



## **Longitudinal Assessment of Student Persistence, Achievement, and Attitude in a Flipped Biomedical Engineering Classroom using Pencasts and Muddiest Point Web-enabled Tools**

### **Dr. Casey Jane Ankeny, Arizona State University**

Casey J. Ankeny, PhD is lecturer in the School of Biological and Health Systems Engineering at Arizona State University. Casey received her bachelor's degree in Biomedical Engineering from the University of Virginia in 2006 and her doctorate degree in Biomedical Engineering from Georgia Institute of Technology and Emory University in 2012 where she studied the role of shear stress in aortic valve disease. Currently, she is investigating cyber-based student engagement strategies in flipped and traditional biomedical engineering courses. She aspires to understand and improve student attitude, achievement, and persistence in student-centered courses.

### **Dr. Stephen J Krause, Arizona State University**

Stephen Krause is professor in the Materials Science Program in the Fulton School of Engineering at Arizona State University. He teaches in the areas of introductory materials engineering, polymers and composites, and capstone design. His research interests include evaluating conceptual knowledge, misconceptions and technologies to promote conceptual change. He has co-developed a Materials Concept Inventory and a Chemistry Concept Inventory for assessing conceptual knowledge and change for introductory materials science and chemistry classes. He is currently conducting research on NSF projects in two areas. One is studying how strategies of engagement and feedback with support from internet tools and resources affect conceptual change and associated impact on students' attitude, achievement, and persistence. The other is on the factors that promote persistence and success in retention of undergraduate students in engineering. He was a coauthor for best paper award in the Journal of Engineering Education in 2013.

## **Longitudinal Assessment of Student Persistence, Achievement and Attitude in a Flipped Biomedical Engineering Classroom using Pencasts and Muddiest Point Web-enabled Tools**

Studies show that student-centered instruction can be more effective than teacher-centered. Here, we investigated achievement, persistence, and attitude regarding several student-centered strategies in a one-credit, large-scale, statistics and design of experiment course for upper-division biomedical engineering (BME) undergraduates. More specifically, we asked “What is the effect of the flipped classroom, pencasts/online lectures, cyber-based muddiest point (unclear concept) collection, and group-based activities on attitude, achievement, and persistence?”

Two components comprised the course. Prior to class, students watched pencasts, submitted the muddiest and most interesting points online, and completed practice problems. In class, students engaged in a review of the muddiest/most unclear points in class and then applied lecture material through group activities including statistical software-oriented problem solving sessions and design projects with the support of undergraduate teaching assistants and the instructor.

To evaluate these student-centered strategies, three aspects were considered: persistence, attitude, and achievement. Persistence was measured as the number of students present during the second week of class and remaining at the final. To measure student value and attitude, two validated, custom surveys were administered in the middle and at the end of the semester anonymously: 1) the Student Value Survey on Muddiest Points (SVM) which focused on interest and usefulness as well as cost (emotion, time, effort) related to muddiest point collection and 2) the BME Student-centered Strategies (BSS) Survey regarding the flipped classroom, pencasts, muddiest points, and group activities. Lastly, most recently, a ten-question concept quiz was created and piloted to assess achievement related to key statistical and design of experiment concepts.

Persistence tracked for three semesters showed a value of greater than 98%. Student attitude surveys completed during the same time frame also showed positive outcomes, supporting the notion of high self-efficacy. Briefly, with respect to the SVM, the majority of students ( $n=149$ ) agreed with statements concerning value (94%), interest (62%), and cost (78%). According to the BSS survey, all engagement strategies were favorable with opinions of the pencast statistically higher than the rest of the interventions (0.9/1,  $n=132$  students) and the flipped classroom statistically lower than the other interventions (0.69/1,  $n=132$  students). In terms of achievement, pre-instruction data of the concept quiz yielded a score of 44% ( $n=82$ ) for Fall 2014 and post-instructions scores were 75% for Spring 2014 ( $n=33$ ) and 76% for Fall 2014 ( $n=49$ ). Analysis of the fall paired data showed a large, statistically significant increase in conceptual understanding ( $n=37$  pairs).

In general, this multi-faceted, integrated assessment approach focusing on persistence, attitudinal, and achievement supported this unique instructional paradigm as an effective pedagogy for teaching and learning in the flipped classroom. Further, this work demonstrates that longitudinal tracking is an effective means for continuous improvement of course content and pedagogy.

## Introduction

Research has shown that student-centered, active learning instruction can be more effective than teacher-centered instruction.<sup>1,2</sup> In this study, we investigate persistence as well as student value and attitude of several strategies in a student-centered biomedical engineering statistics and design of experiments course for junior-level undergraduates. Here, we ask “What is the effect of the flipped classroom, pencasts, cyber-based muddiest point (unclear concept) collection, and group-based activities on student attitude and persistence?” The following are student engagement strategies explored longitudinally in this study: the flipped classroom, web-enabled online lectures called pencasts, cyber-based muddiest point collection, and group-based activities.

In the flipped classroom, the lecture is delivered outside of the classroom, typically in the form of an online video. Many studies have investigated the effectiveness of the flipped classroom. More specifically, Mason, et al. found that the flipped classroom allowed instructors to deliver more content and showed similar or improved student achievement in comparison to the traditional engineering classroom.<sup>3</sup> Further, Wilson found that the flipped classroom was effective in terms of attitude and performance in the statistics setting.<sup>4</sup>

To facilitate the flipped classroom, many forms of the online lecture have been introduced including those produced with screencasting software and Photoshop posted on YouTube<sup>5</sup>, animated PowerPoint slides, and the emerging pencast.<sup>6</sup> Here, we focus on the pencast. More specifically, pencasts are created using a smart pen, capturing both handwriting and voice and then distributed easily as a small, audio PDF. Pencasts in this course are typically fifteen minutes long and contain information typically written on white boards during lectures.

