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Board 2: Biomedical Engineering Division: Student Assessment of Active Learning Elements in 100-level Introductory Biomedical Engineering Course

Nicole Lauren Ramo, University of Michigan

Nicole earned a B.Sc. degree in mechanical engineering with a concentration in bioengineering from Kettering University (Flint, MI, USA) in 2012. The experiential learning program at Kettering allowed Nicole to work as a research assistant at Henry Ford Hospital's Bone and Joint Center (Detroit, MI, USA) for 2.5 years where she developed a love of research. Nicole went on to earn her PhD in bioengineering from Colorado State University (Fort Collins, CO, USA) in 2018. There she gained experience working as a graduate teaching assistant for computer aided engineering, biomedical engineering capstone design, and biomedical engineering introductory classes. She served as a Graduate Teaching Fellow for the College of Engineering during the 2016/2017 academic year. Nicole is currently a instructional post-doctoral fellow in the Transforming Engineering Education Laboratory within the Biomedical Engineering Department at the University of Michigan. Her engineering education interests include collaborative active learning, assessment methods and accreditation, and curriculum design.

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Nicole L Ramo, Colorado State University

Nicole Ramo earned a B.Sc. degree in mechanical engineering with a concentration in bioengineering from Kettering University (Flint, MI, USA) in December of 2012. The experiential learning program at Kettering allowed Nicole to work as a research assistant at Henry Ford Hospital's Bone and Joint Center (Detroit, MI, USA), where she developed a passion for research. Nicole is currently a doctoral candidate in The School of Biomedical Engineering at Colorado State University (Fort Collins, CO, USA). She has experience working as a graduate teaching assistant for computer aided engineering, biomedical engineering capstone design, and biomedical engineering introductory classes. Nicole's engineering education interests include active learning, metacognitive thinking, and the use of technology platforms. Her doctoral research is focused on the material properties of spinal cord tissues to contribute to the understanding and treatment of spinal cord injuries.

Jasmine Erin Nejad, Colorado State University

Jasmine Nejad is a PhD student in the Biomedical Engineering program at Colorado State University (CSU). She completed her B.S. in Biochemistry and M.S. in Biomedical Engineering at Arizona State University. Her research is focused on low-cost biosensor systems and microfluidics for point-of-care applications. She is a Walter Scott, Jr. College of Engineering Graduate Teaching Fellow (GTF) for the 100-level introductory course for biomedical engineering at CSU. Her work in the GTF program focuses on improving retention rates in first- and second-year engineering students by better understanding how students learn and implementing novel teaching strategies in the classroom to improve learning outcomes.

Prof. Ketul C. Popat, Colorado State University

Dr. Popat is an Associate Professor in the Department of Mechanical Engineering/School of Biomedical Engineering at Colorado State University. Prior to that, he was working as a Research Specialist in the Department of Physiology at University of California, San Francisco. He has authored over 85 peer-reviewed publications in journals such as Langmuir, Biomaterials, Journal of Orthopedic Research, Journal of Biomedical Materials Research, etc. and has and h-index of 37. He has also presented his work at numerous national and international level conferences. He received his Ph.D. in Bioengineering from University of Illinois at Chicago in 2003, M.S. in Chemical Engineering from Illinois Institute of Technology, Chicago in 2000 and B.E. in Chemical Engineering from M. S. University in India in 1998.

Dr. Kimberly Catton P.E., Colorado State University

Professor of Practice Civil and Environmental Engineering

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Abstract

This study describes the results of implementing intermittent active group learning sessions in a traditional lecture-only introductory course. Approximately 1 out of every 5 class periods was devoted entirely to group active learning focused on reviewing, applying, or otherwise emphasizing important topics from the lectures. This approach required little modification of previously prepared lecture materials and minimized the in-class time lost to student group formation. At the mid-point and conclusion of the semester-long course, students were asked to complete surveys which assessed their opinion on the course structure, the value of the various types of learning activities used and the benefit of the active learning sessions in general. Results show that students felt the problem-solving activities helped them "understand/apply course material and/or learn more about biomedical engineering" better than the research-based and hands-on activities. Correlating student assessments with demographical information revealed significant effects of gender, age group, learning style, and study habits. This study provides an example of an initial step instructors can take to transition from a lecture-only to a more active course structure and suggests that this method may be best received by younger, male students, and/or those who are already predisposed to social learning. The significant effects of social study habits (e.g., working on homework or studying with their activity group instead of alone) underscore the benefits of consistent activity groups over the course of the semester.

