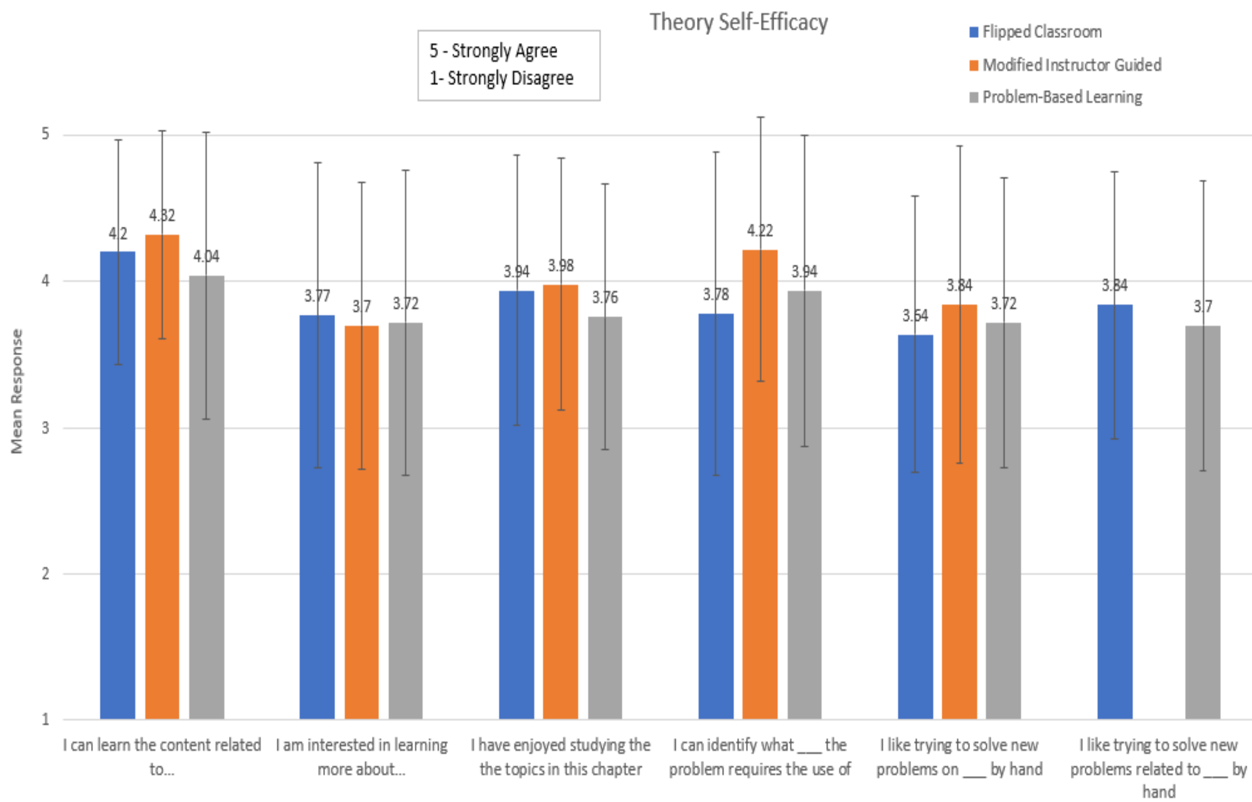

Figure 10: Theory Self-Efficacy Survey Results

Self-Efficacy Comparison

Tables 7-9 show the t-test results for the Self-Efficacy Surveys between each method. Paired t-tests were completed between each of the three methods on each individual question. From Table 7 below, comparing Flipped Classroom and Modified Instructor-Guided, at a 5% significance level, Modified Instructor-Guided performed better in Theoretical self-efficacy for the statement "I can identify when a problem requires the use of …." At a 10% significance level, Flipped Classroom performed better in Statistical self-efficacy for the statement "I can learn the statements taught in my statistics courses," and Modified Instructor-Guided performed better in RStudio self-efficacy for the statement "I can write syntactically correct statements in R for…."