An additional student-centered engagement strategy is cyber-based muddiest point collection. Muddiest points are student-generated unclear concepts first introduced in 1988 by Frederick Mosteller. Mosteller asked students three questions: 1) What was the most important point in lecture? 2) What was the muddiest? and 3) What would you like to hear more about?<sup>7,8</sup> Muddiest points have been classically solicited via paper and pencil and addressed in class using handouts or incorporating into the beginning of the next class lecture.<sup>9</sup> Recently, muddiest points have been collected online using Concept Warehouse available through Oregon State University or through Blackboard<sup>5</sup>. In Concept Warehouse, students electronically submit both the muddiest and most interesting point of the lecture and the data is automatically output in tabular form, with an intensity scale of 0-5 and a word cloud with word size proportional to word frequency. This allows instructors to easily pinpoint the muddiest and most interesting concepts.

Finally, group-based activities such as in-class activities and projects have been found to be an effective student-centered engagement strategy<sup>10</sup>. Here, students work with team members to complete short-term or long-term assignments or projects. In this study, we will explore both short-term assignments in the form of class problem sets involving statistical software and long-term design projects focusing on design of experiment and statistical analysis of previously untested hypotheses.

Overall the organization of classes is as follows: students watch pencasts, submit the muddiest and most interesting points online, engage in a review of the muddiest points in class, and then apply the lecture material in-class using group activities. Moreover, this study was conducted in a course comprised of roughly equal numbers of males and female at the junior level. In this study, we hypothesize that the aforementioned student-centered strategies (the flipped classroom, muddiest point exercise, pencasts, and group activities) are effective in the biomedical engineering statistics classroom.

## **Methods**

### ***Surveys***

Two surveys were administered anonymously to discern student value and attitude regarding engagement strategies midway through the semester and at the end of the semester: 1) the validated Student Value Survey on Muddiest Points (SVM) created by Carberry, et al. which is based on expectancy value theorem<sup>11</sup> and focuses on interest and utility value as well as cost related to muddiest point collection<sup>12</sup> and 2) the validated survey called the BME Student-centered Strategies (BSS) Survey regarding the flipped classroom, pencasts, cyber-enabled muddiest points, and group activities.<sup>13</sup> Both surveys were assessed for reliability and validity using pilot study data. After the first semester, the BSS Survey was adjusted from a 5-point scale to a 4-point scale. Further, to allow for pairing of multiple surveys and the concept quiz by student, each student created and included the same anonymous identifier on each instrument.

### ***Statistical Analysis for Attitudinal Surveys***

Prior investigation did not show marked differences between the mid and end-of- semester administrations. This may be explained by the fact that there were no changes in instructional paradigm during this time. For this reason, we focused on a longitudinal study using the post-semester data over three semesters (FA13 = Fall 2013, SP14 = Spring 2014, and FA14 = Fall 2014). To look for statistical differences over time, a Kruskal Wallis test for non-parametric data was completed for both the SVM survey ( $n_{FA13} = 37$ ,  $n_{SP14} = 40$ , and  $n_{FA14} = 55$ ) and the BSS Survey ( $n_{FA13} = 48$ ,  $n_{SP14} = 43$ , and  $n_{FA14} = 58$ ). A Bonferroni correction was applied to post-tests looking for differences between individual groups. Data was normalized to 1 in order for multiple semester comparison with the BSS Survey. The SVM Survey was normalized to the same scale for consistency. For the SVM survey, results represented in the Figure 1 show percent agreement which was calculated by combining ratings of “agree” and “strongly agree” and dividing by total student number. Questions were grouped by category (“interest”, “utility”, and “cost”). Percentages for the general categories were determined by averaging scores for related questions.

It is important to note that because student attitude, persistence, and achievement were not monitored when this course was taught in a traditional manner by other instructors, we are unable to make retrospective comparisons between student-centered and teacher-centered instruction in this biomedical engineering statistics course.

### ***Concept Quiz Development and Analysis***

In order to assess mastery of key concepts and to complement previous attitudinal and persistence data, a concept quiz comprised of 10 questions was created. The concept quiz was piloted as a post-test ( $n_{\text{post}}=33$ ) and the following semester, it was administered as both a pre- and post-test ( $n_{\text{pre}}=82$ ,  $n_{\text{post}}=49$ , and  $n_{\text{pairs}}=37$ ). The percentage of correct answers was calculated and for the semester with before and after instruction administrations, a paired Student's t-test was used to look for statistical differences in conceptual mastery. Further, to look for correlation between attitudinal and achievement measures, a Pearson's R correlation study was completed.

### ***Persistence Analysis***

To complement the student attitude data, persistence in this flipped, student-centered statistics course was determined by comparing the number of students enrolled in the course on the 21<sup>st</sup> day, a university standard, to the number of students taking the final exam.

## **Results**

### ***Student Value Survey on Muddiest Points Analysis***

Over the course of three semesters 149 students completed the SVM survey. Analysis of the percent agreement showed that the majority of the students thought that the muddiest point exercise was of interest (61.5%), was useful (94%), and did not take too much time or emotion (22%) as shown in Figure 1 below.

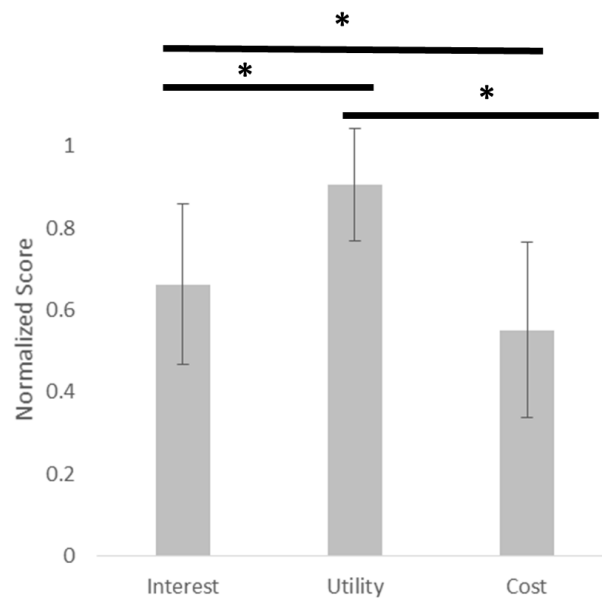
<b>INTEREST/ATTAINMENT VALUE</b>	
<b>motivated me to do well in the course</b>	<b>51%</b>
<b>was an effective way to increase engagement</b>	<b>64%</b>
<b>helped me better understand my own learning</b>	<b>64%</b>
<b>increased my level of responsibility</b>	<b>67%</b>
<b>UTILITY VALUE</b>	
<b>will be of value after graduation</b>	<b>92%</b>
<b>was useful in career and/or graduate school goals</b>	<b>93%</b>
<b>helped me see relevance of stats to the real world</b>	<b>97%</b>
<b>COST</b>	
<b>required too much effort</b>	<b>26%</b>
<b>made me frustrated and anxious</b>	<b>26%</b>
<b>required too much time</b>	<b>14%</b>

