Application and Comparison of Active Learning Implementation Methods in Biochemistry Education

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APPLICATION AND COMPARISON OF ACTIVE LEARNING IMPLEMENTATION METHODS IN BIOCHEMISTRY EDUCATION

by

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ABSTRACT

Biochemistry has continued to be one of the most complex and important subjects in science education. The purpose of this research is to investigate active learning implementation methods in a Biochemistry I context to determine the most effective means of preparing current science undergraduates. Two Biochemistry I classes over two semesters were analyzed in this study, with class A using a variable active learning schedule and class B using a consistent active learning schedule. Four aspects were analyzed to determine active learning validity: perception of different active learning properties, standardized final exam grades, class grade, and teaching implementation. The consistent schedule of daily active learning in class B showed an increase in mean final exam score by 12.72%, significantly improved mean student grade in the class from a high C to a low B ($p = 0.0038$), and comparing student perception of active learning data, showed a significant decrease in student desire for passive learning ($p = 0.025$), increased desire for active learning ($p = 0.022$), and increased desire for flipped classrooms ($p = 0.042$) after first experiencing opposite results in the first semester of implementation which had increased desire for passive learning ($p = 0.003$) and teacher-centric learning ($p = 0.026$). A variable active learning schedule showed no significant values besides an increase in individual learning desire ($p = 0.037$) and a marginally significant increase in desire for passive learning ($p = 0.053$) both in its second semester of implementation. This research supports that a consistent, daily active learning curriculum making up approximately 40-50% of daily instruction is preferable compared to a variable lecture schedule with active learning days in between lecture days in undergraduate Biochemistry I large-class instruction given that professors perform it over multiple semesters.

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INTRODUCTION

The Programme for International Student Assessment (PISA) test, a standardized test used to compare critical thinking skills between countries, ranks the USA as 19th in the world (National Science Board, 2007). One out of five 15-year-old students scored low performance science scores in the USA, making the USA lower than 37 countries in science education (Department of Education, 2015). In 2015, the USA was ranked 24th in science literacy and 38th in math, making it substantially lower than expected considering the budget spent on education (Department of Education, 2015).

In response to this fall in educational standing versus foreign nations, The National Science Board established by the National Science Foundation created a detailed action plan to address three deficiencies in US science education: horizontal, vertical, and professional challenges (National Science Board, 2007). Horizontal challenges focus on the differing standards between schools which ultimately lead to stratification of knowledge between poor and advanced standards. Vertical challenges focus on the lack of connection between previously gained knowledge and present education. The final dilemma, professional challenges, highlights the problem of poorly trained educators as well as the structural issues of implementing new programs in classrooms.

The call to action to fix these problems is most apparent in post-secondary education. With a growing need for trained specialists in the medical and chemistry field, new pedagogical methods to meet the demand for critical thinking and application skills are required. One such approach, active learning, has been a proposed way to tackle this dilemma. Active learning incorporates the student into the learning process, encouraging independent thinking. Application of material exposes students to future situations in a safe environment, allowing students to apply their own scientific investigation skills to solve problems.

Several post-graduate institutions have taken active learning seriously as a method of improving the education of United States' schools. The Accreditation Council for Pharmacy Education (ACPE), the council responsible for standardizing the requirements for pharmacists across the USA, has listed its own new active learning strategies as requirements for pharmacy school education (ACPE, 2007). This model of instruction has also been spreading in medical education, accounting for 75% of all large group instruction methods in medical schools (McCoy et al. 2018). Graduate school programs have begun investigating active learning strategies, with curriculum reform incorporating active learning currently being published for biomedical sciences masters' programs (Bosch & Casadevall, 2017). Even dental schools have implemented new active learning strategies, with many proposing similar styles used in medical schools (Kellesarian, 2018).

Biochemistry I is arguably one of the most important subjects for students to master to become effective scientists with bachelor's degrees. For students who wish to pursue education beyond a bachelor's degree, biochemistry covers a substantial portion of the standards covered on the exam required for medical school entry (AAMC, 2018). Even excluding this exam, biochemistry is often the most advanced chemistry course taken by undergraduates, invariably forming a foundation that students will build on in the future of their careers. Due to biochemistry's influence, examining what changes can occur to more effectively meet the standards of higher institutions is required.

Problematically, while active learning is slowly being integrated into post-secondary education, there has been much less progress in undergraduate Biochemistry I. Even though Biochemistry I is essential for biology, chemistry, dentistry, pharmacy, and medical post-undergraduate work, the validity of active learning in classes with large student instruction remains mostly untested. Standardization of active learning curriculum is seldom seen in undergraduate education, as it is difficult to coordinate professors when no governing body enforces a standard teaching system like that of medical schools. Often when covering active learning in undergraduate biochemistry, only specific active learning methods are tested without factoring other aspects into the analysis of its validity. Studies often examine one method or specifically find student and teacher opinion of a technique without discussing the interaction of one method with another. Often studies do not cover how professors should be balancing lecture content with active learning and student participation.

The goal of this thesis, therefore, is to determine which active learning implementation methods are valid in an undergraduate Biochemistry I context with a focus on variable amounts of active learning during class instruction versus a consistent daily schedule of active learning. Three aspects are analyzed to cover the many sides of what constitutes validity of active learning; testing whether these aspects are possible to reach in an undergraduate setting will provide support as to which active learning strategies and methods are best suited for Biochemistry I.

Aspect 1. The curriculum, as well as its implementation, is still a question in biochemistry education. Active learning can be composed of multiple strategies ranging from flipped classroom designs to student-centric learning. Implementing these strategies in an undergraduate setting will provide support as to which active learning strategies are or are not valid in Biochemistry I. This includes analyzing whether consistent active learning: active learning composing half of classroom time daily, is more or less effective compared to variable-schedule active learning: when active learning is during specific days followed by days of mostly teacher-centric lectures.

Aspect 2. Do students, professors, and faculty have resources and a supportive environment for active learning? If the students are against active learning, if the faculty is not supportive of teachers implementing active learning, or if there is not institutional support to implement active learning, active learning is not a valid option.

Aspect 3. The active learning curriculum must address the vertical, horizontal, and professional challenges as defined by The National Science Foundation (National Science Board, 2007). The new curriculum must connect to previous knowledge to meet the vertical challenge, standardize learning requirements to meet the horizontal challenge, and prepare professors with the proper teacher training to meet the professional challenge.

BACKGROUND

Active Learning Research in Science: Select Findings

Active learning is the newly adopted system to meet the current challenges posed by the National Science Foundation. A recent meta-analysis of 224 studies on active learning found that active learning not only increased student grades by an average of half a letter grade, but also that each average exam score improved by approximately 6% (Freeman et al., 2014). The same meta-analysis determined that students given traditional lecturing were 1.5 times more likely to fail, with a 21.8% failure rate in active learning versus 33.8% during traditional lectures (Freeman et al., 2014). Altogether, the study found that by not putting active learning in place, an average of $3.5 million in tuition costs from students who failed could have been prevented (Freeman et al., 2014).

With these figures in mind, active learning may be the future of education. While many studies exist regarding active learning, there are still questions as to how active learning can be implemented in large-scale classrooms in colleges. While studies cover certain aspects of active learning, there can be a lack of comparison between the methods together in undergraduate biochemistry. Examining which pedagogical styles of implementation are effective in an undergraduate context is necessary to create a better picture of how active learning can be used in Biochemistry I.

In a study using active learning in organic chemistry over four semesters versus a semester without active learning, there were dramatic increases in student achievement (Jones-Wilson, 2005). While 30% of students were above the 70th percentile in the non-active learning semester, 70% of the students were above the 70^{th} percentile in the active learning semesters (Jones-Wilson, 2005). Students in an active learning classroom showed an 11.1-27% improvement in mean score on the standardized ACS organic chemistry exam compared to those in a traditional classroom (Jones-Wilson, 2005).

This trend also is observed in biology courses. Biology II classrooms comparing classes over three years before and after active learning found that students gained better scores on exams, with the class average on the final exam being 91% during one of the years of active learning versus the 85% average during the non-active learning year tested (Armbruster et al., 2009). This result was surprising, as the year tested with active learning had more challenging questions, with 25% of its questions being higher-order questions as defined by Bloom's taxonomy versus the 15-18% of the questions being higher-order in the non-active learning year (Armbruster et al., 2009). Students in this study also reported a significant increase in positivity towards the course between two of the years of active learning implementation versus traditional methods (Armbruster et al., 2009). Positive reports increased from 65% to 89% of the students, making this system a valuable addition for other biology II classes to consider (Armbruster et al., 2009). Increased positivity towards the material is beneficial, as it increases student desire to both participate in the course and learn more about the subject.

