2018 ASEE Annual Conference & Exposition
Paper ID #23804

The Impact of Integrating a Flipped Lecture in a Biotransport Laboratory Course on Student Learning and Engagement

Asem Farooq Aboelzahab, Purdue University, West Lafayette (College of Engineering)

Asem Aboelzahab is the Lab and Assessment Coordinator in the Weldon School of Biomedical Engineering at Purdue University. He has been at Purdue since 2014. He instructs/coordinates undergraduate labs including Bioinstrumentation, Biotransport, and Capstone Senior Design. He also serves as the school's ABET coordinator. Asem received his BS and MS degrees in Bioengineering from the University of Toledo in Toledo, Ohio.

Tamara Lea Kinzer-Ursem, Purdue University-Main Campus, West Lafayette (College of Engineering)

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Abstract

Introduction: Inquiry-based learning is vital to the engineering design process, and most crucially in the laboratory and hands-on settings. Through the model of inquiry-based design, student teams are able to formulate critical inputs to the design process and develop a stronger and more relevant understanding of theoretical principles and their applications. In the junior-level Biotransport laboratory course at Purdue University's Weldon School of BME, the curriculum utilizes the engineering design process to guide students through three (3) different modules covering different Biotransport phenomena (diffusivity, mass transport, and heat transfer). Students are required to research, conceptualize, and generate hypotheses around a module prompt. Students design, execute, and analyze their own experimental setups to test the hypotheses within an autodidactic peer-learning structure. *Methods:* A multi-year study was completed spanning from 2014 to 2016, assessing students' end of course evaluations. With an integration of the flipped lecture into the lab being first implemented in 2015 (prior to 2015, the flipped lecture was a stand-alone course offered outside of the lab sections), the data presented here offers a comparison of student evaluations between these two course structures. Per the student response rates, the sample size for each year was: n=81 (2016); n=60 (2015); n=48 (2014). The surveys were anonymous and a host of questions related to overall course satisfaction, structure, and content were posed. *Results:* Analysis of the data showed a consistent increase in overall student satisfaction with the course following the implementation of the new structure. The percent of students giving a satisfactory rating or higher for the 2014, 2015 and 2016 course offerings was 79%, 89%, 92%, respectively. This shows a significant difference between 2014 and 2016. *Conclusion:* The integration of a flipped lecture into the lab successfully improved student satisfaction and self-perceived understanding of course material. This format also improved the delivery of content to students as assessed by maintaining pertinence to the lab topics and clear understanding of learning concepts.

Keywords: Inquiry-based learning; Flipped lecture; Laboratory modules; Active-learning

Introduction

The Biotransport Laboratory at Purdue University's Weldon School of Biomedical Engineering Program implements three main pedagogical learning methods, including inquiry-based, active-learning, and flipped-classroom strategies. Inquiry-based learning has been studied extensively and is reported to have positive impact on student performance and on the application of fundamental theory.[1-4] Through this guided inquiry method, students identify and work through a problem utilizing scientific methods of hypothesizing, designing, testing, observing, analyzing and reporting their results to gain an understanding of a topic while actively immersing themselves within experimentation.[5] The impact of this pedagogy on retention of information and skill development is profound.[6] Through inquiry-based learning, students are encouraged to be independent thinkers and build fundamental skills to help them address a problem.[7-9] Applying this technique within a lab environment, as is presented in this study, is expected to help improve student learning and mastery of skills versus a traditional laboratory that provides a clear protocol of steps to reach an end goal.[10-12]

Active learning methods provide students more freedom to interact with each other and learn in a more lateral manner from their peers, which has been found to be favorable for students and at the very least, achieves similar outcomes, if not better, than traditional classrooms.[13-15] It should be noted however, as with all learning methods, that the inquiry-based active-learning environment presents a challenge to students who require more guided support. Conversely, the growth in independence of student exploration and learning is a strong outcome of this learning method.[14]