Table 7: Self-Efficacy Survey t-Tests Between Flipped Classroom and Modified Instructor-Guided

		Flipped Classroom			Modified Instructor-Guided				
Self Efficacy Type	Question	Sample Size (n)	Mean	Std. Dev.	Sample Size (n)	Mean	Std.Dev.	**t_0**	**p-value**
Statistical Self Efficacy	Q1	64	4.310	0.680	50	4.160	0.760	1.550	0.062
	Q2	64	4.200	0.830	50	4.120	0.990	0.519	0.302
	Q3	64	3.670	1.030	50	3.600	1.020	0.353	0.363
RStudio Self Efficacy	Q1	64	3.220	1.270					
	Q2	64	3.220	1.240	50	3.600	1.310	-1.246	0.108
	Q3	64	3.270	1.230	50	3.620	1.070	-1.372	0.086
	Q4	64	3.200	1.310	50	3.460	1.220	-0.852	0.198
	Q5	64	3.020	1.330	50	3.360	1.200	-1.109	0.135
	Q6	64	3.620	1.240	50	3.840	1.140	-0.813	0.209
	Q7	64	3.250	1.220	50	3.520	1.100	-1.047	0.149
Theoretical Self Efficacy	Q1	64	4.200	0.770	50	4.320	0.710	-1.148	0.127
	Q2	64	3.770	1.040	50	3.700	0.980	0.361	0.360
	Q3	64	3.940	0.920	50	3.980	0.860	-0.265	0.396
	Q4	64	3.780	1.100	50	4.220	0.900	-2.252	0.013
	Q5	64	3.640	0.940	50	3.840	1.080	-1.052	0.148
	Q6	64	3.840	0.910					

From Table 8 below, comparing Flipped Classroom and Problem-Based Learning, at a 5% significance level, six out of the seven RStudio questions had statistically significant differences in means, and all favor Problem-Based Learning. The statements with the largest differences are: "The use of R helped my understanding of … ," "I am confident I can explain how to approach problems related to … in R to my classmates," "I can identify and correct errors in my R code related to… ," and "I like trying to solve new problems about … using RStudio." However, at a 10% significance level, Flipped Classroom performed better in Statistical self-efficacy for two statements: "I can learn the statements taught in my statistics courses" and "I am interested in learning new topics in statistics related to ISE."

Table 8: Self-Efficacy Survey t-Tests Between Flipped Classroom and Problem-Based Learning

		Flipped Classroom			Problem-Based Learning				
Self Efficacy Type	Question	Sample Size (n)	Mean	Std. Dev.	Sample Size (n)	Mean	Std.Dev.	**t_0**	**p-value**
Statistical Self Efficacy	Q1	64	4.310	0.680	54	4.170	0.810	1.375	0.086
	Q2	64	4.200	0.830	54	4.040	0.790	1.313	0.096
	Q3	64	3.670	1.030	54	3.740	1.020	-0.360	0.360
RStudio Self Efficacy	Q1	64	3.220	1.270	54	3.720	1.110	-1.881	0.031
	Q2	64	3.220	1.240	54	3.670	1.150	-1.692	0.047
	Q3	64	3.270	1.230	54	3.690	1.000	-1.778	0.039
	Q4	64	3.200	1.310	54	3.720	1.060	-1.947	0.027
	Q5	64	3.020	1.330	54	3.590	1.030	-2.134	0.017
	Q6	64	3.620	1.240	54	3.910	0.990	-1.223	0.112
	Q7	64	3.250	1.220	54	3.890	0.960	-2.817	0.003
Theoretical Self Efficacy	Q1	64	4.200	0.770	54	4.040	0.980	1.138	0.129
	Q2	64	3.770	1.040	54	3.720	1.040	0.250	0.401
	Q3	64	3.940	0.920	54	3.760	0.900	1.174	0.121
	Q4	64	3.780	1.100	54	3.940	1.060	-0.740	0.230
	Q5	64	3.640	0.940	54	3.720	0.990	-0.467	0.321
	Q6	64	3.840	0.910	54	3.700	0.990	0.844	0.200