Active Learning and the Professor

While these results seem promising, other studies have shown opposing results. Introductory biology professors who had done little research on active learning and limited active learning training were less effective in increasing student performance with active learning strategies (Andrews et al., 2011). Andrews et al. showed little difference between active learning and non-active learning classrooms when teachers were not given training (2011). Even when trained effectively to teach active learning, educators must recognize when students are losing touch with the material; this is a separate skill. Another study investigating why students in medical school begin to drift from caring about active learning in classes found that students who disengaged with active learning mainly felt that they did not know how to engage with active learning or did not have previous skills for higher-order thinking to the level desired by the professors (White et al. 2014). These points bring up the differences between what makes a teacher effective versus ineffective at active learning and give an idea on what can be done to promote better educational outcomes. Ineffective instruction may be due to training, student ability to participate, or personal differences in learning.

What might improve the poor results in these studies is knowledge as to what skills make an educator most able to teach active learning. One study used 29 novice and 14 expert active learning biology professors based on their experience, number of years teaching active learning in biology, to find this answer (Auerbach et al., 2018). The study analyzed the written descriptions reported by the participants as they observed class instructions in active learning. Experts were 5.8 times more likely than novices to note “holding students accountable” during their observations (Auerbach et al., 2018). “Holding students accountable” included noticing how in-class assignments, in-class assessments, or participation in the learning could be a possible grade at any moment, therefore holding the students accountable for learning (Auerbach et al., 2018). Beyond making students participate in class, experts were 2.9 times more likely to give logic and reasoning for the observations they reported in their evaluations than novices (Auerbach et al., 2018). Experts defined reasons for why activities were performed and class, and how each activity related to learning. From this comes the main difference between what separates experts and novices in active learning: expert educators can identify practices which promote student accountability during class with possible graded assessments while having rational reasons for why activities are performed in class. Professional education in active learning needs to incorporate this idea properly in the training of educators to better promote active learning systems.

To use this principle during class time, teachers can use a technology-based response system. Studies have shown diverse ways to test students with clicker devices in active learning, either basing the entire class time on application questions the students respond to or occasionally using them to gauge the understanding of students (Solomon et al., 2018). These systems provide quantitative real-time evidence for the educator to assess what students understand. As an additional bonus, students are held responsible by being required to pay attention. Clickers unfortunately tend to limit responses to multiple-choice-only answers. An exploration into other novel technology in organic chemistry contexts has discussed the integration of new technology into coursework, such as apps which connect students and teachers both during and after class (Shea, 2016). These applications allow longer, written responses which promote critical thinking, as well as discussion boards to post and answer questions both inside and outside of class (Shea, 2016).

The other principle used by active learning experts revolves around the idea that experts give logical, purposeful reasons for all instruction. Standardization acts as a method of meeting this principle, as standards give students a set of expectations in a thought-provoking way. Learning objectives serve as standards to provide students a list of expectations from them; as discussed previously, experts in active learning have explanations and reasoning for what is performed in lecture while holding students accountable for meeting specific checkpoints. Standardized learning objectives are used by students as study tools as well. A study conducted with 185 students taking biochemistry and molecular biology class found that 47.4% of students employed learning objectives as questions to answer to confirm understanding (Osueke et al., 2018). Beyond this, 24.1% of students incorporated the learning goals as a guide for their studying, with 13.5% transforming them into a tool for self-assessment (Osueke et al., 2018). In that study, 57.1% of students indicated that objectives made it more explicit as to expectations for examination and 23.3% stated that learning goals helped with the organization of material for the course (Osueke et al., 2018).

Investigating Active Learning Instructional Methods

With standardization covering horizontal consistency across classes, the question becomes which teaching strategies will be used to meet them. Choosing which active learning strategy is appropriate for the curriculum is itself a challenge. Research indicates a student-centered approach typically goes together with active learning education. A student-centered approach focuses on students controlling the learning performed in the classroom, adapting learned skills to real-life scenarios. This classroom style contrasts teacher-centric models which use a trained professional who lectures and leads the class. Studies of student-centric active learning approaches in introductory biology have shown a significant positive relationship to student achievement (Derting & Ebert-May, 2010). Using the Biology Field Test, a standardized senior-year exam for undergraduate biology students, Derting & Ebert-May found an increase in scores, suggesting the active learning courses had benefitted the student learning long-term (2010).

Taking student-centric learning further is a flipped classroom model. Flipped classrooms perform lecture content outside of class to use in-class time for active-learning application of the material. When implementing flipped classrooms in organic chemistry instruction, grades increased by a statistically meaningful amount (Cormier & Voisard, 2018). The study consisted of three groups of students: high, moderate, and low achievement groups; from these groups, the study found that low achievers had a 10% average increase in score, moderate achievement students had a 7% increase, and high achievement students had a non-statistically significant 1% increase (Cormier & Voisard, 2018). It is understandable that the largest effect is seen in the lowest achieving students, as they have the most room for improvement compared to the other groups.

Flipped classrooms have benefits beyond increases in student scores. A study on flipped classrooms in medical sciences found a significant decrease in multi-tasking behavior during flipped classes versus traditional lectures (McLean et al., 2016). Multi-tasking diverts attention from learning, with over 80% of the students checking social media and over 80% texting during a normal class versus around 20% checking social media and 50% texting in flipped classrooms tested (McLean et al., 2016). Beyond improving focus on the material by limiting multitasking during class, flipped classrooms have the benefit of having recorded lecture content that the student can access outside of class. The study concerning flipped classrooms in medical science courses found that 35% of students reported relistening to the material content before the active learning application during class as a review (McLean et al., 2016). The ability to pause videos and write notes the student may not have had time to write is also beneficial to students, with 16% of those surveyed reporting that they would pause online lecture videos to take notes (McLean et al., 2016).

The flipped classroom model is not the only method used to promote active learning systems. Cooperative learning in which students work together to solve problems has been associated with active learning; this is in opposition to individual learning, in which the student learns alone (Stockwell et al., 2017). A study performed on eighty students taking biochemistry found that while both individual learning and cooperative learning students had similar results with strictly recall questions, a significantly better result was seen on questions involving prediction in the cooperative learning students (Stockwell et al., 2017). Taking this into account, it is suggestive that while students recall the same amount of information regardless of system, active learning using cooperative learning exposes students to more opinions and applies material to higher-order thinking.

A Disclaimer Concerning Active Learning and its Side Effects

Though the background in active learning research expresses the positives of active learning, one must also recognize that with implementation of any new system, negatives result as well. Current research in education has been reported to not consider these negative alternatives as a part of the conclusions reached in education studies, though it remains a pivotal component of research investigation (Zhao, 2017). Despite reporting positive results, there have been studies suggesting that a small subset of students may suffer in active learning classrooms as it can be anxiety-inducing (England et. al., 2017). In one study, 16% of the students tested from three undergraduate biology courses reported increased anxiety (England et. al., 2017).

When the study compared anxiety levels to student anticipated grade, there was a statistically significant association with lower reported score with higher self-reported anxiety (England et. al., 2017).

Other personal factors, such as socioeconomic status may similarly play a role in active learning. College students may not be able to afford computers to watch flipped classroom videos or may find it challenging to participate when time online is limited to university-owned computers. Some studies have indicated that minority populations in science, specifically females, can better perform in active learning classrooms, but the considerations of individual characteristics in the learning process and the hidden side effects are important when interpreting education data (Roberts et. al., 2018).

METHODS

Analytical methods are used to test the three aspects of active learning implementation. Aspect one asks which active learning systems are usable in undergraduate classrooms and whether consistent or variable active learning schedules are best for biochemistry. Aspect two considers the opinion and support of faculty and students regarding active learning. Aspect three focuses on horizontal, vertical, and professional challenges currently facing science education. An active learning system is invalid in the context of this experiment if it does not adequately cover one of the aspects.

Two undergraduate Biochemistry I professors participated in this experiment, each with one classroom per semester involved in this study. The participating professors had different experience levels: one professor was teaching for the first time, and one professor had multiple years of experience teaching Biochemistry I. In this way, the effect of experience on active learning implementation can be tested. The professor with multiple years of teaching (professor A) had a class composed of 220 students while the professor who had not previously taught Biochemistry I (professor B) had a class of 300 students. These teachers were followed over two semesters of active learning implementation to note differences over time. Due to using surveys in the classroom, approval for this research was granted by the UCF IRB as exempt-research (Appendix A).