The flipped lecture model inherently helps support the introduction of both the aforementioned pedagogies in that it provides students with self-paced access to the bulk of the course lecture material online, allowing for more practical problem-solving, critical thinking, and skills development exercises within the class time.[15-20] This method lends itself to the simple integration of active and inquiry-based learning activities to help relate the theoretical content learned through video-based lectures or other supplemental materials. Through these active in-class activities, student engagement amongst each other as well as with instructors has been shown to improve.[21-22] Through these 3 principles, we attempt to create an encouraging environment for students to learn while providing consistent support from the instructional team in an inquiry- based laboratory course with an integrated flipped lecture offered during each lab section. In this study, the combination of these learning methods has been demonstrated to improve student satisfaction in the course.

Course Description

In this work, we present a three-year analysis of the junior-level Biotransport laboratory course at Purdue University's BME Program. Structured as a guided inquiry-based lab, this course implements three 4-6 week modules with a focus on various applications of Biotransport phenomena allowing students to explore the experimental design process. Other tenants of the course focus on the design-build-test-learn cycle[23] and an integration of experimental inquiry and application of theory through computational modeling of the system under study. These modules focus on the transport phenomena of (1) nutrient diffusion through tissue, (2) drug delivery through the study of pharmaco-dynamics models, and (3) heat-transfer and cryopreservation techniques for long-term tissue storage. For each module, student teams are given a related module prompt that guides them to generate a testable hypothesis about the module and to identify variables and parameters whose variation (both experimentally and computationally) would allow them to test the hypothesis. Through the course of each module, student teams follow a typical schedule as follows:

1. Watch online lecture videos and complete lecture quiz
2. Participate in an In-Lab short lecture/problem-solving session
3. Complete a literature review

4. Design and present an experimental and computational model/protocol
5. Complete experimental runs and analysis (design-build-test-learn cycle)
6. Complete computational modeling runs and analysis (design-build-test-learn cycle)
7. Demonstrate individual progress
8. Report data through a formal laboratory report

Through this process, students are expected to combine both an experimental and computational model to evaluate the identified problem and test their constructed hypotheses. Computational software (namely COMSOL and Matlab) are used to develop mathematical models to help students predict experimental outcomes and define their parameters and variables. Through varying roles within each team across all three modules, each student is expected to obtain experience with both the experimental design, data gathering, computational modeling, and data analysis over the course of the semester. Team dynamics and individual participation are assessed regularly through the CATME tool for peer evaluations[24-25] as well as individual demonstrations. Through these various methods of assessment, students obtain regular and diverse feedback within each module and across modules.

The focus of this work is to assess student satisfaction across course structures (summarized in Table 1) over the 3 years being analyzed (2014, 2015, and 2016). It is important to note here that the analysis provided in this study does not directly assess learning outcomes in and of itself, but rather assesses the students' satisfaction and perception of the course's ability to achieve these outcomes. Specifically, the aim is to assess the impact of an innovative structural change (flipping the classroom and integrating into the lab) to the course starting in 2015 on student satisfaction with the course. The remainder of this section will explain the details of the course structure during 2014 and the changes made in 2015.

Table 1: Summary of course structure and structure changes by years

Years	Lecture Structure	Lab Structure
2015-Present	• Flipped lecture (online videos) • Lecture integrated into lab sections • Active-learning/ problem solving sessions at start of lab sections	• 3 Modules • 4 Sections • Office hours use increased
2014	• Flipped lecture (online videos) • Active-learning/ problem solving sessions held separately from lab	• 3 Modules • 3 Sections
2006-2013	• Traditional lecture • Held separately from lab	• 4 Modules • 3 Sections

Students register for both a 3-hour lab section as well as a separate lecture. Historically, the separate lecture course was taught as a traditional lecture, with the majority of the time used by the faculty to introduce new information. In 2014, the lecture content was flipped and placed online via recorded videos by the faculty. The class time was then used to review lecture content, solve sample problems, discuss experimental protocols, and work one-on-one with individual students/groups. The innovation implemented in 2015 and being assessed in this paper involved cancelling the stand-alone lecture course all-together and integrating its content (online videos and in-class problem-solving) into each individual lab section. As a result of this change, the course faculty dedicated more time to be available in each lab section and holding problem-solving activities to reinforce online lecture content at the start of each module.