**Figure 1. Average Results from Muddiest Point Survey:** The above chart outlines the SVM survey statements by category (“interest”, “utility”, and “cost”) and indicates the percentage of students in agreement with the associated statements. Results represent post-semester averages from three semesters ( $n=149$ ).

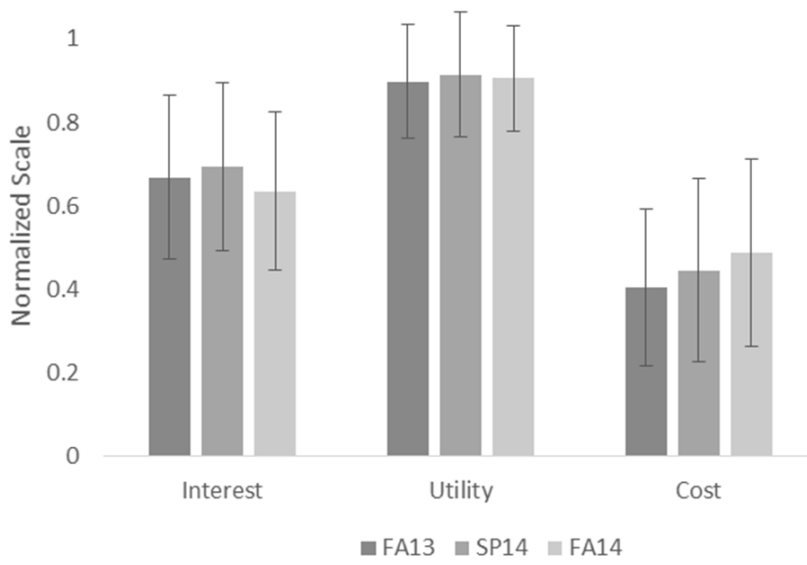
More specifically, in terms of interest, 51% of the students felt that the muddiest point exercise motivated them to do well in the course and 64% thought that it the muddiest point exercise was

an effective strategy to increase engagement and allow them to better understand their learning. 67% felt that the muddiest points exercise increased their responsibility for their own learning. In terms of utility value, 92% felt that the material learned in the course will be of use after graduation and 93% thought that the material will be useful in their career. Lastly, 97% said that the material in the course allowed them to see the relevance of statistics to the real world. In terms of cost, 74% of the students thought that the muddiest point exercise did not require too much effort and did not make them anxious or frustrated. 86% of the student did not think that the muddiest point exercise took too long.

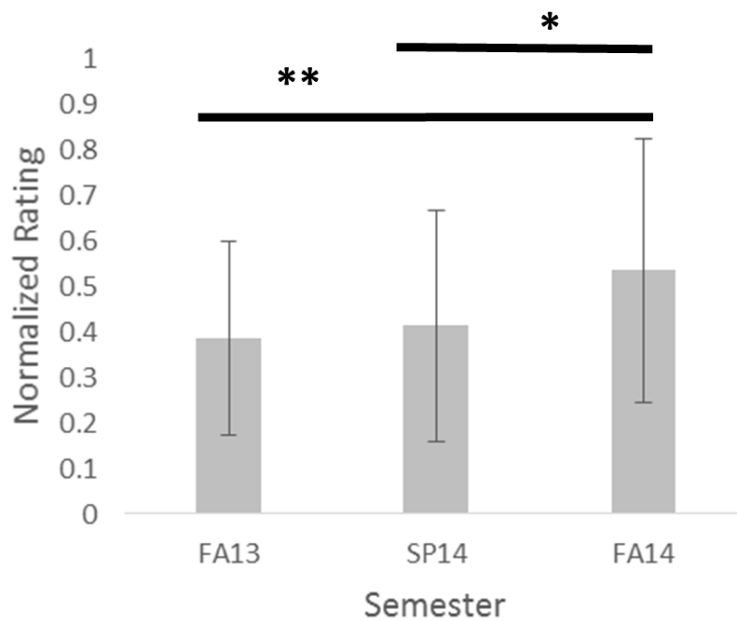
As implied in Figure 1, the students felt differently about the muddiest point exercise and associated in course material in terms of “interest”, “utility”, and “cost”. More specifically, there was a statistically significant different in opinion among these three categories when the data was pooled over three semesters as shown below in Figure 2. The normalized data showed that students thought most favorably about the utility of the course material explained in the muddiest point exercise and least favorably about the cost in terms of time and emotion. It is important to note that the y-axis represents a normalized scale where a value of one is the maximum score in terms of agreement. Investigation of changes among semesters showed that there was no statistically significant differences in opinion from semester to semester as shown in Figure 3 below.



**Figure 2. Statistical Analysis of Student Value of Muddiest Points:** Analysis of post-semester data shows that students felt most favorably about the utility of the course material covered in the muddiest points exercise and least favorably about the cost in terms of cost and emotion (n=149 over 3 semesters;  $p < 0.001$ ; error bars indicate standard deviation). On a related note, the cost statement scores were subtracted from one to make the scale as if the statements were positively worded.



**Figure 3. Investigation of Semester Differences in the SVM Survey:** There was no statistical difference in “interest”, “utility”, and “cost” among semesters ( $n_{FA13}=48$ ,  $n_{SP14}=43$ , and  $n_{FA14}=58$ ). On a related note, the “cost” statements were negatively worded.