Aspect One Methodology: Determining the Appropriate Curriculum Design

To identify the strategies used by professors implementing active learning, data collection methods used in prior research were consulted and a new active learning inventory measurement tool was constructed (Van Amburgh et al., 2007). The tool by which this study charts active learning categorization got its inspiration from is used in pharmaceutical education to both categorize and identify active learning systems; it was chosen based on its ability to categorize active learning strategies into different levels (high, medium, and low) as well as its research backing in pharmaceutical education which requires active learning as established by the Accreditation Council for Pharmacy Education (Van Amburgh et al., 2007). Cooperative learning, scenarios, and connecting concepts are just some of the examples of higher-order active learning tasks possible in classrooms while minute-papers and computer-based interaction are examples of lower-order (Van Amburgh et al., 2007). The tool used in this active learning research uses similar values and their complexity levels as indicated by Van Amburgh et al., with calculations to indicate how much of the instruction time was used for different complexity levels of active learning (2007). The active learning measurement chart similarly does these things though in a modified way (Appendix B).

Comparing mean time of active learning activities over a few observations will give an idea of whether the course is variable versus consistent in its approach to active learning. Variable active learning in the case of this study means teacher-centric lecturing followed by days where active learning makes up the entire class time in between. Consistent active learning is defined by daily classes of active learning where half of class time is active learning and half is lecturing or explaining daily.

Beyond this, the average score on the final exam for both classes was recorded. This final exam is standardized by the department at the college where this study is performed, allowing it to be an effective comparison between semesters. Student grades were also collected as de-identified data when possible and compared with a Welch's t-test as well. The grades are mainly a means to compare a professor over time to themselves to see if there is a change in how teaching style affects student understanding rather than a comparison between one teacher versus another.

Aspect Two Methodology: Measuring Student and Faculty Opinion

Surveys which measure student and faculty opinion use Likert-style questions to indicate student perception in active learning curriculum (Wiggins et al., 2017). Student and teacher opinion on different active learning components as well as non-active learning counterparts were possible to analyze.

Surveys in this experiment used the standard categories of student agreement from strongly disagree to strongly agree with the following choices: strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree (Wiggins et al., 2017). This thesis focuses on different aspects of active learning on undergraduate biochemistry and therefore, questions had to be created according to the what was necessary to measure in this study. Graphs were generated with the number of each response to understand changes over time for each specific question. To avoid random answering, a question which asked for a particular answer was given, identifying students who were either rushing through questions or not legitimately answering the survey.

For this study, four specific areas were targeted: active versus passive learning, traditional versus flipped classrooms, teacher versus student-centered learning models, and individual versus cooperative learning. Each of these four categories offered a better idea of how active learning should be implemented while noting student and teacher opinion for analysis. To test opinion of these categories, students and faculty were surveyed at the beginning and the end of the semester over two semesters (Appendix C). Surveys at the start of the semester were compared with those at the end to determine if the educators or the students changed opinions throughout the semester. Increase in desire for active learning questions indicate support of the curriculum while increase in desire for passive learning questions reject active learning as a valid teaching method for college Biochemistry I.

Teachers were given these same questions though their survey was more extensive, assessing the overall workload and confidence the educators have when teaching the curriculum (Appendix D). These added questions measure the workload involved in active learning and whether educators feel that active learning implementation is possible. Also, the surveys question the support of other faculty members to gauge how the university may affect active learning being put into practice.

Aspect Three Methodology: Standardization and Training of Educators

The American Society for Biochemistry and Molecular Biology (ASBMB), the main body for biochemistry standardization, was one of the leading guides as to the standards for this curriculum (ASBMB, 2017). Difficulty levels are listed for each learning objective by the ASBMB, with each objective acting as a guide to meet the horizontal challenge of standardizing biochemistry coursework across undergraduate education. Furthermore, the standards incorporate previous chemistry knowledge effectively into biochemistry lessons, therefore meeting the vertical challenge of aspect three. Using their publication as an example, one can see the incorporation of Bloom's taxonomy as well as open-ended application questions (ASBMB, 2017). The required textbook, as well as the order of concepts chosen by the faculty, did not perfectly match the order or grouping of the ASBMB however the standards used were similar in what was covered in the course (ASBMB, 2017). The standards in the participating classes are more specific to the instruction at UCF and not as broadly applicable. Nevertheless, the standards used in the class and tested on the standardized final exam mostly fit in line with the official standards of the ASMB (Appendix E).

Both classes were provided the same standards to meet the horizontal challenge. Participating professors worked together to create video lessons for a flipped classroom. Learning how to make videos was mainly the responsibility of the educators. Both classes used similar standard technologies including a clicker-based system to measure student understanding in real-time as well as an online application which allowed cooperative learning and group discussion both during and outside of class. Measuring presence or absence of standards in the classroom as well as adherence to them is necessary to see if the standardization portion, or horizontal challenge, was met.

Statistical Methods

Statistical methods use Welch's t-tests for surveys in this study. T-tests allow comparisons to be made between the beginning and end of the semester. Welch's t-tests were used due to their ability to function despite unequal variances; Student's t-tests often lead to inaccurate results when a large difference in participants is used and current research suggests Welch's t-tests should be the default for psychology research for perception measurement (Delacre et al., 2017). Due to the sample size changing in both semesters, Welch's t-tests eliminate variability as a factor. As the sample was taken from the same class at the start and end of the semester, it is a method that works best for this study. The value a= 0.05 was used to compare p-values to, as is the standard in research for determining statistical significance.

Possible Dilemmas

Since undergraduate sciences are amenable to active learning methods, implementing these methods for Biochemistry I is a challenge. Cooperative learning, flipped classrooms, and student-centric learning are all effective active learning methods, however they may not apply well to Biochemistry I. Ultimately, some students are bound to fail the course regardless of the instruction method, as biochemistry is a difficult subject. Assuming strategies will reach everyone in the class is unrealistic.

Several problems may arise in implementation. Undergraduate classes at UCF pose a challenge due to their large number of students which can be difficult to control without experience. Furthermore, professors themselves may affect results. In a study concerning the opinion of professors teaching active learning in physiology for the first time, 22% of the educators reported lack of proper training to devise an active learning plan (Miller & Metz, 2014). Furthermore, 11% of the teachers in the study felt that the administration was not available to assist in the application of the curriculum (Miller & Metz, 2014). 89% of the professors in the physiology active learning study claimed there would not be sufficient time to give active learning lessons as a major concern (Miller & Metz, 2014). When put into practice the timing for lessons became much less of an issue, changing to 33% of professors reporting it as an issue at the end of the study versus the original 89% (Miller & Metz, 2014). Analyzing these results, it seems that teachers may struggle with correct implementation. Though the curriculum was designed before the semester for the faculty in this thesis, deviations and unforeseen circumstances were inevitable.

Regarding professors, only so much control is possible, as their classrooms are going to be different depending on past teaching experience and teaching ideologies. Professors may choose different amounts of active learning in their classrooms or may rely on past teacher-centric methods instead of active learning. The inverse is also possible: a teacher may be too willing to do active learning without allowing time to lecture and introduce new concepts.

RESULTS

Semester One: Fall 2018

Professor A used computer-based interaction systems and cooperative cases as active learning strategies. Observation 1 indicated two instances of active learning, observation 2 had four cases of active learning, and observation 3 had four cases of active learning during the random dates of data collection. Professor B used computer-based interaction systems, preconception checks, question and answer, and cooperative cases as active learning strategies. Observation 1 indicated nine instances of active learning, observation 2 had eight cases of active learning, and observation 3 had seven cases of active learning during the random dates of data collection.