Introduction

The objective of an introductory engineering course is often two-fold: to equip students with the necessary knowledge and skills to be successful in subsequent courses and to inspire students by engaging them with the specific field [1]–[7]. Accordingly, effective introductory courses are important for students' future success in their program of study, and therefore, careers [1], [3], [8]–[11]. As summarized by Temple et al. [3]:

> "[F]irst year courses can improve academic performance, stimulate interest and improve retention, and better prepare students for future coursework. It is important that students acquire the qualities that prepare them to be successful engineers in the changing workplace, including the ability to work on and communicate with members of a multidisciplinary and professional team."

Research on high-impact educational practices has shown that in-class active or collaborative learning in introductory science, technology, engineering, and math (STEM) courses supports the two objectives above and improves both student engagement and retention [1], [3], [5], [9], [12]–[17].

With this in mind, the School of Biomedical Engineering at Colorado State University sought to improve the 100-level Introduction to Biomedical Engineering course (BIOM-101).

This high enrollment (approximately 150 student) course is required for all undergraduate students pursuing a biomedical engineering major or minor and is typically taken the first fall of enrollment in the degree program. The course has been offered every fall for the past seven years and, until 2016, was almost exclusively lecture-based with little to no formalized in-class peer-to-peer interaction. In Fall 2015, the course met three times per week with each instructional class periods consisting of 45 minutes of one-sided discourse with the instructor teaching from a PowerPoint presentation, followed by up to 5 minutes of multiple choice iClicker questions on the material just covered (as a note, instructional class periods are considered any class period not devoted to examinations or group presentations).

The significant time, effort, and planning required to restructure an entire course from traditional lecture-based to “flipped” can be prohibitive (or at least discouraging) for some university instructors who may already have a full workload [15], [18]–[21]. In a “flipped” or “inverted” class, instructional content is delivered to students out of class (typically through video lectures) while in-class time is devoted to discussion, application, and/or collaborative learning [12], [15], [19]–[24]. One option is to “flip” only specific portions or lessons at a time, but this still requires the creation of out-of-class instructional content (e.g., videos) in addition to the development of in-class learning activities [19], [21], [23], [24]. As the BIOM-101 course had been taught traditionally in the past by the same instructor, PowerPoint based lectures that covered all course content had already been developed but were not suitable for use alone as out-of-class instruction. Therefore, the School of Biomedical Engineering developed a unique course structure which allowed for incorporation of active learning with minimal restructuring of previously used lecture presentations and reduced disruptions from student groups forming and disbanding in the tiered auditorium where the class is held.

For the Fall 2016 and 2017 BIOM-101 class, 1 of every 4-5 class periods were allocated entirely to active group learning in consistent student teams with an approximate two-week frequency. The remaining class periods were taught the same way as in Fall 2015 with a slight decrease in level of detail to free up time for the active learning classes. On the dates dedicated to active learning, the students sat with their team the entire time and worked through activities that were meant to explore important concepts from the lecture in more detail, apply the content to a real-world example, or otherwise emphasize certain topics previously covered. The learning activities utilized can be categorized into three main types: (1) Problem-Solving, (2) Hands-On, and (3) Research.

This approach can be seen as an initial step towards “flipping” the class that is relatively easier on both the instructor and the students. The instructor was responsible for developing a finite number of in-class learning activities, but was still able to use the majority of predeveloped lecture material as is. In a fully “flipped” course, these same activities could be used with the lecture material presented out-of-class, as videos for example. The students were exposed to all new course material through the familiar traditional lecture structure so they were not responsible for any independent out-of-class learning (which has been a topic of criticism for students in other studies [12], [19], [21], [22], [25]). Student evaluation of the structure of the course (e.g. active learning for entire class periods), the value of each type of learning activity, and the benefit of the active learning in general were collected at the mid-point and the conclusion of the course through Likert-scale surveys. These responses were then correlated with demographical information including age, gender identity, special population status (e.g. international or first-generation student), and learning style.