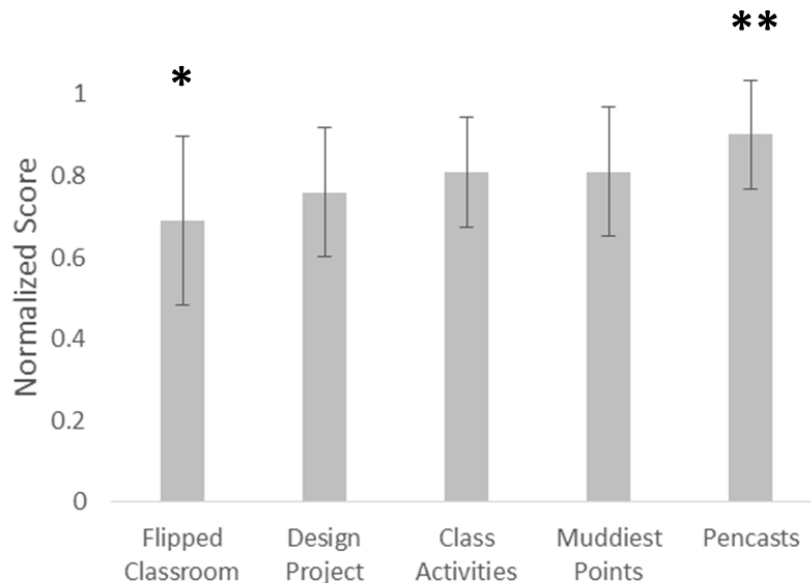


**Figure 4. Investigation of Emotion in Student Value of Muddiest Point Survey:** Kruskal Wallis analysis of the three semester datasets shows that there is a modest but statistically significant increase in anxiety or frustration related to submission of the muddiest point feedback over time ( $n_{FA13}=48$ ,  $n_{SP14}=43$ , and  $n_{FA14}=58$ ; \*  $p=0.026$  and \*\*  $p=0.009$ ).

Looking at the individual statements, there was only a statistically significant differences among semesters in the statement referring to whether the completion of the muddiest point exercise made them frustrated or anxious. There was a small but statistically significant increase in agreement with that statement in the 3<sup>rd</sup> semester (Fall 2014 – FA14) as shown in Figure 4 above.

***BME Student-centered Strategies (BSS) Survey Analysis***

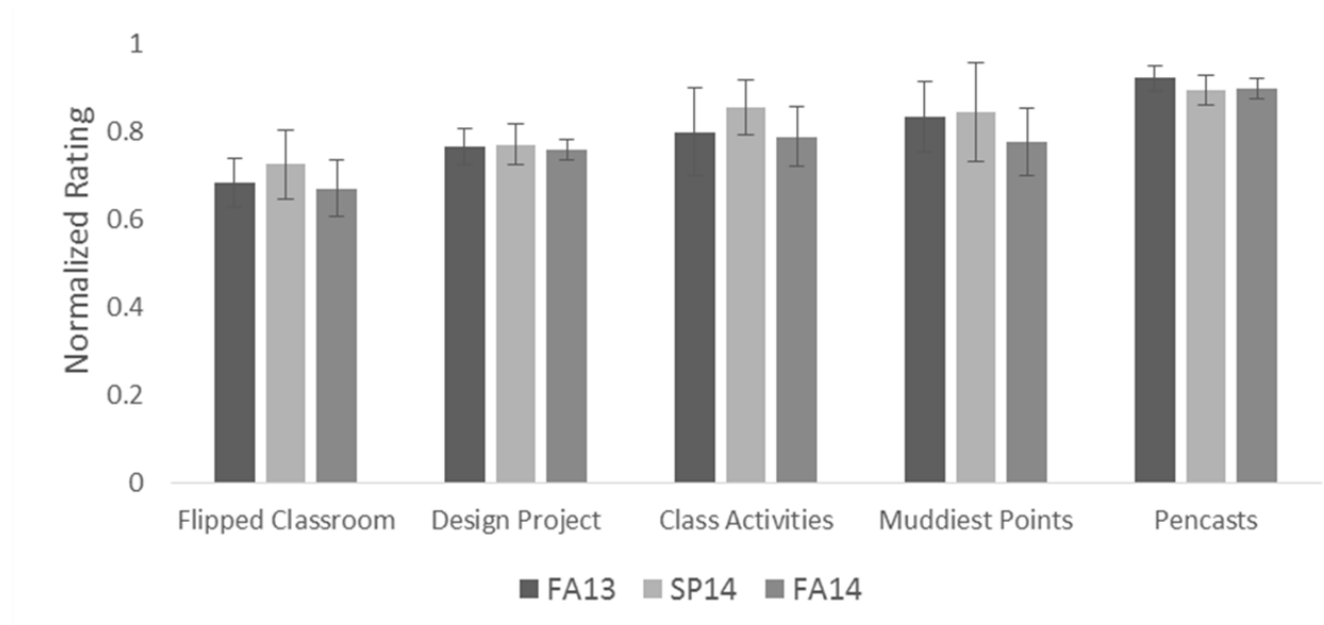
As mentioned above, data were normalized such that a value of one means “strongly agree or favor”. Data from the post-semester were grouped by semester and by category (“flipped classroom”, “design project”, “class activities”, “muddiest points”, and “pencasts”). In general, students exhibited positive opinions for all five engagement strategies. Statistical analysis provided a way to begin determining which strategy was most effective. Moreover, Figure 5 below shows that the least favorable student engagement strategy is the flipped classroom and the most favorable student engagement strategy is implementation of the pencasts. More specifically, statistical analysis showed that the opinion of the flipped classroom is statistically lower than all other strategies except the design project (\* p<0.004). On the other hand, student attitude about the pencasts was statistically higher than the other four interventions (\*\* p<0.001).