Table 1: Fall 2018 Professor A Active Learning Strategies

Observation 1			
Description	Time Start-Time End	Time	Complexity
Computer-Based Interaction Systems	11:43AM-11:44AM	1 minute	Low
Computer-Based Interaction Systems	12:18PM-12:20PM	2 minutes	Low
Observation 2			
Description	Time Start-Time End	Time	Complexity
Cooperative Case (#1)	11:30AM-11:44AM	14 minutes	High
Cooperative Case (#2)	11:50AM-12:00PM	10 minutes	High
Cooperative Case (#3)	12:04PM-12:12PM	8 minutes	High
Cooperative Case (#4)	12:14PM-12:20PM	6 minutes	High
Observation 3			
Description	Time Start-Time End	Time	Complexity
Computer-Based Interaction Systems	11:32AM-11:35AM	3 minutes	Low
Cooperative Case (#1)	12:11PM-12:14PM	3 minutes	High
Computer-Based Interaction Systems	12:14PM-12:16PM	2 minutes	Low
Cooperative Case (#2)	12:16PM-12:20PM	4 minutes	High

Table 2: Fall 2018 Professor B Active Learning Strategies

Observation 1			
Description	Time Start-Time End	Time (minutes)	Complexity
Case (#1)	7:30 AM – 7:35 AM	5	High
Computer-Based Interaction Systems	7:36 AM - 7:37 AM	1	Low
Preconception Check	7:37 AM - 7:41 AM	4	Low
Cooperative Case (#2)	7:55 AM - 7:58 AM	3	High
Cooperative Case (#2)	8:00 AM - 8:10AM	10	High
Question and Answer	8:20 AM - 8:21 AM	1	Low
Cooperative Case (#3)	8:24 AM - 8:36 AM	12	High
Cooperative Case (#4)	8:38 AM – 8:40 AM	2	High
Computer-Based Interaction Systems	8:44 AM – 8:45 AM	1	Low
Observation 2			
Description	Time Start-Time End	Time (minutes)	Complexity
Computer-Based Interaction Systems	7:30 AM - 7:32 AM	2	Low
Cooperative Case (#1)	7:33 AM – 7:39 AM	6	High
Cooperative Case (#2)	7:40 – 7:48 AM	8	High
Cooperative Case (#3)	7:57 – 8:07 AM	10	High
Cooperative Case (#4)	8:19 – 8:24 AM	5	High
Computer-Based Interaction Systems	8:25 AM - 8:28 AM	3	Low
Question and Answer	8:30 AM - 8:31 AM	1	Low
Cooperative Case (#5)	8:38 – 8:44 AM	8	High
Observation 3			
Description	Time Start-Time End	Time (minutes)	Complexity
Computer-Based Interaction Systems	7:30 AM - 7:32 AM	2	Low
Cooperative Case (#1)	7:37 AM - 7:46 AM	9	High
Cooperative Case (#2)	7:58 AM - 8:08AM	10	High
Cooperative Case (#3)	8:22 AM - 8:30 AM	8	High
Question and Answer	8:20 AM - 8:21 AM	1	Low
Cooperative Case (#4)	8:23 AM – 8:28 AM	5	High
Computer-Based Interaction Systems	8:47 AM – 8:50 AM	3	Low

Professor A spent an average of 35.33% of lecture time implementing active learning activities compared to 50% of in Professor B's class. Professor B on average had more active learning tasks and used more high complexity strategies versus professor A. Standard deviations were 29.68% for A versus 2.7% for professor B. Average time spent doing active learning is 4.67 minutes for professor A with a standard deviation of 3.47 minutes while professor A spent 5.0 minutes per activity with a standard deviation of 0.51 minutes. Note that three observations may not accurately reflect the semester. Further observations would make the data more accurate.

Table 3: Fall 2018 Observation Data

	Observation 1		Observation 2		Observation 3	
Professor	A	B	A	B	A	B
Number of low complexity tasks/total	2/2= 100%	4/9= 44.4%	0/4= 0%	3/8= 37.5%	2/4= 50%	3/7= 42.86%
Number of medium complexity tasks/total	0/ = 0%	0/9= 0%	0/4 = 0%	0/8 = 0%	0/4 = 0%	0/7 = 0%
Number of high complexity tasks/total	0/2= 50%	5/9 = 55.6%	4/4 = 100%	5/8 = 62.5%	2/4 = 50%	4/7 = 57.14%
Time spent on active learning/total time	3/50 = 6%	39/80 = 48.75%	38/50 = 76%	43/80 = 53.75%	12/50 = 24%	38/80 = 47.5%
Time spent on non-active learning/total time	44/50= 94%	41/80 = 51.25%	14/50 = 24%	37/80 = 46.25%	38/50 = 76%	42/80 = 52.5%
Average time per active learning activity	1.5 minutes	4.33 minutes	9.5 minutes	5.38 minutes	3 minutes	5.43 minutes

Table 4: Fall 2018 Mean Class Time Data

Professor	Mean % of Class Time Active Learning (3 Random Observations)	Mean Time per Active Learning Activity (3 Random Observations)
A	(24+6+76)/3= 35.33% Standard Deviation= 29.68%	(1.5+9.5+3)/3= 4.67 minutes Standard Deviation= 3.47 minutes
B	(48.75+53.75+47.5)/3= 50.00% Standard Deviation= 2.7%	(4.33+5.38+5.43)/3= 5.05 minutes Standard Deviation= 0.51 minutes

Comparing student perception of active learning data between start and end of the semester using a= 0.05, students in class A reported no significant changes in opinion, while in class B, there was a significant increase in desire for passive learning (p= 0.003) and teacher-centric learning (p= 0.026). Neither class had a significant change in traditional versus flipped classroom perception nor a significant difference in cooperative versus individual learning. Note that strongly agree was indicated as 1, agree as 2, neither agree nor disagree as 3, disagree as 4, and strongly disagree was 5 in the data as Likert-data scores.

Table 5: Fall 2018 Student Survey Data

	Question 1		Question 2		Question 3		Question 4	
Class	t-value	p- value	t-value	p- value	t-value	p- value	t- value	p- value
A	0.906	0.365	-0.296	0.768	0.316	0.752	-0.882	0.378
B	2.993	0.003	-0.509	0.611	1.243	0.215	-1.473	0.142
	Question 5		Question 6		Question 7		Question 8	
Class	t-value	p- value	t-value	p- value	t-value	p- value	t- value	p- value
A	1.632	0.104	-0.174	0.862	0.602	0.548	-1.623	0.106
B	2.236	0.026	-0.857	0.392	-0.255	0.799	-0.140	0.889

Question Guide	
Question	Topic
1 and 2	Active learning (1) versus passive learning (2)
3 and 4	Traditional classrooms (3) versus flipped classrooms (4)
5 and 6	Teacher-centric (5) versus student-centric (6) learning model
7 and 8	Individual learning (7) versus cooperative learning (8)

Semester Two: Spring 2019

Professor A used computer-based interaction systems, question and answer, and cases as active learning strategies. Observation 1 indicated three instances of active learning, observation 2 had three, and observation 3 had twelve during the random dates of data collection. Professor B used computer-based interaction systems, peer teaching, small group discussion, and cooperative cases. Observation 1 indicated nine instances of active learning, observation 2 had six, and observation 3 had six during the random dates of data collection.

Table 6: Spring 2019 Professor A Active Learning Strategies

Observation 1			
Description	Time Start-Time End	Time (minutes)	Complexity
Cases (#1)	2:35 PM – 2:40 PM	5	High
Computer-Based Interaction Systems	3:14 PM – 3:16 PM	2	Low
Computer-Based Interaction Systems	3:17 PM – 2:20 PM	3	Low
Observation 2			
Description	Time Start-Time End	Time (minutes)	Complexity
Cases (#1)	2:34 PM – 2:44 PM	10	High
Cases (#2)	2:50 PM – 3:06 PM	16	High
Cases (#3)	3:08 PM – 3:14 PM	6	High
Observation 3			
Description	Time Start-Time End	Time (minutes)	Complexity
Cases (#1)	2:38 PM – 2:45 PM	7	High
Question and Answer	2:49 PM – 2:54 PM	5	Low
Question and Answer	2:54 PM – 2:56 PM	2	Low
Question and Answer	2:56 PM – 2:58 PM	2	Low
Cases (#2)	2:58 PM – 3:00 PM	2	High
Cases (#3)	3:04 PM – 3:06 PM	2	High
Cases (#4)	3:06 PM – 3:09 PM	3	High
Cases (#5)	3:09 PM – 3:12 PM	3	High
Cases (#6)	3:12 PM – 3:14 PM	2	High
Cases (#7)	3:14 PM – 3:16 PM	2	High
Cases (#8)	3:16 PM – 3:17 PM	1	High
Cases (#9)	3:17 PM – 3:20 PM	3	High