From Table 9 below, comparing Modified Instructor-Guided and Problem-Based Learning, at a 5% significance level, Problem-Based Learning performed significantly better in RStudio self-efficacy for the statement "The use of R helped my understanding of … ." and Modified Instructor-Guided performed better in Theoretical self-efficacy for the statement "I can learn the content related to… ." At a 10% significance level, Modified Instructor-Guided performed better in Theoretical self-efficacy for the statements "I have enjoyed studying the topics in this chapter" and "I can identify what … the problem requires the use of."

Table 9: Self-Efficacy Survey t-Tests Between Modified Instructor-Guided and Problem-Based Learning

		Modified Instructor-Guided			Problem-Based Learning				
Self Efficacy Type	Question	Sample Size (n)	Mean	Std.Dev.	Sample Size (n)	Mean	Std.Dev.	t_0	p-value
Statistical Self Efficacy	Q1	50	4.160	0.760	54	4.170	0.810	-0.082	0.467
	Q2	50	4.120	0.990	54	4.040	0.790	0.513	0.305
	Q3	50	3.600	1.020	54	3.740	1.020	-0.686	0.247
RStudio Self Efficacy	Q1				54	3.720	1.110		
	Q2	50	3.600	1.310	54	3.670	1.150	-0.236	0.407
	Q3	50	3.620	1.070	54	3.690	1.000	-0.333	0.370
	Q4	50	3.460	1.220	54	3.720	1.060	-1.020	0.155
	Q5	50	3.360	1.200	54	3.590	1.030	-0.943	0.174
	Q6	50	3.840	1.140	54	3.910	0.990	-0.315	0.377
	Q7	50	3.520	1.100	54	3.890	0.960	-1.778	0.039
Theoretical Self Efficacy	Q1	50	4.320	0.710	54	4.040	0.980	1.925	0.029
	Q2	50	3.700	0.980	54	3.720	1.040	-0.100	0.460
	Q3	50	3.980	0.860	54	3.760	0.900	1.444	0.076
	Q4	50	4.220	0.900	54	3.940	1.060	1.466	0.073
	Q5	50	3.840	1.080	54	3.720	0.990	0.572	0.284
	Q6				54	3.700	0.990		

Exit Survey Analysis

The Exit Survey was completed by 70 students. The students were first asked what their impression was of each method and could respond on a scale ranging from "Strongly Preferred" to "Strongly Not Preferred." From Figure 11 below, you can see that, on average, students feel neutral about all three methods. However, 42.86% of students "Preferred" or "Strongly Preferred" the Flipped Classroom Method and 41.43% of students "Preferred" or "Strongly Preferred" the Modified Instructor-Guided Method. It should also be noted that PBL was the only method with any response to "Strongly Not Preferred" at 10.14% of students.