**Figure 5. Aggregated Student Opinion about Student Engagement Strategies.** Kruskal Wallis analysis showed that the opinion of the flipped classroom is statistically lower than all other strategies except the design project (\* p<0.004). On the other hand, student attitude about the pencasts was statistically higher than the other four interventions (\*\* p<0.001). Data analyzed includes all three semesters (n=132).

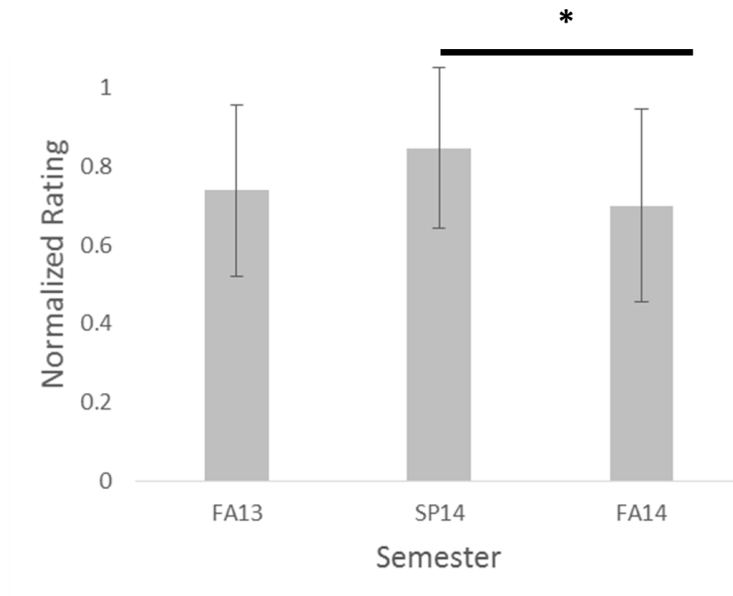


Semester differences in student opinion of the five engagement strategies was investigated. In summary, statistically analysis showed that there was no statistical difference in opinion about the strategies among different semesters as shown below in Figure 6. Further, analysis showed that overall student opinion about the strategies was favorable.

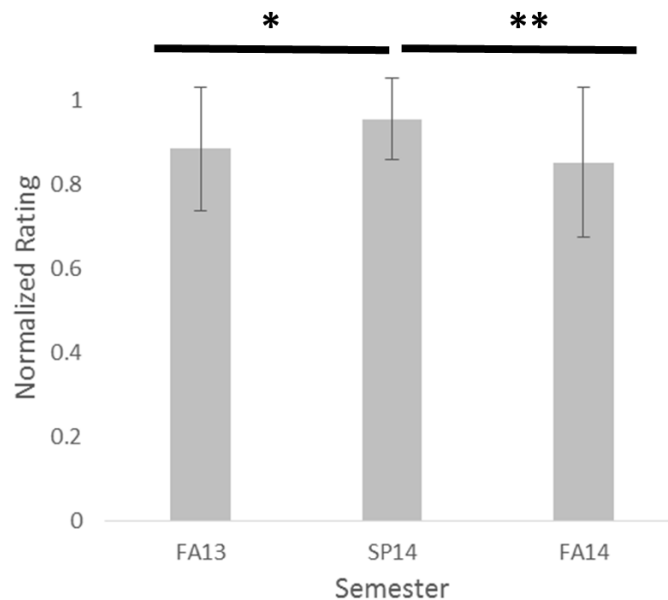


**Figure 6. Student Opinion about Engagement Strategies by Semester.** Kruskal Wallis analysis among semester data showed that there was no statistical difference in student opinion among semesters ( $n_{FA13}=37$ ,  $n_{SP14}=40$ , and  $n_{FA14}=55$ ).

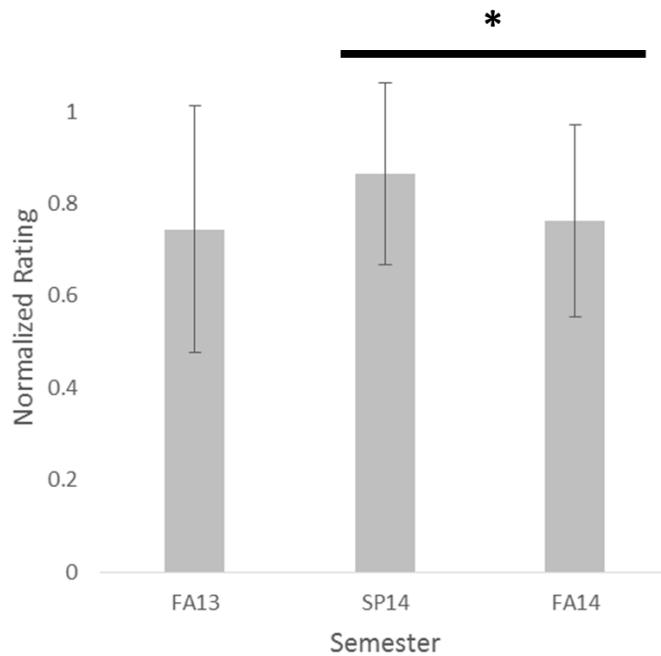
Additionally, analysis was completed looking at each individual statement to see if there were differences in student opinion about particular aspects of each intervention. It is important to note that although there were differences in student opinion among the semesters, overall opinion about the strategies was high. Only three statements showed a difference. With respect to the agreement about the response to muddiest point feedback answering students' questions, there was a statistically increase in student agreement in the Spring 2014 semester (off-major map semester) than the Fall 2014 semester as shown in Figure 7 below. Further, a similar statistically significant increase in student opinion was found in the off-major map semester (Spring 2014) as compared to the two fall semesters in terms of the clarity related to the muddiest point responses as seen in Figure 8 below. With respect to the class activities, students again in the spring semester had a significantly higher degree of agreement with respect to the utility of software-based, in-class activities in their future as shown below in Figure 9.



**Figure 7. Student Opinion about Muddiest Point Exercise’s Ability to Answer Questions.** Overall students held a favorable opinion about the response to muddiest points feedback in terms of ability to answer their question. Interestingly, there was a statistically significant increase in student opinion in the Spring 2014 semester (off-major map semester). Analysis was completed using the Kruskal Wallis test ( $n_{FA13}=37$ ,  $n_{SP14}=40$ , and  $n_{FA14}=55$ ; \*  $p=0.002$ ).