Table 7: Spring 2019 Professor B Active Learning Strategies

Observation 1			
Description	Time Start-Time End	Time	Complexity
Computer-Based Interaction Systems	11:30 AM – 11:31 AM	1 minute	Low
Cooperative Case (#1)	11:32 AM – 11:36 AM	4 minutes	High
Computer-Based Interaction Systems	11:40 AM – 11:41 AM	1 minutes	Low
Cooperative Case (#2)	11:41 AM – 11:44 AM	3 minutes	High
Cooperative Case (#3)	11:44 AM – 11:50 AM	6 minutes	High
Cooperative Case (#4)	11:55 AM – 11:58 AM	3 minutes	High
Cooperative Case (#5)	12:06 PM – 12:08 PM	2 minutes	High
Cooperative Case (#6)	12:08 PM – 12:12 PM	4 minutes	High
Computer-Based Interaction Systems	12:12 PM – 12:13 PM	1 minutes	Low
Observation 2			
Description	Time Start-Time End	Time	Complexity
Computer-Based Interaction Systems	11:30 AM – 11:32 AM	2 minutes	Low
Peer Teaching	11:33 AM – 11:34 AM	1 minute	Medium
Cooperative Case (#1)	11:42 AM – 11:46 AM	4 minutes	High
Cooperative Case (#2)	11:47 AM – 11:48 AM	1 minute	High
Cooperative Case (#3)	12:06 PM – 12:10 PM	4 minutes	High
Cooperative Case (#4)	12:13 PM – 12:20 PM	7 minutes	High
Observation 3			
Description	Time Start-Time End	Time	Complexity
Computer-Based Interaction Systems	11:30 AM – 11:33 AM	3 minutes	Low
Cooperative Case (#1)	11:36 AM – 11:40 AM	4 minutes	High
Cooperative Case (#2)	11:49 AM – 11:51 AM	2 minutes	High
Cooperative Case (#3)	11:54 AM – 11:55 AM	1 minute	High
Small Group Discussion	12:00 PM – 12:04 PM	4 minutes	Medium
Cooperative Case (#4)	12:09 PM – 12:15 PM	6 minutes	High

Professor A spent an average of 50.67% of lecture time doing active learning activities compared to 42.67% of in professor B’s class. Standard deviations were 21.75% for A versus 5.25% for professor B. More high complexity tasks were performed in professor B’s class (14 versus 13). Average time spent doing active learning is 5.44 minutes for professor A with a standard deviation of 3.72 minutes while professor B spent 3.09 minutes per active learning activity with a standard deviation of 0.40 minutes.

Table 8: Spring 2019 Observation Data

	Observation 1		Observation 2		Observation 3	
Professor	A	B	A	B	A	B
Number of low complexity tasks/total	2/3= 66.67%	3/9= 33%	0/3= 0%	1/6 = 16.67%	3/12= 25%	1/6= 16.67%
Number of medium complexity tasks/total	0/3= 0%	0/9= 0%	0/3= 0%	1/6 = 16.67%	0/12= 0%	1/6= 16.67%
Number of high complexity tasks/total	1/3= 33.33%	6/9= 66.67%	3/3= 100%	4/6 = 66.67%	9/12= 75%	4/6= 66.67%
Time spent on active learning/total time	10/50= 20%	25/50= 50%	32/50= 64%	19/50 = 38%	34/50= 68%	20/50 = 40%
Time spent on non-active learning/total time	40/50= 80%	25/50= 50%	18/50= 36%	31/50 = 62%	16/50= 32%	30/50= 60%
Average time per active learning activity	3.33 minutes	2.78 minutes	10.67 minutes	3.17 minutes	2.33 minutes	3.33 minutes

Table 9: Spring 2019 Mean Class Time Data

Professor	Mean % of Class Time Active Learning (3 Random Observations)	Mean Time per Active Learning Activity (3 Random Observations)
A	(20+64+68)/3= 50.67% Standard Deviation= 21.75%	(3.33+10.67+2.33)/3= 5.44 minutes Standard Deviation= 3.72 minutes
B	(50+38+40)/3= 42.67% Standard Deviation= 5.25%	(2.78+3.17+3.33)/3= 3.09 minutes Standard Deviation= 0.40 minutes

Comparing student perception of active learning data using a= 0.05 from start to end of this semester, students in class A reported a significant increase in desire for individual learning (p= 0.037) and a marginal increase in passive learning (p= 0.053), while in class B there was a significant decrease in desire for passive learning (p= 0.025), a significant increase in desire for active learning (p= 0.022), and a significant increase in desire for flipped classrooms (p= 0.042).

There was no significant increase nor decrease in desire for teacher nor student-centric learning models.

Table 10: Spring 2019 Survey Data

	Question 1		Question 2		Question 3		Question 4	
Class	t-value	p- value	t-value	p- value	t-value	p- value	t- value	p- value
A	1.944	0.053	-0.378	0.706	1.151	0.251	0.202	0.840
B	-2.257	0.025	2.300	0.022	-0.315	0.753	2.041	0.042
	Question 5		Question 6		Question 7		Question 8	
Class	t-value	p- value	t-value	p- value	t-value	p- value	t- value	p- value
A	-0.498	0.619	1.246	0.214	2.093	0.037	1.364	0.174
B	0.829	0.408	-0.324	0.746	-0.040	0.968	1.024	0.306

Question Guide	
Question	Topic
1 and 2	Active learning (1) versus passive learning (2)
3 and 4	Traditional classrooms (3) versus flipped classrooms (4)
5 and 6	Teacher-centric (5) versus student-centric (6) learning model
7 and 8	Individual learning (7) versus cooperative learning (8)

Final Exam Grade Data

Class A reported an average score of 45% and class B reported an average score of 48.44% on the standardized departmental final exam. The second semester yields different results. Class A had an average score of 41.65% on the final exam while class B had an average score of 61.16%. Class B’s average final exam scores therefore improved by 12.72% while class A’s average final exam score stayed consistent, neither increasing nor decreasing (a 3.35% non-significant decrease in score). Questions shared in both classes on the standardized exam were also gathered to see changes in mean score over the semesters. Note that mean final exam score was only performed over two consecutive semesters and therefore may not fully represent data accurately. More testing would be best to further back up these results or disprove the results.

Table 11: Final Exam- Percentage of Students with Correct Answer

Question	Class A		Class B	
	Fall Student % Correct	Spring Student % Correct	Fall Student % Correct	Spring Student % Correct
Q1	38	64	24.66	77.58
Q2	71	68	94.52	91.03
Q3	37	21	39.73	69.51
Q4	39	61	60.27	79.37
Q6	65	68	64.38	81.61
Q7	32	31	71.23	83.41
Q9	32	39	42.47	45.29
Q12	72	68	56.16	70.40
Q14	72	43	NA	64.57
Q15	55	46	19.18	27.35
Q19	64	36	52.05	65.02
Q20	49	39	57.53	65.02
Q21	14	23	27.4	29.60
Q22	22	19	32.88	27.35
Q25	35	41	47.95	46.19
Q26	41	43	52.05	78.48
Q27	64	65	93.15	96.41
Q28	NA	17	50.68	60.99
Q29	51	43	57.53	76.23
Q33	48	35	71.23	80.72
Q34	45	52	42.47	62.78
Q35	26	24	24.66	28.70
Q36	49	39	34.25	75.78
Q40	29	28	28.77	34.08
Q42	35	23	28.77	37.67
Q44	40	47	36.99	34.98
De-Identified Grade Data Retrieved from: Dr. Jonathan Caranto				

Table 12: Final Exam Average Grade

Class	Fall 2018 Average Final Exam Score	Spring 2019 Average Final Exam Score	Change in Score
Class A	45%	41.65%	-3.35%
Class B	48.44%	61.16%	+12.72%
De-Identified Grade Data Retrieved from: Dr. Jonathan Caranto			

Course Grade Differences

Grades were unable to be collected from class A. This is due to inaccessibility of the data, as it was not reported from the department by the time this thesis was published. Class B however did have data available.

Regarding class B, data was collected for both semesters and the significance of the course grade distribution change between semester one and two was also recorded. Mean student grade was measured in a scale assigning a value from 1 to 5: F= 1, D= 2, C= 3, B= 4, and A=5. This was used due to inability to access specific student grades, as these are protected by FERPA. From the grade distribution data provided, a value was also generated to test significance in the change of grade between grades of students in semester one versus two. The mean score for fall 2018 for class B was a C (3.86) while the mean score for spring 2019 was a B (4.10). Fall class B had N= 278 versus the spring class with N=232 when collecting grade data. The variability from the change in student enrolment size was accounted for in the Welch's t-test. Note that the first semester for class B used extra credit to raise scores due to low student grades yet the grades still significantly increased by the second semester lacking that same extra credit (p= 0.0038). These values should be cautiously interpreted, as exact individual scores could not be used. This sacrifices specificity for how much the increase in scores is.