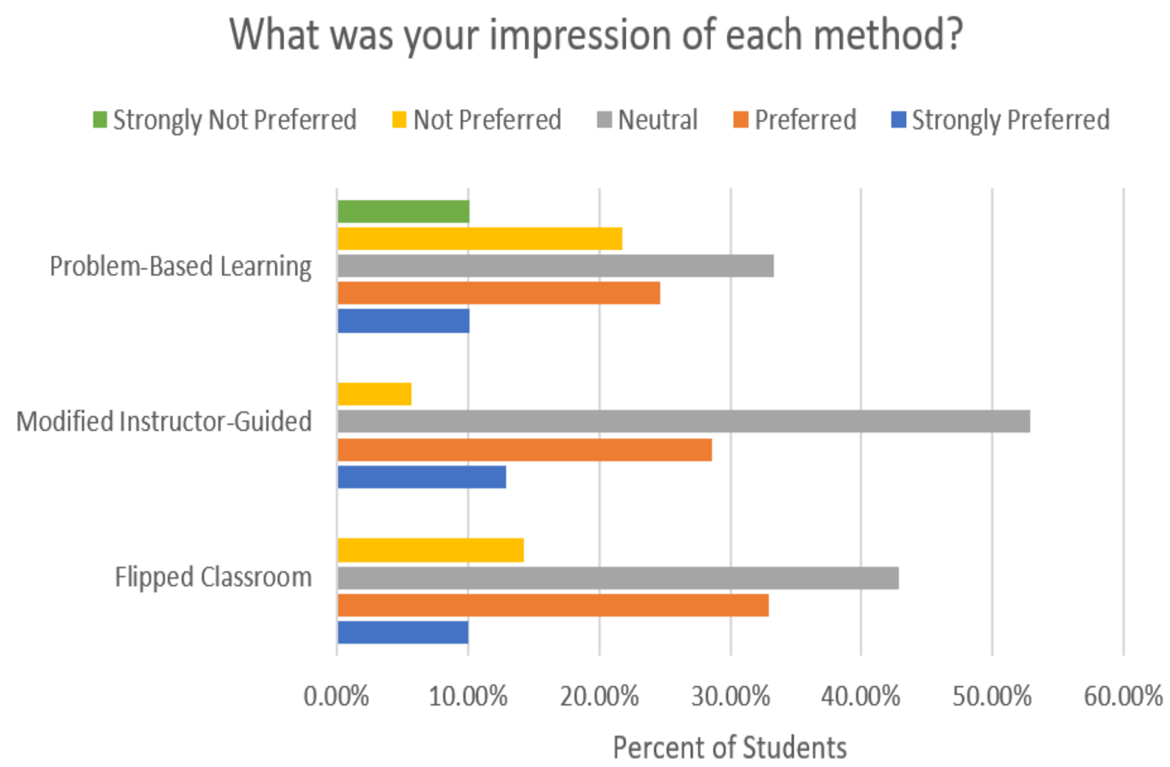

Figure 11: Student Impressions of Each Method

Then, the students were asked to rank which teaching method they preferred most and least and which chapter material they enjoyed learning the most. From Figure 12 below, students preferred Modified Instructor-Guided the most and Problem-Based Learning the least, with Flipped Classroom trailing only 1.45% behind. Looking at the material learned with each method, students enjoyed the material taught with Modified Instructor-Guided the most and the material learned with Problem-Based Learning the least.