Inherently, the integration of these active problem solving sessions into the lab sections allowed for a stronger instructor to student ratio, providing students more timely and direct feedback and interaction with the instructors. The faculty, lab instructor, and two teaching assistants were available for each lab period, providing an instructor to team ratio of 1:1.5 (maximum student occupancy per section is 24; maximum teams per section is 6). As the program grows and student cohort size expands, the implementation of this new structure and its inherent advantage of high instructor to student ratios is expected to be a critical strength of this course.

We hypothesize that this integrated format will help students better relate theory to practice and provide an overall stronger content delivery platform and increased student satisfaction.

Methods

This study compares student evaluations and feedback over 3 subsequent offerings in the spring semester of 2014 (n=48), 2015 (n=60), and 2016 (n=81). This study will focus on comparing student satisfaction with the course structure (summarized in Table 1) and use of teaching methods to achieve outcomes between these two distinct course structures (2014 and 2015-2016).

Through the initial implementation of the integrated course structure in 2015, several changes in student engagement were anticipated. For example, due to the removal of the stand-alone lecture and instead integrating this content in the start of each lab section, student teams were expected to more frequently use out of class time to complete experimental design and runs. Therefore, an increase in office hour attendance was expected and the instructional team began recording this data in 2015.

Assessment tool

Students completed an anonymous end of course evaluation each year assessing the ability of the course to employ various learning methods, teach fundamental course content, and provide clear feedback and regular assistance in lab. Student satisfaction was assessed within each category, in addition to overall course evaluations. The specific indicators for evaluation are presented in Table 2.

Table 2: End of course evaluation questions to assess student self-reported learning outcomes and satisfaction with course

Category	Course evaluation questions
Diversity of learning methods	LM1. This course gives me skills and techniques directly applicable to my career
	LM2. In this course, many methods are used to involve me in learning
	LM3. Lab experiences assist me in learning concepts
	LM4. Developing the design project is a good learning experience
	LM5. This course demonstrates how to apply concepts and methodologies
	LM6. This course contributed to my ability to work in a team to solve problems
Understanding of course content	CC1. This course contributed to my ability to use theoretical equations from fluid, heat, and mass transport topics to describe, model, analyze, and explain data collected from a
	CC2. This course contributed to my ability to design experiments in transport phenomena, collect relevant data, and create a comprehensive report that clearly demonstrates their findings
	CC3. This course contributed to my ability to propose and evaluate engineering design solutions to biologically or medically relevant problems using transport phenomena theory
	CC4. The concepts taught in this course were closely integrated with the concepts I learned in BME 304
Course logistics and clarity of expectations	CL1. Assignments are pertinent to topics presented in class
	CL2. Course assignments are returned quickly enough to benefit me
	CL3. Assistance is always available throughout lab sessions
	CL4. I am able to complete the lab activities in the time allotted
	CL5. Expectations about specific lab procedures are clearly stated

Statistical Analysis

For comparison of the three-year data (provided in percent of students agreeing with the given statement), a Chi-squared test was employed to analyze statistically significant differences between each years' results. A 95% confidence interval was used ($p < 0.05$) to indicate significant statistical difference in the year-to-year data.

Results and Discussion

To analyze how the structure of lecture/course delivery in a Biotransport Laboratory correlated with student perceptions of the course, we analyzed data from three years of student end-of-course evaluations. Assessments of overall satisfaction with the course, course content, course structure, and teaching methods are analyzed to quantify the difference between the 3 years being studied.