Table 13: Student Mean Course Grade

Class	Fall 2018 Mean Student Grade (values 1-5)	Spring 2019 Mean Student Grade (values 1-5)	Significance of Course Grade Change Between Semesters	
			t-value	p-value
Class A	Not Available	Not Available	Not Available	Not Available
Class B	3.86	4.10	t= -2.91	p= 0.0038
De-Identified Grade Data Retrieved from: Dr. Jonathan Caranto				

Teacher Perception Data

Teacher perception was collected at the beginning and end of the semester. Likert scale values are as follows: 1- strongly agree, 2- agree, 3- neither agree nor disagree, 4- disagree, 5- strongly disagree. Professor A agreed with active learning, student-centric models of teaching, and cooperative learning while professor B reported the same excluding student-centric models. These are all associated with active learning. Professor B neither agreed nor disagreed with passive learning, traditional classrooms, and flipped classrooms. Professor A perception data was unable to be collected for spring 2019 at the end of the study. Professor B decreased their desire for passive learning and traditional classrooms. Professor B greatly increased desire for flipped classrooms, teacher-centric learning, and individual learning by the end of the study. At both the start and the end of the study, professor B continued to strongly agree with cooperative learning.

Table 14: Teacher Likert Scale Perception Data- Instructional Methods

Question Topic	Professor	Fall 2018 Start	Spring 2019 End
Passive Learning	A	4	NA
	B	3	4
Active Learning	A	1	NA
	B	2	1
Traditional Classroom	A	4	NA
	B	3	4
Flipped Classroom	A	2	NA
	B	3	1
Teacher-Centric Learning Model	A	5	NA
	B	4	2
Student-Centric Learning Model	A	1	NA
	B	4	4
Individual Learning	A	5	NA
	B	5	3
Cooperative Learning	A	1	NA
	B	1	1

Questions were asked to determine the teacher's perception of how active learning implementation is viewed. Both professors expressed that they had access to active learning resources, felt supported by peers, and did not have enough time to create an active learning curriculum. Professor A strongly disagreed that traditional teaching teaches more than active learning, that staff do not have resources for active learning implementation, that previous teaching experience prevents active learning from being implemented, that the professor needs more experience in active learning before teaching active learning, and creating curriculum for active learning requires significant effort outside of class to apply it. Professor A strongly agrees that support is available by peers and the department and believes that students are benefiting from active learning curriculum.

Professor B strongly disagrees that there are not resources available for active learning and strongly agrees that the faculty and department support active learning endeavors. While all other responses for professor B stayed constant, two question answers changed from the first semester: professor B reported increased belief that previous teaching experience does not make active learning implementation more difficult, and increased agreement that current methods of teaching need to change. Unlike professor A, professor B believes that more active learning teaching experience must be done before judging active learning. Professor B neither agrees nor disagrees that the students are benefiting from active learning and that traditional teaching methods teach more information than active learning.

Table 15: Teacher Likert Scale Perception Data- Implementation

Question	Professor	Fall 2018 Start	Spring 2019 End
Traditional teaching methods teach more information than active learning	A	5	NA
	B	3	3
I do not have access to active learning resources	A	5	NA
	B	5	5
I feel supported by my peers and the department when applying an active learning curriculum	A	1	NA
	B	1	1
Training in active learning would help me with implementing active learning curriculum	A	3	NA
	B	1	1
Prior teaching experience prevents active learning from being easily implemented	A	5	NA
	B	3	4
My students are benefiting from active learning curriculum	A	1	NA
	B	3	3
I need more experience teaching with active learning methods in order to judge active learning appropriately	A	5	NA
	B	2	2
Active learning curriculum requires significant effort outside of class in order to apply it	A	5	NA
	B	2	2
I do not have enough time to create an active learning curriculum	A	4	NA
	B	4	4
Currently used teaching methods need to change, whether it be through active learning or another method	A	3	NA
	B	2	1

Comparison Between Semesters

Putting all the data together, a simple chart is formed to compare class A and class B as a reference chart. This table does not include all data in previous charts but summarizes the most important findings for discussion and data interpretation. As a reminder, interpret the data according to the possible confounding variables discussed previously in results.

Table 16: Data Comparison Chart

Class	Class A		Class B	
Active Learning Implementation Strategy	Variable Schedule		Consistent Schedule	
Semester	Fall 2018	Spring 2019	Fall 2018	Spring 2019
Mean % of class time active learning	35.33% (SD: 29.68%)	50.67% (SD: 21.75%)	50.00% (SD: 2.7%)	42.67% (SD: 5.25%)
Mean Time per active learning activity	4.67 minutes SD: 3.47min.	5.44 minutes SD: 3.72min.	5.05 minutes SD: 0.51min.	3.09min SD: 0.40min.
Statistically significant student perception value increases	None	Individual learning: p= 0.037 Passive learning (marginally): p= 0.053	Passive learning: p= 0.003 Teacher-centric: p= 0.026	Active learning: p= 0.022 Flipped classrooms: p= 0.042
Statistically significant student perception value decreases	None	None	None	Passive learning: p= 0.025
Mean standardized final exam score	45%	41.65%	48.44%	61.16%
Mean grade in course (5= A, 4=B, 3=C, 4=D, 1= F)	Not Available	Not Available	3.86: C	4.10: B
Significance in class grade changes between semesters	Not Available		p= 0.0038 t= -2.91 Increase in scores	

DISCUSSION

Semester One: Fall 2018 Data Analysis

A clear distinction in the styles of active learning teaching is visible with the data obtained in the first semester of implementation. Professor A, the professor with several years of Biochemistry I teaching experience, spent 35.33% of class time on average doing active learning. This is lower than the amount performed in class B. Comparing the mean percentage of class time spent doing active learning, the standard deviation of 29.68% for class A is very high compared to the 2.7% standard deviation for class B. This value indicates that the amount of active learning performed was variable depending on the day in class A. This professor implemented a system of traditional lecturing with active learning days spread across the curriculum along the way. Another number supporting this is the average time spent per active learning activity. One observation was a mean time of 9.5 minutes per active learning activity while the other two observations were below 4 minutes (3 minutes and 1.5 minutes).

Professor B on the other hand used a daily active learning strategy, with the mean amount of the class time doing active learning as 50% with a standard deviation of 2.7% across observed days. This standard deviation is lower, suggesting the percentage of class time doing active learning was more consistent.

This difference in methods allows comparison between active learning with traditional lecturing with full active learning days along the way (this paper will label this as the variable strategy) or daily half-lecture/half-active learning (this paper will label this as the consistent strategy).

Class A student perception overall did not have any statistically significant values during the first semester of implementation according to the a= 0.05 value used in this study. Due to having many traditional lecture days in between the active learning days, there may not have been a dramatic change in opinion. Also, this was the lowest percentage of class time performing active learning of all semester averages. This lack of change in opinion suggests that students are alright with the status quo of how class A functioned. The system did not make the students dislike active learning more than at the start of the semester.

Class B had significant data findings. The significant increase in desire for passive learning (p= 0.003) and teacher-centric learning (p= 0.026) using a= 0.05 both support that the students desired more teacher guidance in class B. These results are the opposite of what is expected, as students are indicating decreased desire for active learning through these answers. Factors that may have contributed to this include trying active learning teaching for the first time, less resources for teaching due to not previously teaching this course, and time constraints or time allocation problems for activities.

Both professors favor computer-based interaction systems and case-study-style questions for doing active learning. These methods are closest to the methods used currently at the university where this study was performed. Both professors also used approximately the same number of high-level active learning activities, albeit with different distributions across the days measured. Both believed that there was support from faculty and the department, though they also both reported that there was not enough time to prepare active learning curriculum.

The first semester has shown that while active learning implementation can be implemented in Biochemistry I, it is far from optimal as it was performed during this semester. Flipped classrooms and cooperative learning perception did not change across either class, indicating that whatever was performed in both classes did not make a significant difference to student views. Online lecture content as well as working cooperatively may be challenging to implement in the first semester of active learning curriculum.