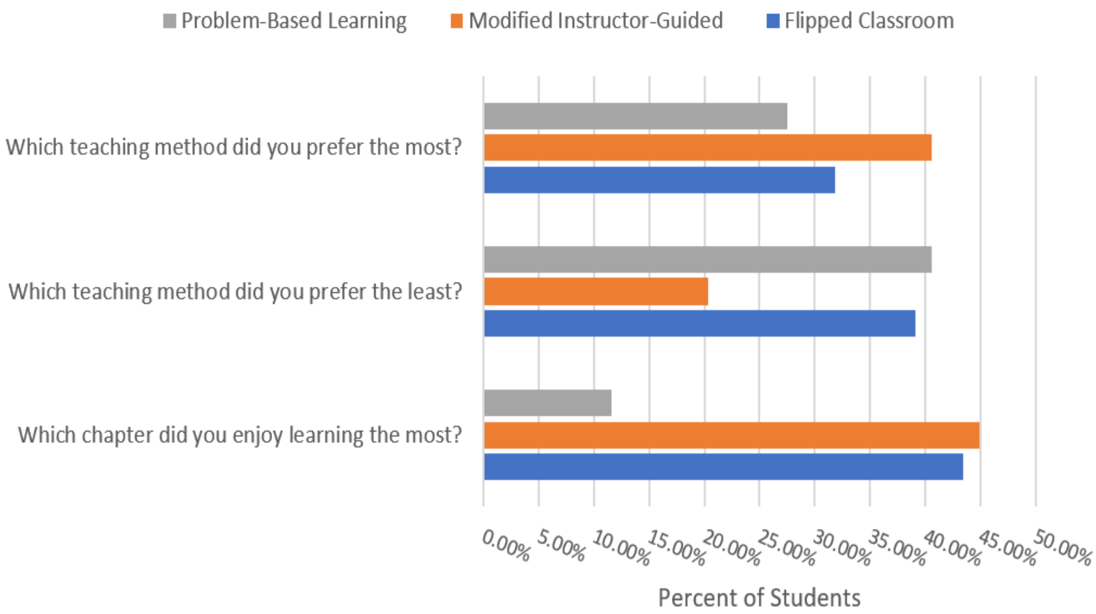

Figure 12: Student Ranking of Teaching Methods

Students were also asked to report how much time was spent outside of the classroom studying with each method. From Figure 13 below, students, on average, spent 3-4 hours on all three methods.

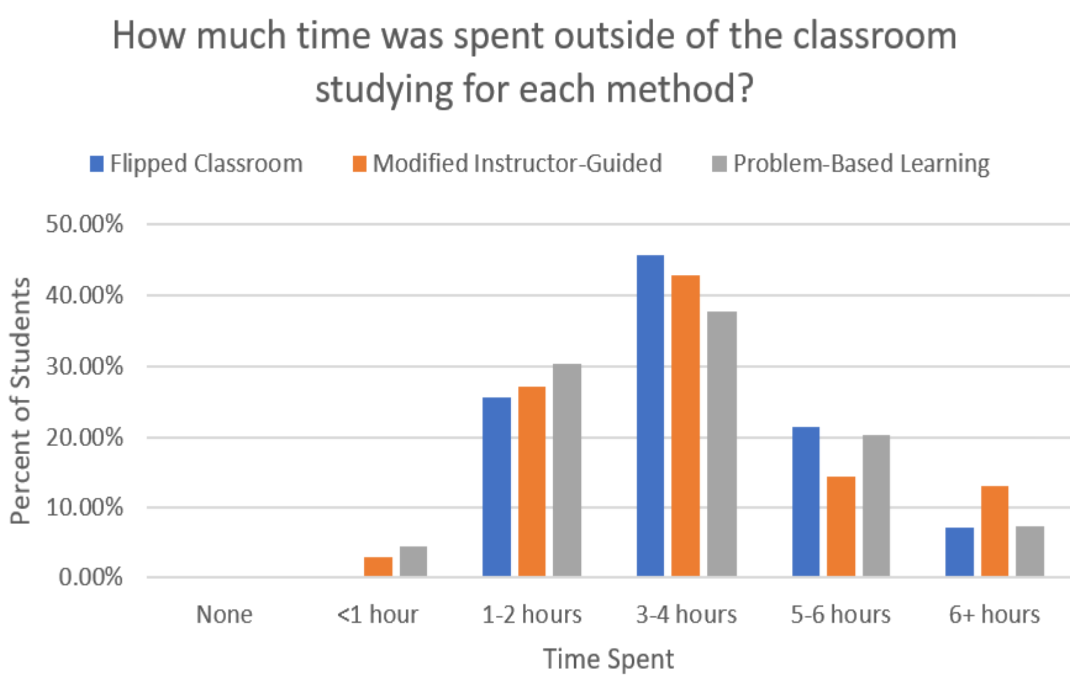

Figure 13: Student-Reported Time Spent Outside of the Classroom for Each Method

The last question of the survey asked if the students faced any challenges with switching teaching methods throughout the course. Most of the students stated they did not have any problems, but a few mentioned it made it slightly more difficult to adjust to new material and threw off their normal schedule.

Discussion

Based on our Computational Assessment results, both Flipped Classroom and Modified Instructor-Guided demonstrate significantly better results in student achievement than Problem-Based Learning. However, this could be because PBL was applied on Statistical Inference of Two Samples and is typically a more difficult topic for students to grasp. When comparing whether Flipped Classroom or Modified Instructor-Guided was better, there only showed a statistically significant difference when looking at the theory-based questions.