Overall course satisfaction

Students were asked to rank their overall satisfaction with the course. An increase in overall student satisfaction with the course year-to-year was seen (Figure 1), with a significant difference between 2014 (79.25%) and 2016 (92.41%), representing an overall 13.16% increase. The linear increase across the 3 years is very indicative of students' satisfaction with the course overall. It is important to note that due to 2015 being the first year of integrating the lecture into the lab, it was expected that a few offerings would be needed for a strong improvement to be seen. However, in just two years, there was a significant measurable increase in student satisfaction.

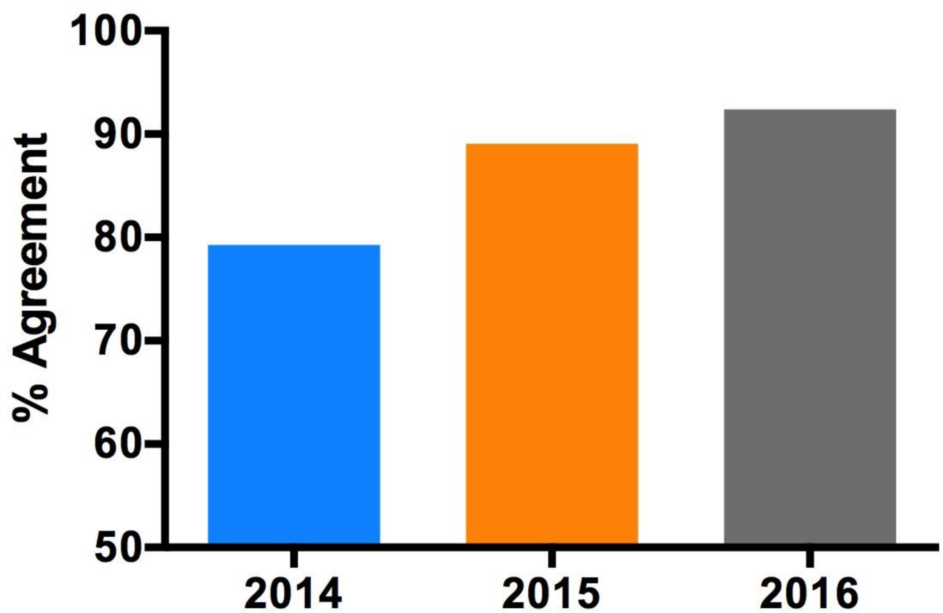


Figure 1: Overall course satisfaction. *Measure of overall student satisfaction with course through an end-of-semester anonymous course evaluation. The plot shows the % of students giving the course a rating of either "Excellent" or "Good" (% Agreement). Out of a scale of: Excellent, Good, Fair, Poor, Very Poor. * $p < 0.05$.*

Learning Methods

The ability of the course to employ various learning methods and offer students new technical and teamwork skills was analyzed using six (6) related questions in the end-of-course evaluation (LM1-LM6 in Table 1, analysis in Figure 2). It is evident that the integrated structure of the lecture and lab (2015 and 2016) saw higher student satisfaction across all learning methods and skills employed in the course. Particularly notable, is the course's ability to help students learn concepts and apply these concepts and methodologies to their experimental designs (LM3 and LM5 with 2014 to 2016 increases of 12.15% and 8.29%, respectfully). It is a positive result that these two components related to learning concepts and methodologies resulted in the highest impact (statistically significant difference between 2014 and 2016) due to the new course structure. Since the lecture's main goal is to introduce concepts and methods for students to use in lab, the integration in 2015 was concluded to have helped students relate material more clearly and apply their knowledge more seamlessly to their laboratory experimental design.