**Figure 8. Student Opinion about Clarity Associated with the Muddiest Point Response.** In general, there was a high opinion about the clarity associated with the muddiest point responses. Interestingly, there was a statistically higher opinion in the clarity associated with the muddiest point response in the spring semester (off-major map) semester as compared to the fall semesters ( $n_{FA13}=37$ ,  $n_{SP14}=40$ , and  $n_{FA14}=55$ ; \*  $p=0.032$  and \*\*  $p = 0.002$ ).

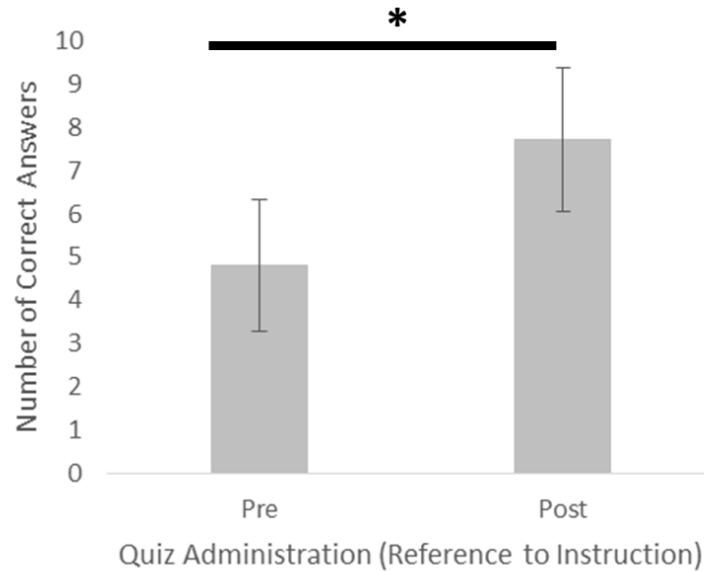


**Figure 9. Student Opinion about Utility of Software-based, In-class Activities in the Future.**

In general, there was a high opinion about utility of software-based, in-class activities in the future. Interestingly, there was a statistically higher opinion in the utility in the spring semester (off-major map) semester as compared to the Fall 2014 semester ( $n_{FA13}=37$ ,  $n_{SP14}=40$ , and  $n_{FA14}=55$ ; \*  $p=0.009$ ).

### *Concept Quiz Analysis*

A ten question concept quiz covering the main course objectives was created and piloted during Spring 2014. During Fall 2014, it was administered both before and after instruction. During the pilot semester, students scored a 75% on the concept quiz post-instruction ( $n=33$ ). In the Fall, students scored a 44% before instruction ( $n=82$ ) and a 76% after instruction ( $n=49$ ), showing improved understanding of key statistical concepts. Further, looking at those students that took both the pre- and post-assessments ( $n=37$  pairs), there was a statistically significant increase in understanding as shown below in Figure 10.



**Figure 10. Percent Correct in Concept Quiz Before and After Instruction.** According to a paired t-test, there was a statistically significant improvement in understanding of key statistical concepts before and after instruction (n=37 pairs, \* p <0.001).

### *Correlation between Attitude and Achievement Data*

As mentioned above, a Pearson’s R correlation study was completed to look for links between the attitudinal surveys (SVM and BSS Surveys) and the achievement data (Concept Quiz). Pearson’s R values were all close to zero (no correlation) when investigating the SVM categories (“interest”, “utility”, and “cost”) as well as the BSS categories (“flipped classroom”, “design project”, “in-class activities”, “muddiest points”, and the pencasts”) as compared to the achievement scores.

### *Student Persistence Analysis*

To ascertain student persistence, enrollment on the 21<sup>st</sup> day of class was compared to the number of students who took the final exam. 90 out of 91 (99%), 57 out of 58 (98%), and 97 out of 98 (99%) enrolled on the 21<sup>st</sup> day of class on the Fall 2013, Spring 2014, and Fall 2014 semesters, respectively, took the final exam.

### **Discussion and Conclusion**

This work employs the use of two validated and reliable surveys to evaluate student attitude about several student engagement strategies including cyber-based muddiest points, pencasts, the flipped classroom, and team-based classroom activities and design project.<sup>12,13</sup> Further, this

work outlines the creation, piloting, and preliminary results of an achievement-based instrument, the Statistics for Biomedical Engineers Concept Quiz. To round out, the assessment of this active learning environment persistence was also measured. To date, the authors have only been involved in a fully student-centered version of the course. It would be of interest to compare these results to a lecture-based version of the course in the future.

In summary, the SVM survey showed favorable opinions about the muddiest point exercise in terms of the subcategories: interest, utility, and cost. Further, each semester, students rated the muddiest point exercise similarly as shown by the lack of statistical difference among subcategory ratings. This was to be expected because the implementation of the exercise was consistent among all three semesters. Also, the three categories explored in the SVM survey were rated differently. All semesters felt most favorably about the utility of the exercise with 94% of the students agreeing that the muddiest point content was useful and least favorably about the time and emotion related to completion of the exercise as shown in Figure 2.

Anecdotally, students have trouble remembering to submit online each week. Interestingly, when looking at the individual questions related to “cost” of completing the muddiest point exercise, there was a statistically significant increase in frustration and anxiety for the Fall 2014 semester over the other two semesters. In order to reduce the cost of completing the exercise, future efforts will be made to create a system to remind the students to submit. Future analysis will investigate the effectiveness of this system.