Beyond this, one must remember that students do not always use online resources regardless if they are available. Views for online lecture videos used in flipped classrooms were sometimes lower compared to the number of students enrolled in these courses. The videos were produced during the semester which may have led to videos being uploaded later and subsequently used less. Despite class B requiring online videos and class A making them optional, neither made a change to student views.

Semester Two: Spring 2019 Data Analysis

Like semester one, the professors used different approaches to active learning implementation. Professor A continued the variable strategy used in semester one: active learning during one entire day followed by normal traditional lecturing. This strategy is shown by random observation data, which found class time to be 50.67% active learning with a standard deviation of 21.75%. This large standard deviation indicates that the time spent doing active learning was greatly varied according to the day measured. Note that these data points are based on random observations that may be affected by the instruction on the observed days being different from the norm.

Professor B used the same strategy for active learning implementation as the previous semester as well. This is the consistent strategy: daily half-lecture/half-active learning during class time. Random observation data supports this, as 42.67% of class time on average was spent doing active learning with a standard deviation of 5.25%. The small standard deviation indicates that active learning was mostly consistent over random observations. Note that the mean percentage of class time spent active learning has decreased from semester one (from 50% to 42.67%).

Class A student perception of active learning data using a= 0.05 had one value as significant and one marginally significant: increase in desire for individual learning (p= 0.037) and desire for passive learning marginally (p= 0.053). All other perception questions stayed constant across the semester, suggesting the curriculum did not change student views but did marginally make students desire passive learning instead of active learning. The increase in desire for individual learning while cooperative learning opinion did not change significantly suggests that while class A instruction did not change student views on cooperative learning, something influenced their increased like for learning alone. Note that semester one showed that the mean percentage of class time doing active learning upon random observation was 35.33% while in semester two, it was 50.67%. The increase in mean time spent active learning seen in class A most likely is due to increased practice in active learning as well as having prepared activities from the previous semester. Class B had a similar average to this: 50.00% of class time on average doing active learning during semester one.

With only three observations each semester and only two semesters of implementation, it is difficult to determine if differences in percentage of course instruction time doing active learning was a substantial factor in student perception changes. One should note that the questions regarding non-active learning (teacher-centric, passive learning, individual learning) increased in class A (individual learning, semester two) and in class B (in semester one) when the mean percentage of class time of the course spent active learning was 50% or greater. It should be cautiously interpreted whether there is a point where active learning is taking up too much of the class time as there is a lack of long-term data to test this connection as a substantial factor. In any case, this hypothesis does not explain everything, as the first semester of implementation in class A showed no statistically significant change in student perception. With 35.33% of mean percentage of class time spent active learning, this is the lowest percentage of the observed classes. This may be too little of the class time doing active learning to change perception. Yet again, this test should be repeated long-term to test whether this connection is legitimate.

In class B, the class using the consistent strategy, participating students indicated a significant decrease in desire for passive learning ($p= 0.025$) and a significant increase in desire for active learning ($p= 0.022$). This result indicates that class B both made students favor active learning more while decreasing their desire in passive learning. Students in the previous semester, semester one, reported increased desire for teacher-centric learning and passive learning. The second semester of implementation did follow through with this, providing more time for non-active learning for explanations to balance the student-centric learning. As this is the second semester of implementation, one must also consider that professors will better use active learning in courses over multiple semesters of implementation. This may have an effect on the results. There was no significant increase or decrease in desire for both teacher and student-centric learning models like the first semester of implementation, further supporting this.

Class B showed another significant value: a significant increase in desire for flipped classrooms ($p= 0.042$). Note that this increase is an increase in desire for flipped classrooms in general and it is not specific only to biochemistry. Class B provided lecture content outside of class as a requirement for the course similar to how it was provided in semester one. The videos were available from the start of the semester, unlike semester one, where they were added as the professors made them weekly. Class A did not require flipped classroom videos as part of the grade for participation. This may be why class A did not show differences in opinion versus class B, as students are less likely to use resources if they are not required to use them.

A difference is seen between both classes in the standardized final exam mean scores of class A and class B and its difference in semester one versus semester two. Class A reported an average score of 45% and class B reported an average score of 48.44% on the standardized departmental final exam which are similar results during semester one. Class A had an average score of 41.65% on the final exam while class B had an average grade of 61.16% on the final exam during semester two. Class B's average final exam scores changed by a 12.72% increase while class A's average final exam score lowered by a non-significant 3.35%. As individual scores on the final exam were not provided, understanding significance of this is difficult. The increase of 12.72% from semester one to semester two in class B provides support that a consistent active learning system was preferable over a variable schedule.

CONCLUSION

The results of this study suggest a consistent daily active learning approach is the preferred system for Biochemistry I education in an undergraduate, large-group instruction context. Class B, which used this system, reported an increase in final exam scores by 12.75% after the first semester of implementation, increased student desire for active learning significantly, decreased student desire for passive learning significantly, and significantly increased student desire for flipped classroom active learning models given the system is implemented more than one semester. Beyond this, class B found a higher mean student grade from semester one to semester two, increasing significantly from a C mean grade to a B. Grade values in this calculation must be cautiously examined, for the specific grades were not available. Distributions were used instead as close approximations due to grade privacy of specific scores. While this may be due to professors knowing what to expect on the department final exam due to previous semester knowledge, class A had almost the same score over both semesters. If knowledge from the previous semester was a factor, class A would have shown an increase as well. In regard to student grades in the course, class B showed a significant increase in class grade when comparing the first semester to the second semester of implementation.

Something also can be said for class A, which remained consistent with student perception the first semester, though one significant value for student desire for individual learning during semester two of implementation and one marginally significant increase in passive learning desire. Final exam scores in class A decreased by 3.35% but this is not a significant difference. Note that more semesters of implementation would be best to limit outstanding factors and their effect on the data. In any case, both classes either did not change perception or did not in most cases change student perception to view active learning negatively. Unfortunately, limitations to grade access means that grade data comparison of class A is not possible at the time of this thesis publication.

Ultimately, the preferred system of active learning instruction determined from this study is the method performed by professor B: consistent active learning which takes up approximately 40-50% of class time. Student perception by the end of the second semester supported student desire for active learning, mean score on the departmental standardized final increased by 12.75%, teacher perception of active learning remained positive (excluding reporting not having enough time to create the curriculum), student grades significantly increased from the first to the second semester of implementation, and consistency with mean amount of class time spent on activities was reached with mainly high-level active learning tasks. Class B was able to use the same standards as class A to cover the horizontal challenge and incorporated previous knowledge of organic chemistry into the curriculum. It is important to note that the data supports that it takes multiple semesters before this effect was seen, therefore, this study recommends that active learning be implemented over multiple semesters before judgment of effectiveness.

As a cautionary note, professor B has an enzymology background which may have artificially increased correct answers by students on questions in biochemistry related to enzyme kinetics and structure. Professor A was responsible for multiple classes besides the biochemistry course measured in this study which may have hampered time to create or implement active learning. Professor B had only one class, with the rest of their responsibility involved in research. This difference in class instruction workload may be a factor in the class performance. Teaching assistants were used extensively for cooperation in class B compared to A as well; this may be a factor in why individual learning was found to be significant in class A during the second semester of implementation. Grading differences and assignment differences throughout the semester make comparison between professors difficult, which is why final exam mean score was used as a more accurate measurement. More semesters of implementation and testing would be required to make a more accurate picture of the results or more consistent grading criteria.

Future studies may want to investigate whether professor experience in teaching a course affects results, as there is a possibility that the results shown may be due to previous experience limiting active learning adaptation in class A. Beyond this, future studies may want to address what time is optimal to prepare future educators about active learning to maximize its effect in biochemistry education.