These results are somewhat conflicting to previous studies. Overall, traditional methods tend to perform better when learning theoretical concepts, whereas active-learning methods tend to perform better when learning software. For example, when applying active-learning techniques on a computer science course, it was found that students who were actively engaged and attended laboratory sessions generally received better grades in the course [8]. Although the Modified Instructor-Guided resulted in better performance with theory, there were no statistically significant results when looking at RStudio understanding. One study found that the Flipped Classroom methods should perform better in content-based courses [11], but this finding disagrees with our results.

These discrepancies could be attributed to the HyFlex format of the course. With this format, students could choose their preferred method of content delivery, meaning students could choose to attend the lecture live or watch it on their own time. This flexibility allows students to learn the material when they feel most motivated. This also means there were no active measures for the in-class portion of the Flipped Classroom method, where the active-learning techniques were implemented.

Looking at self-efficacy between all three methods, Flipped Classroom performed better in Statistical self-efficacy, Problem-Based Learning performed better in RStudio self-efficacy, and Modified Instructor-Guided performed better in Theoretical self-efficacy. This means that students tend to enjoy the material and feel a sense of usefulness from the course with the Flipped Classroom method. This can be supported by the results of the Exit Survey. Many students noted that they preferred Flipped Classroom because they could watch the lectures when they felt motivated to learn, thus being more likely to enjoy learning the material and finding more interest in the content. However, students felt more confident in their ability to apply the theory with Modified Instructor-Guided. This finding agrees with the Computational Assessment and previous studies that state more traditional methods help solidify theoretical concepts. When looking at RStudio self-efficacy, students reported feeling most confident with the PBL method, however these results are not reflected in the Computational Assessment. Students performed significantly worse with the PBL method compared to Flipped Classroom and Modified Instructor-Guided.

The Exit Survey results demonstrated that on average students tend to prefer the Modified Instructor-Guided method the most and the Problem-Based Learning method the least. However, students were also asked to provide comments on each teaching method and their experience. Students tend to prefer the Modified Instructor-Guided method because they feel it holds them more accountable for learning the material, there are fewer outside distractions, and students find this method to be more interactive and engaging. There was also an overwhelming number of students who mentioned that this method of learning comes more naturally to them since this is the method they are most accustomed to. Some disadvantages students found with this method are that they do not receive as many practice problems, students become unfocused in class, and if a student gets lost during the lecture, it is much harder to catch up again.

Students tended to prefer Flipped Classroom due to its flexibility with student schedules, the ability to watch lectures when students feel motivated to learn and know they will be able to stay focused, and short video content is easier to remain engaged. Flipped Classroom also allows students to learn at their own pace by pausing and rewinding videos. A few disadvantages students found with Flipped Classroom is the inability to ask questions while learning the material, therefore, students go to class feeling confused and ill-prepared. This challenge has been a common finding with previous Flipped Classroom studies [9, 19]. Students also mentioned that Flipped Classroom is too time consuming for the students, however, in the Exit Survey, students reported spending, on average, the same amount of time outside of the classroom as the other two methods.

When asked about why students prefer the PBL method, students mentioned they liked the repetitive exposure to concepts due to more practice problems, the ability to interact more with the instructor, and it encouraged students to be more hands-on and engaged by interacting with other students and attending the instructor’s office hours. A few common disadvantages that students mentioned are that the students would divide up the work, so they were not getting a holistic view of the content and only became proficient with the topics they solved themselves. Also, when the work was divided up, students mentioned that it became much harder to identify which topics they were not understanding. Many students did not like the overall flow of the method, specifically how they learned the material after solving the case study. They did not feel confident enough in the material to know whether they were solving the question correctly.

Conclusion

The aim of this study was to determine which teaching method is most conducive for students to master the theory and be proficient with software. We applied three different teaching methods, including Flipped Classroom, Modified Instructor-Guided, and Problem-Based Learning, in an introductory application-based statistics course. Modified Instructor-Guided was found to be most influential when learning theory. It allows students to best understand the material and feel a sense of confidence when applying it to problems. Flipped Classroom resulted in the highest enjoyment and interest in the course. And although Problem-Based Learning resulted in the highest confidence in RStudio, both Flipped Classroom and Modified Instructor-Guided produced higher results for RStudio understanding. From the results of this study, we can recommend a HyFlex version of the Modified Instructor-Guided method in order for students to both master the theory and be proficient with software.