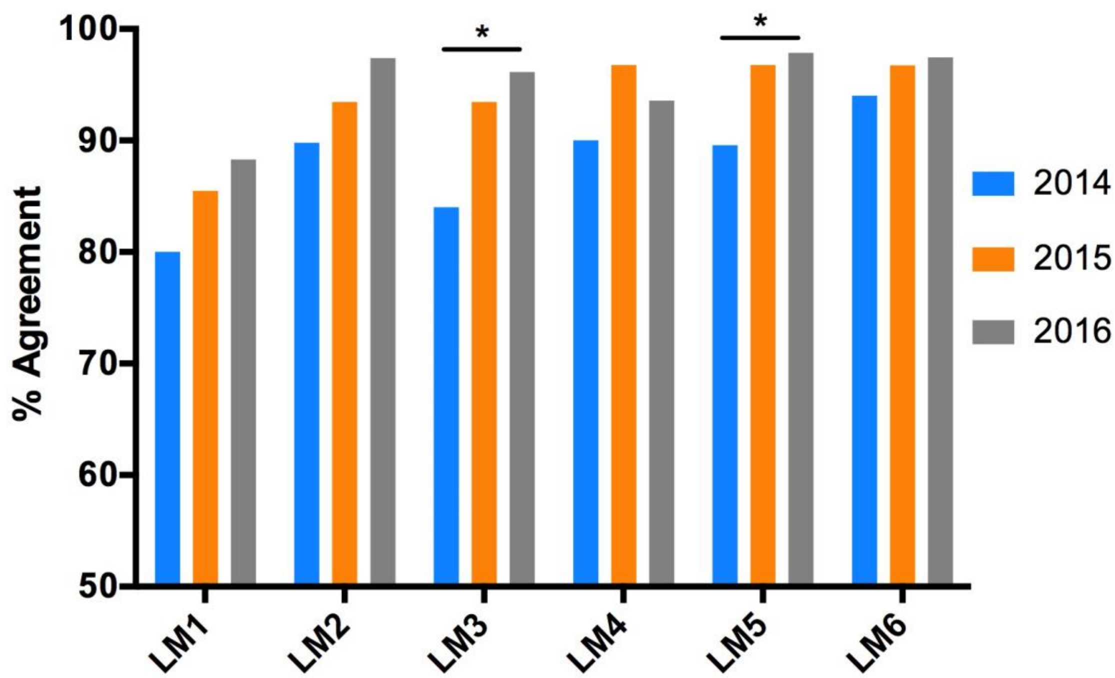


Figure 2: Learning Methods. *Measure of overall student satisfaction with how course applies various teaching/learning strategies to help students understand new concepts and stay engaged with the material introduced in the course. The plot shows the % of students giving a rating of either "Strongly Agree" or "Agree" (% Agreement). Out of a scale of: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree.* * $p < 0.05$.

Although significant increases were not seen across other student responses of the course's learning methods, there was a general increasing trend across the years studied, with students assessing the course more highly in contributing to their ability to work on a team, develop their projects, and learn new skills and techniques helpful for their careers.

<u>Course Content</u>

To assess student's perceptions of how well the course content prepared students for their Capstone senior design course, and how it connects to other relevant courses in the curriculum, data from four (4) related questions in the end-of-course evaluation (CC1 - CC4 in Table 1) were analyzed (Figure 3). Student's assessment of their own ability to propose and evaluate engineering design solutions (which is a critical skill required for their senior design course) improved significantly in 2016 and 2015 relative to 2014.

Additionally, an increased number of students felt that the course was more closely linked to its pre-requisite transport course (BME 304) within the curriculum. The students' perception of the course's ability to meet these criteria showed 24.21% and 13.73 % increases, respectively. This improvement is particularly significant due to the difficulty in correlating course content across the broader curriculum. The data shows that after the change in course structure, more students felt that course content was integrated with other courses in the curriculum. This is believed to be a direct result of delivering active-learning and problem solving sessions In-Lab. We speculate that this increase in student response was also a result of two indirect, yet beneficial, changes that were a result of the course structure change in 2015. 1) More direct and immediate feedback was given to students as a result of the increased student to instructor ratio (lecture faculty available in all lab sections, along with lab coordinator and two teaching assistants); providing the faculty an opportunity to adjust the content to help student teams with their actual experiments. And 2) students were better able to understand how the biotransport theory (provided in a pre-requisite course; BME 304) related to the lab because of an increased emphasis on integration of computational modeling and experiment.