APPENDIX A: IRB APPROVAL

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Determination of Exempt Human Research

From: UCF Institutional Review Board #1
FWA00000351, IRB00001138

To: Jonathan Caranto and Co-PI: Robert Borgon

Date: August 03, 2018

Dear Researcher:

On 08/03/2018, the IRB reviewed the following activity as human participant research that is exempt from regulation:

Type of Review:	Exempt Determination
Project Title:	Implementation of Active Learning Curriculum to Determine its Validity in Biochemistry I Education
Investigator:	Jonathan Caranto
IRB Number:	SBE-18-14220
Funding Agency:	
Grant Title:	
Research ID:	N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

This letter is signed by:

Renea Carver

Signature applied by Renea C Carver on 08/06/2018 08:17:04 AM EDT Designated Reviewer

APPENDIX B: ACTIVE LEARNING MEASUREMENT CHART

Observation 1			
Description	Time Start-Time End	Time	Complexity
Observation 2			
Description	Time Start-Time End	Time	Complexity
Observation 3			
Description	Time Start-Time End	Time	Complexity

APPENDIX C: STUDENT SURVEY AND RESPONSE SHEET

Survey

Instructions: Write responses on the survey response sheet. Do not write your name on this survey. For the following questions, choose the answer A-E on this survey according to the level in which you agree or disagree with the statement. A indicates strongly agree, B indicates agree, C indicates neither agree nor disagree, D indicates disagree, and E indicates strongly disagree.

1. Passive learning is defined as learning through listening or note taking as an expert explains topics. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
2. Active learning is defined as teaching in a way which engages students in learning through activities that apply information during class time. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
3. Traditional classrooms are defined as classes which have instructional content during class and homework/activities outside of class time. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
4. Flipped classrooms are defined as classes which have instructional content outside of class (online) and homework/activities in class. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
5. The teacher-centered learning model is defined as classes which have the teacher in control of what students learn, how the students learn, and how students are assessed. The teacher is therefore responsible for the learning. I believe classes should be like this.
   A. Strongly agree
   B. Agree

C. Neither agree nor disagree
D. Disagree
E. Strongly disagree

6. The student-centered learning model is defined as classes which have the student in control of what students learn, how students learn, and how students are assessed. The student is therefore responsible for their own learning. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
7. Choose agree (choice D) for this question. This is meant to eliminate random answers
    A. Strongly disagree
    B. Disagree
    C. Neither agree nor disagree
    D. Agree
    E. Strongly agree
8. Individual learning is defined as learning which focuses on learning without working with others. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
9. Cooperative learning is defined as learning which focuses on learning with others in groups. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
10. By choosing yes (A), I agree to allow this survey data to be used for research purposes
    A. Yes
    B. No

Survey Response Sheet

1) ______
2) ______
3) ______
4) ______
5) ______
6) ______
7) ______
8) ______
9) ______
10) ______

APPENDIX D: PROFESSOR SURVEY AND RESPONSE SHEET

Survey

Instructions: Write responses on the survey response sheet. Do not write your name on this survey. For the following questions, choose the answer A-E on this survey according to the level in which you agree or disagree with the statement. A indicates strongly agree, B indicates agree, C indicates neither agree nor disagree, D indicates disagree, and E indicates strongly disagree.

1. Passive learning is defined as learning through listening or note taking as an expert explains topics. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
2. Active learning is defined as teaching in a way which engages students in learning through activities that apply information during class time. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
3. Traditional classrooms are defined as classes which have instructional content during class and homework/activities outside of class time. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
4. Flipped classrooms are defined as classes which have instructional content outside of class (online) and homework/activities in class. I believe classes should be like this.
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
5. The teacher-centered learning model is defined as classes which have the teacher in control of what students learn, how the students learn, and how students are assessed. The teacher is therefore responsible for the learning. I believe classes should be like this.
    A. Strongly agree
    B. Agree

   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
6. The student-centered learning model is defined as classes which have the student in control of what students learn, how students learn, and how students are assessed. The student is therefore responsible for their own learning. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
7. Choose agree (choice D) for this question. This is meant to eliminate random answers
   A. Strongly disagree
   B. Disagree
   C. Neither agree nor disagree
   D. Agree
   E. Strongly agree
8. Individual learning is defined as learning which focuses on learning without working with others. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
9. Cooperative learning is defined as learning which focuses on learning with others in groups. I believe classes should be like this.
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
10. Traditional teaching methods teach more information than active learning
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
11. I do not have access to active learning materials
   A. Strongly agree
   B. Agree

   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
12. I feel supported by my peers and the department when applying an active learning curriculum
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
13. Training in active learning would help me with implementing active learning curriculum
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
14. Prior teaching experience prevents active learning from being easily implemented
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
15. My students are benefiting from active learning curriculum
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
16. I need more experience teaching with active learning methods in order to judge active learning appropriately
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree
17. Active learning curriculum requires significant effort outside of class in order to apply it
   A. Strongly agree
   B. Agree
   C. Neither agree nor disagree
   D. Disagree
   E. Strongly disagree

18. I do not have enough time to create an active learning curriculum
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
19. Currently used teaching methods need to change, whether it be through active learning or another method
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree
20. By choosing yes (A), I agree to allow this survey data to be used for research purposes
    C. Yes
    D. No

Survey Response Sheet

1) ______
2) ______
3) ______
4) ______
5) ______
6) ______
7) ______
8) ______
9) ______
10) ______
11) ______
12) ______
13) ______
14) ______
15) ______
16) ______
17) ______
18) ______
19) ______
20) ______

APPENDIX E: QUESTION GUIDE AND DEPARTMENTAL STANDARDS

Question	Concept list	Details
Q1	1b	ID of phosphodiesterase
Q2	P3	Entropy
Q3	P3	Temp dependence on free energy
Q4	P6	H-bond acceptor/donors
Q6	P1	pKa
Q7	6f	PCR primer design
Q9	1c	Amino acid props
Q12	P1, 1c	Amino acid properties/pKa/pH
Q14	P1, 1c, 6a	Amino acid properties/pKa/pH
Q15	1c, 6d	Amino acid properties/absorbance
Q19	2c	Bohr Effect
Q20	1c	Amino acid/structure
Q21	2c	Cooperativity/Hill/structure-function
Q22	2c	Structure-function/protein
Q25	1a	Disaccharide numbering
Q26	2d	Structure-function/fatty acid
Q27	3	Linearization
Q28	3	Reaction coordinates
Q29	2c	Structure-function/enzyme
Q33	3a	Michaelis-Menten/Solve parameters
Q34	3a	Michalis-Menten/Assumptions
Q35	3a	Michaelis-Menten/Expt. Design
Q36	3b	Inhibitor type
Q40	1d, 2d	Solubility/membrane structure-function
Q42	4	Bio-signaling/PDE function
Q44	3	Hess law

List of Major Biochemistry Concepts

Reinforcement of prior knowledge from prerequisites:

1. Buffers, titration curves, pH, pKa
2. Functional group reactivity and protonation and charge states.
3. Thermodynamics (free energy, enthalpy, entropy, and reduction potentials)
4. Kinetics: transition state theory, 1st and 2nd order rates and molecularity
5. Nernst equation
6. Intermolecular forces and solubility: hydrogen bonds, hydrophobic and stacking interactions

Biochemistry concepts:

1. Biomolecules, their polymerizations, and molecular forces necessary for their self-assembly into macromolecular structures
    a. Simple sugars: polysaccharides glyosidic bond, anomeric carbon
    b. Nucleotides: DNA/RNA, phosphodiester linkage, secondary RNA structure, B DNA
    c. Amino acids: Protein, structure of 20 amino acids, α helixes, β sheets.
    d. Lipids Membranes: glycerophospholipid and sphingolipids, micelles and liposomes, difference of transmembrane and integral proteins.
2. Structure function relationships of biological macromolecules
    a. Carbohydrates in energy storage and cell structure.
    b. Structure of nucleotides, DNA, RNA in their role in information storage
    c. Proteins and enzymes in ligand binding, catalysis and signaling
        i. Conformational dynamics of protein/enzymes (e.g., lock-and-key vs. induced fit)
        ii. Allosteric and cooperativity
        iii. Hill coefficient
    d. Membranes transmembrane transport, and formation of chemiosmotic gradient.
3. Enzyme kinetics
    a. Michaelis-Menten kinetics
    b. Competitive, Uncompetitive and Mixed Inhibition
4. Signaling
    a. Signal receptors (receptor tyrosine kinase and GPCR)
    b. Signal cascades (second messenger, kinase cascade)
    c. Regulatory mechanisms including positive and negative effectors.
5. Energetics of Biochemical reactions
    a. ‘High energy’ compounds
    b. Catabolism and anabolism
    c. Metabolic flux
6. Common biochemical experiments and interpretation of data
    a. Affinity, ion exchange, and size exclusion chromatography
    b. SDS-PAGE
    c. Protein characterization by electrospray Ionization Mass spectrometry
    d. UV-vis absorption spectroscopy
    e. Site-directed mutagenesis
    f. PCR
    g. Sanger sequencing

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