There are a couple of limitations to this study. The first limitation was that this course was delivered as a HyFlex course due to COVID-19, meaning in-person attendance was not enforced. To some degree, students could choose their level of involvement in the implemented teaching method. There were also no active measures for the active-learning portion of the Flipped Classroom method and the PBL method lacked a focus on solving theory-based questions. Both of these limitations could have biased our results and should be addressed in future studies. Another limitation is the increasing difficulty of the course. Problem-Based Learning was applied to a particularly difficult chapter which could have influenced the students' computational results as well as their perception of the method.

To address these limitations, we suggest conducting this study over multiple semesters to try and replicate our results. To remove bias, this study should be conducted on a non-HyFlex course, and the methods should be applied on chapters with varying levels of difficulty. This will allow for students to receive the intended experience of each teaching method, and we can see whether the same preference for the Modified Instructor-Guided method holds.

Acknowledgements

This research and publication were developed in part for Tara Ippolito's Undergraduate Honors Thesis for Fall 2021. Tara graduated Sum Cum Laude from UF in Industrial and Systems Engineering.

References

[1] Landrum, M., & Hayes, A., & Giamichelle, J., & Sabahi, S., & Motamedi, S. (2021, July), *Fundamental Theorem Learning With Optimum Pedagogy for Technology Integration in Quality Control Course* Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. https://peer.asee.org/37212

[2] Rohrabaugh, A. P. and Cooper, C. M. (2016). Calculators in high school classrooms. Honors Research Projects, 313.

[3] Lin, Y. (2019). Impacts of a flipped classroom with a smart learning diagnosis system on students' learning performance, perception, and problem solving ability in a software engineering course. *Computers in Human Behavior*, 95, 187-196. doi:10.1016/j.chb.2018.11.036

[4] Baumgartner, I. (2014). A set of best practices to design face-to-face teaching sessions for technology-centered university-level computing courses. *International Journal of Engineering Pedagogy (iJEP)*, 4(4), 59. doi:10.3991/ijep.v4i4.4000

[5] Zappe, S., Leicht, R., Messner, J., Litzinger, T., & Lee, H. W. (n.d.). “Flipping” the classroom to explore active learning in a large undergraduate course. *2009 Annual Conference & Exposition Proceedings*. doi:10.18260/1-2—4545

[6] Saterbak, A., Wettergreen, M., & Roberts, Z. (n.d.). Teaching first-year engineering design using a flipped classroom model. *2016 ASEE Annual Conference & Exposition Proceedings*. doi:10.18260/p.26033

[7] Velegol, S. B., Zappe, S. E., & Mahoney, E. (2015). The evolution of a flipped classroom: Evidence-based recommendations. *Advances in Engineering Education*.

[8] Troya, J., Parejo, J. A., Segura, S., Gamez-Diaz, A., Marquez-Chamorro, A. E., & Del-Rio-Ortega, A. (2021). Flipping laboratory sessions in a computer science course: An experience report. *IEEE Transactions on Education*, 64(2), 139-146. doi:10.1109/te.2020.3016593

[9] Schultz, D., Duffield, S., Rasmussen, S. C., & Wageman, J. (2014). Effects of the flipped classroom model on student performance for Advanced Placement High School Chemistry Students. *Journal of Chemical Education*, 91(9), 1334-1339. doi:10.1021/ed400868x

[10] Mason, G. S., Shuman, T. R., & Cook, K. E. (2013). Comparing the effectiveness of an inverted classroom to a traditional classroom in an upper-division engineering course. *IEEE Transactions on Education*, 56(4), 430-435. doi:10.1109/te.2013.2249066

[11] Schrlau, M. G., Stevens, R. J., & Schley, S. (2016). Flipping core courses in the undergraduate mechanical engineering curriculum: Heat transfer. *Advances in Engineering Education*.