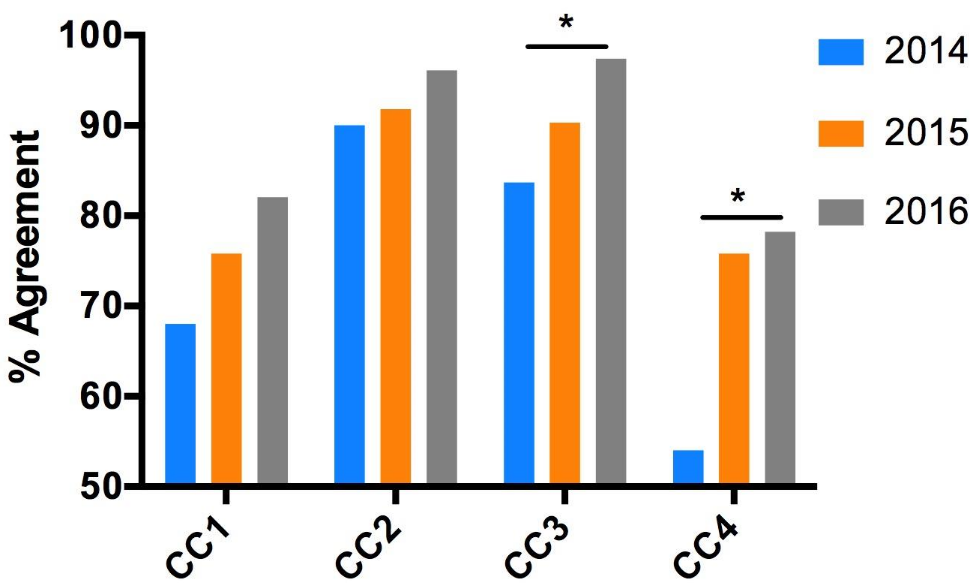
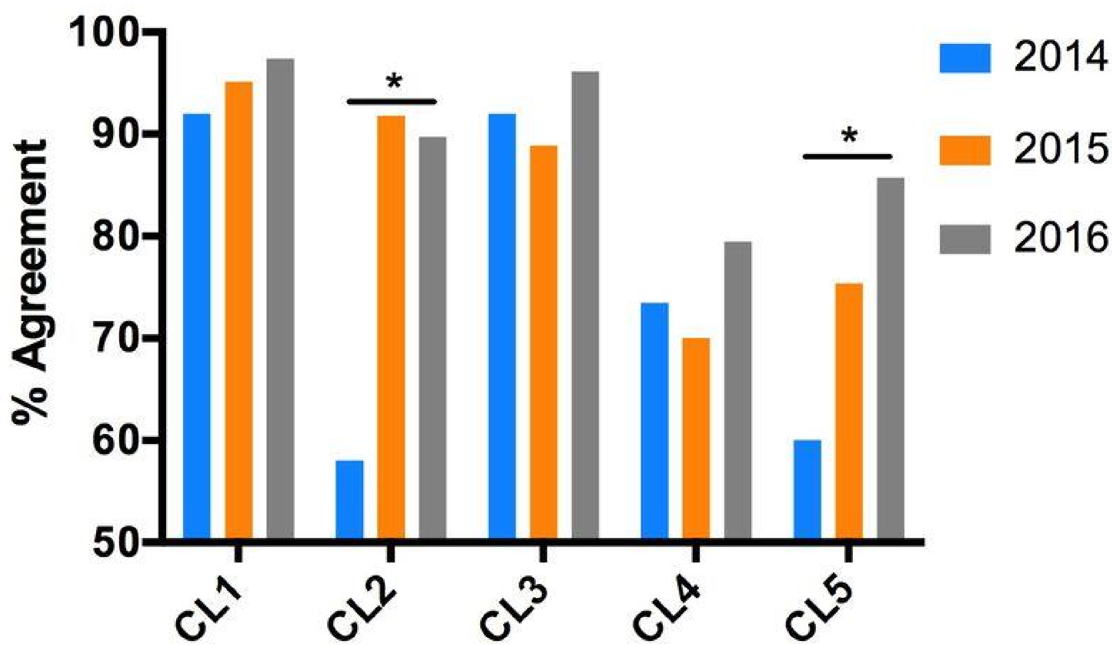