A longitudinal study of the five student engagement strategies assessed through the BSS survey (flipped classroom, muddiest points, pencasts, the design project, and classroom activities) showed above neutral/positive results. This supports the work of others demonstrating several of the same techniques as effective; however, as far as the authors are aware, this is the first time this combination of strategies has been evaluated in a biomedical engineering setting. The design and problem solving aspect present in both the design project and classroom activities, have been shown to be effective in biomedical engineering settings in terms of achievement.<sup>14</sup> More specifically, another study by Garmendia, et al. showed positive trends for efficacy and attitude as a result of team-work in a design project setting; however, because of the different content area and assessment of the design project’s effect, it is difficult to make a direct comparison.<sup>15</sup> Additionally, one study completed by Bingham showed a similar improvement in student attitude regarding a real-world project in an introductory statistics course.<sup>16</sup>

Analysis showed there was no statistical difference in student opinion about these five strategies over time which was to be expected as the implementation did not change. Interestingly, students rated the flipped classroom statistically lower and the pencasts, the method used to create lectures for the flipped classroom, statistically higher than the other interventions. With respect to the flipped classroom, many students believed that the flipped setting was appropriate in this one-hour per week statistics and design of experiment course; however, they would not recommend the flipped classroom in other more time intensive classrooms. Mixed feelings about the flipped classroom have been observed by other researchers in the statistics and engineering setting.<sup>3,4</sup> Because the flipped classroom is a new concept, many students may not be familiar with the format or benefits of this paradigm; however, Mason, et al. showed that over

time students adapted to the format and found the flipped classroom to be effective and satisfactory.<sup>3</sup> This is reinforced by the following anecdotal quote: “I feel that this is the only one that would work in this way. The pencast lectures could be helpful in other classes in addition to normal lectures.” Future work will focus on improving the flipped classroom.

Undoubtedly, the most effective engagement strategy used in this course was the pencast as supported by the BSS survey. The authors suggest this strategy as an easy, fast, first-step in converting the traditional classroom into a student-centered classroom. The effectiveness of the pencast has also been supported by others such as Roesch who showed improvement in achievement in those that viewed pencasts as compared to those that did not.<sup>17</sup>

When investigating differences in student opinion within individual aspects of the each category, we found that there was a statistically significant difference between on-major map and off-major map semester responses with respect to the muddiest points exercise’s ability to answer questions, the clarity of these responses, as well as the utility of software-based, in-class activities in the future. In all cases, we saw an increase in opinion in the off-major map semester. This suggests students may benefit more from student-centered education strategies if not on the traditional course progression. Future investigation of additional off-track semesters is needed.

The authors also highlight a new concept quiz to measure achievement in understanding key statistical concepts. Further, the authors show that a large improvement in scores (44% to approximately 75%) from the beginning to end of the semester, thereby supporting the effectiveness of the student-centered, full engagement, flipped classroom. Although attitude can be indicative of achievement<sup>11</sup>, it is important to confirm that mastery of course concepts with an achievement based assessment. Further, this prevents potential discrepancies found in self-evaluation.

Many researchers have found that interest and utility value are indicative of achievement.<sup>11</sup> Initial investigation between attitude and achievement using Pearson’s correlation did not yield a correlation. Some studies show that achievement could result in improved attitude and therefore a delayed boost in attitude may be seen.<sup>18</sup> Delayed observation as well as additional correlation studies will be investigated.

In addition to attitude and achievement, persistence was investigated to provide a more complete assessment of these educational strategies. In all three semesters, persistence was higher than 98%, meaning that the majority of students did not drop the course in an attempt to take an equivalent course by another instructor with perhaps a different format.

This longitudinal study shows that the muddiest point exercise, team-based classroom activities, and pencasts are effective strategies in the flipped classroom. More specifically, these strategies received very favorable reviews in the BSS Survey. Further, according to the Student Value Survey on Muddiest Points (SVM), students felt that the muddiest point exercise was of interest, value, and did not cost too much in terms of time, emotion, or effort at both the mid-semester and end-of-semester assessments. Moreover, the concept quiz showed marked improvement in

understanding of key statistical concepts after student-centered, full engagement instruction in the flipped classroom. This is further supported by the high level of persistence observed.

In summary, this work describes a unique pedagogy highlighting web-enabled pencasts and muddiest points as well as group activities in a biomedical engineering statistics and design of experiments course for upper-division undergraduates and serves as a mechanism for just-in-time teaching. More specifically, our work demonstrates that pencasts are a simple alternative to creating lectures for flipped classrooms. Additionally, we have demonstrated longitudinally that this instructional paradigm incorporating pencasts, in-class activities, muddiest points, and a design project is an effective pedagogy for teaching and learning in the flipped classroom.

### **Acknowledgements**

The authors acknowledge the support of this work from NSF Grant #1226325.

## **Supplement A: BME Student-centered Strategies (BSS) Survey**

**Select a value from a range of 1-Strongly Disagree to 4-Strongly Agree.**

1. I prefer the flipped\* class to the traditional class setting. \*Flipped meaning review material at home and work on activities in class.
2. Reviewing the "Muddiest Points" does NOT help answer my questions.
3. The design project does NOT show the application of statistics in a real-world setting.
4. Class activities do NOT demonstrate the importance of statistics in the biomedical field.
5. I feel engaged during class activities.
6. The pencast lectures are NOT informative.
7. Watching pencast lectures helps me complete the in-class activities.
8. Most popular Muddiest Points are NOT answered in class with clarity.
9. The pencast lectures do NOT prepare me to complete the homework.
10. Group discussion is beneficial for completing class activities.
11. Online submission of the Muddiest/Most Interesting Points is difficult.
12. The flipped class allows me to prepare my questions before coming to class.
13. The flipped classroom is more effective than the traditional class setting.
14. The homeworks assigned are NOT helpful when completing the in-class assignments.
15. The design project helps me apply the material covered in the pencast lectures and inclass activities.
16. I think learning statistical software (SPSS) during class activities will assist in my career/future educational plans.
17. Working in groups for the design project does NOT facilitate my understanding of statistics.

Please comment below on the usefulness of this class. Would you recommend a flip class for other BME classes? Would you recommend any of the aspects of the flip class (Muddiest Point, Pencast Lecture, In-class Activities, Design Project, etc) for other classes?