[12] Garcia-Martin, J., & Perez-Martinez, J. E. (2017). Method to guide the design of project based learning activities based on educational theories. *International Journal of Engineering Education*, Vol. 33, No. 3, 984-999.

[13] Miller, C. (2020). Mentoring and motivating project based learning in dynamics. *Advances in Engineering Education*, Vol. 8, No. 4.

[14] Yadav, A., Lundeberg, M., Subedi, D., & Bunting, C. (n.d.). Problem based learning in an undergraduate electrical engineering course. *2010 Annual Conference & Exposition Proceedings*. doi:10.18260/1-2—16597

[15] Delgado, D., Velasco, A., Aponte, J., & Marcus, A. (2017). Evolving a project-based software engineering course: A case study. *2017 IEEE 30th Conference on Software Engineering Education and Training (CSEE&T)*. doi:10.1109/cseet.2017.22

[16] Martins, V. F., De Almeida Souza Concilio, I., & De Paiva Guimarães, M. (2018). Problem based learning associated to the development of games for programming teaching. *Computer Applications in Engineering Education*, 26(5), 1577-1589. doi:10.1002/cae.21968

[17] De Camargo Ribeiro, L. R. (2008). Electrical engineering students evaluate problem-based learning (PBL). *The International Journal of Electrical Engineering & Education*, 45(2), 152-161. doi:10.7227/ijeee.45.2.7

[18] Lykke, M., Coto, M., Jantzen, C., Mora, S., & Vandel, N. (2015). Motivating students through positive learning experiences: A comparison of three learning designs for computer programming courses. *Journal of Problem Based Learning in Higher Education*, Vol. 3, No. 2, 80-180. http://dx.doi.org/10.5278/ojs.jpblhe.v0i0.1130

[19] Shnai, I. (n.d.). Systematic Review of Challenges and Gaps in Flipped Classroom Implementation: Toward Future Model Enhancement. Retrieved October 22, 2021, from https://www.researchgate.net/profile/Iuliia-Shnai/publication/320859160_Systematic_Review_of_Challenges_and_Gaps_in_Flipped_Classroom_Implementation_Toward_Future_Model_Enhancement/links/5a01b8cfa6fdcc232e2e75ba/Systematic-Review-of-Challenges-and-Gaps-in-Flipped-Classroom-Implementation-Toward-Future-Model-Enhancement.pdf

[20] Yumuşak, G. (2020). Preparation before class or homework after class? Flipped teaching practice in higher education. *International Journal of Progressive Education*, 16(2), 297-307. doi:10.29329/ijpe.2020.241.20

[21] Austin, J. S. (1996). Effect of graphing calculator use on student achievement in college algebra: gender and age-related differences. (Order No. 9703500, University of Missouri - Kansas City). ProQuest Dissertations and Theses, 135.

[22] Korkmaz, Ö., & Altun, H. (2014). Adapting computer programming self-efficacy scale and engineering students' self-efficacy perceptions. Participatory Educational Research, 20–31. https://doi.org/10.17275/per.14.02.1.1

[23] Woolcock, A. D., Creevy, K. E., Coleman, A. E., Moore, J. N., & Brown, S. A. (2016). Assessing academic self-efficacy, knowledge, and attitudes in undergraduate physiology students. American Journal of Educational Research, 4(9), 652–657.

[24] Canizares, C. A., & Faur, Z. T. (1997). Advantages and disadvantages of using various computer tools in electrical engineering courses. IEEE Transactions on Education, 40(3), 166–171. https://doi.org/10.1109/13.618025

[25] Mamaril, N. A., Usher, E. L., Li, C. R., Economy, D. R., & Kennedy, M. S. (2016). Measuring undergraduate students' engineering self-efficacy: A validation study. Journal of Engineering Education, 105(2), 366–395. https://doi.org/10.1002/jee.20121