Figure 3: Course Content. *Measure of overall student satisfaction with how course applies theoretical Biotransport Phenomena principles to practical experimental prompts. The plot shows the % of students giving a rating of either "Strongly Agree" or "Agree" (% Agreement). Out of a scale of: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree. * $p < 0.05$.*

Course logistics

The final analysis group among the student course evaluations focused on course logistics. Data from five (5) related questions in the end-of-course evaluation (CL1 – CL5 in Table 1) was analyzed (Figure 4). The decrease in student to instructor ratio resulted in increased satisfaction in turn-around time for grading and getting feedback to student. Additionally, by having the entire instructional team together In-Lab, real-time decisions and on-the-spot changes could be implemented relating to specific grading and assignment expectations. As a result, these two course components showed a statistically significant increase in student satisfaction under the integrated course structure.

Students greatly appreciated the ability to receive immediate feedback on their experimental designs and computational models provided by the course instructional team. Someone is always available to help with all facets of their design process. Due to its hands-on nature, this lab course has historically always resulted in students finding assistance whenever needed, especially with more training and online tutorials being created each year to help support student's efforts. One major area for improvement is developing tutorials to get students acquainted with computational software that is novel to them so that they can pursue developing a more advanced mathematical model for their experiments.



4: Course Logistics. *Measure of overall student satisfaction with how course is structured, provides assistance, and clearly defines expectations. The plot shows the % of students giving a rating of either "Strongly Agree" or "Agree" (% Agreement). Out of a scale of: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree. * $p < 0.05$.*

Coincident with the course structure change, we observed a large increase in office hour attendance in 2015- 2016 compared to 2014. Integrating the lecture/problem-solving components of the course into the laboratory (2015 integrated structure) resulted in a decrease in time available (on average, approximately 20 min per session) for the students to spend on their laboratory work. Although data was not collected on this in 2014, the number of individual office hour visits from students during that year were approximated to be between 100 to 150 over the course of the semester. In 2015 and 2016, we saw 465 and 694 individual student visits to office hours, respectively. This shows more than a 4x increase in office hour utilization that cannot be explained by the minimal loss of In-Lab time. Instead we feel that flipping the course has helped develop a culture that allows students to become more comfortable with the course material and the lab environment and encouraged them to explore further aspects of their experimental design. Question CL4 showed no significant difference in the students' perception of their ability to complete the lab within the time allotted across the two course structures, supporting the fact that the course workload remained relatively static and the increased use of office hours was predominately related to the exploratory nature of the course and evolution of expectations among both instructors and students. This has been a positive result of the course change in 2015 and has also helped prepare students for a more rigorous laboratory and design experience in their Capstone Senior Design course.

Conclusion

Inquiry-based learning is a proven method to immerse students in an iterative design and research process that helps build critical thinking and design skills. The Biotransport laboratory course at X University's Biomedical Engineering program has re-developed a traditional lab- lecture sequence into an integrated experience that combines inquiry-based learning, active learning and a flipped classroom to more fluidly relate theory to practice. We have shown that flipping the classroom and bringing active learning and problem-solving sessions into the individual lab sections increased overall student satisfaction. It also significantly improved students' perception of their abilities to learn and apply concepts and methodologies, relate the lab activities to pre-requisite courses, and gain a clearer understanding of the course expectations. The course structure changes also increased instructor to student ratio, which resulted in increased student-instructor interaction, allowing for a more collaborative environment. As a result, we found that integrating active learning and problem-solving sessions into the laboratory improved student learning through an inquiry-based application.

Acknowledgements

The authors would like to acknowledge all of the faculty, staff and teaching assistants who have contributed to the initial development and continuous improvement of the course.

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