## Supplement B: Statistics for Biomedical Engineers Concept Quiz

1. If a sample group has several factors that could produce bias in the data such as gender and age, which method would be best to reduce this bias?
  - A. confounding factor
  - B. grouping factors that could also influence the dependent variable
  - C. randomization
  - D. both B & C
2. All of the following are processes that should be randomized except:
  - A. sample selection
  - B. treatment assignments to each subject
  - C. order of data acquisition
  - D. grouping factors that could also influence the dependent variable
3. Which is the best way to determine sample number?
  - A. have at least three samples per group
  - B. test as many samples as possible
  - C. run analysis that incorporates key attributes of a pilot study
  - D. have four samples for each variable
4. Most physiological phenomena arise from random processes. If gathering data resulting from such a process to perform statistical analysis, increasing the sample number will do which of the following?
  - A. decrease the sample mean
  - B. make the data more normal
  - C. reduce the sample variance
  - D. both B & C
5. The point of any experiment is to either "fail to reject" or "reject" the null hypothesis. In which case would you "fail to reject" your null hypothesis according to rejection criteria?
  - A. the dependent variable increases as the independent variable increases
  - B. the dependent variable decreases as the independent variable increases
  - C. the dependent variable does not change as the independent variable increases
  - D. either A or B
6. Which of the following is NOT an example of an alternative hypothesis?
  - A. the mean of the data of the experimental group will not be equal to that of the control
  - B. the mean of the data of the experimental group will be greater than that of the control
  - C. the mean of the data of the experimental group will be less than that of the control
  - D. all of the above are alternative hypotheses
7. A researcher is interested in investigating the effects that caffeine has on blood pressure in humans. Which of the following tasks should he/she complete in order to control the experiment?
  - A. select a control group in which placebo is administered

- B. block for confounding factors
  - C. randomize order of treatments
  - D. all of the above
8. A company wants to determine if there is a statistically significant difference between their new cholesterol drug and their old cholesterol drug. Which test should the company use to compare the sample means?
- A. ANOVA
  - B. p-test
  - C. t-test
  - D. both B & C
9. Which of the following is/are the correct test(s) to compare sample variances of two populations?
- A. Analysis of Variance (ANOVA)
  - B. t-test
  - C. f-test
  - D. both A & C
10. A biomedical researcher has measured the strength of several different brands of coronary artery stents. Which of the following tests should he/she use to compare the data?
- A. ANOVA
  - B. t-test
  - C. f-test
  - D. none of the above

## Works Cited

1. Prince M. Does Active Learning Work? A Review of the Research. *J Eng Educ.* 2004;93(3):223-231.
2. McKeachie WJ. Student-centered versus instructor-centered instruction. *J Educ Psychol.* 1954;45(3):143-150. doi:<http://dx.doi.org/10.1037/h0060215>.
3. Mason GS, Shuman TR, Cook KE. Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course. *IEEE Trans Educ.* 2013;56(4):430-435. doi:10.1109/TE.2013.2249066.
4. Wilson SG. The Flipped Class: A Method to Address the Challenges of an Undergraduate Statistics Course. *Teach Psychol.* 2013;40(3):193-199. doi:10.1177/0098628313487461.
5. Krause S, Baker D, Carberry A, Koretsky M, Waters C. Muddiest Point Formative Feedback in Core Materials Classes with YouTube, Blackboard, Class Warm-ups and Word Clouds. *Am Soc Eng Educ.* 2013;ID7130.
6. Gupta S. Supplementing Instruction with Pencasts created with a SmartPen. In: *American Society of Engineering Education.* Atlanta: American Society of Engineering Education; 2013.
7. Mosteller F. The “Muddiest Point in the Lecture” as a Feedback Device. *J Harvard-Danforth Cent.* 1989;(April):10-21. <http://isites.harvard.edu/fs/docs/icb.topic771890.files/OTL3-Mosteller-Muddiest.pdf>.
8. Mosteller F. Broadening the Scope of Statistics and Statistical Education Broadening the Scope of Statistics and Statistical Education. *Am Stat.* 1988;42(2):93-99.
9. Cross KP, Angelo T. *Classroom Assessment Techniques: A Handbook for Faculty.* Jossey-Bass Publishers; 1988:1-168.
10. Smith KA, Sheppard SD, Johnson DW, Johnson RT. Pedagogies of engagement: Classroom-based practices. *J Eng Educ.* 2005;94(1):87-101.
11. Eccles JS, Wigfield A. Motivational beliefs, values, and goals. *Annu Rev Psychol.* 2002;53:109-132. doi:10.1146/annurev.psych.53.100901.135153.
12. Carberry A, Waters C, Krause S, Ankeny C. “Unmuddying” Course Content Using Muddiest Point Reflections. *Front Educ.* 2013;Oct 23-26:937-942.
13. Ankeny C, Krause S. Flipped Biomedical Engineering Classroom using Pencasts and Muddiest Point Web-enabled Tools. In: *American Society of Engineering Education.* Indianapolis; 2014.
14. Newstetter WC, Behraves E, Nersessian NJ, Fasse BB. Design Principles for Problem-Driven Learning Laboratories in Biomedical Engineering Education. *Ann Biomed Eng.* 2010;38(10):3257-3267. doi:10.1007/s10439-010-0063-x.
15. Garmendia Mujika M, Garikano Osinaga X, Sierra Uria E, Perez Manso A. Developing Teamwork Efficacy Factors: An Experience in a Project Based Learning Context. *Int J Eng Educ.* 2013;29(3, SI):752-762.

16. Bingham A. Student Attitudes to Real-World Projects in An Introductory Statistics Course. *Int Assoc Stat Educ.* 2010. [http://iase-web.org/documents/papers/icots8/ICOTS8\\_C203\\_BINGHAM.pdf](http://iase-web.org/documents/papers/icots8/ICOTS8_C203_BINGHAM.pdf).
17. Roesch D. Temporally contiguous pencast instruction promotes meaningful learning for dental and dental hygiene students in physiology. *J Dent Educ.* 2014.
18. Harackiewicz J, Hulleman C. The Importance of Interest: The Role of Achievement Goals and Task Values in Promoting the Development of Interest. *Soc Personal Psychol Compass.* 2010:42-52.