Methods

Over the two semesters studied (Fall 2016 and Fall 2017), the BIOM-101 course had an average final enrollment of 140 students and was taught as one section which met for 50-minutes three times a week. The course was taught using Saltzman's 2nd edition *Biomedical Engineering – Bridging Medicine and Technology* textbook which covers molecular and cellular principles, physiological principles, and various sub-disciplines of biomedical engineering (ISBN-13: 978-0521840996). The course is intended for first semester freshman, but as some students decide to pursue a biomedical engineering major or minor later into their studies or have scheduling constraints, 2nd, 3rd, and even 4th year students were also enrolled (Table 1). It should be noted that this classification is based on number of years enrolled in college, not number of credits accumulated, and was self-reported by students through a survey collected at the beginning of the semester. This initial survey also collected demographical information, scores from the Index of Learning Styles Questionnaire hosted by North Carolina State University (https://www.webtools.ncsu.edu/learningstyles/), and assessment of student opinion on working in peer-groups.

Table 1. Breakdown of 2016 and 2017 Cohorts by Year in Collegiate Studies

The majority of students in BIOM-101 were first semester freshman, but students later into their collegiate work were also enrolled.

	Fall 2016 Cohort (% respondents)	**Fall 2017 Cohort (% respondents)**	**Total number of respondents**
1st year	64%	61%	85 + 42 = 127
2nd year	23%	25%	31 + 17 = 48
3rd year	8%	9%	10 + 6 = 16
4th year	5%	5%	7 + 4 = 11

During the first week of the semester, students self-enrolled in teams of 6 or 7 for an out-of-class design project using the self-sign-up group feature of Canvas (Instructure, Salt Lake City UT); these same teams were also used for all in-class learning activities. Class periods devoted to active learning where indicated as such on the course syllabus and schedule. On these scheduled days, the students came into class and immediately sat with their group as shown in Figure 1. This allowed for the learning activity to start right away and for students who arrived late to easily find their group. At the start of a typical active learning session, the activity was introduced and any general questions were addressed. Then, the groups worked together on the assigned task, raising their hands and looking for the undergraduate learning assistant (LA) assigned to their group [26]–[28], the instructor, or graduate teaching assistant if any questions

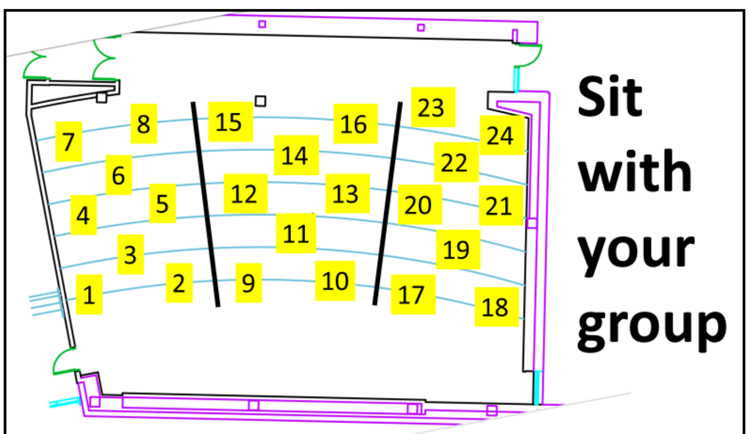


Figure 1. Slide that was displayed at the start of every active learning class period which allowed students to easily find their group.

arose. If needed, clarifying announcements were made to the entire class. Once a group had completed an activity (for the case of problem-solving or hands-on activities), it was checked by their LA, the graduate teaching assistant, or the instructor. The groups were then given a topic to discuss or simply waited for other groups to finish. By the mid-point of the semester, iClickers were used to indicate when groups had finished a task; this was very helpful in determining the best time to bring the class back together to go over the solution or hold class-wide discussion. An active learning class period could consistent of one or more activities, but each activity could be characterized as one of the following:

- Problem-Solving: application of equations or methodologies discussed in class to real-world examples;
- Hands-On: games, activities, or demonstrations that required collaboration between group members; or
- Research: in-class reporting of what was learned from research conducted out-of-class.

Examples of each type of activity can be seen below with a complete list given as an appendix.

Problem Solving

Flow in simple, cylindrical vessel

$$Q = \frac{\pi r^4}{8\mu L}\Delta p, \qquad unit\ analysis: \frac{mm^{\cancel{4}3}}{(\cancel{Pa} * s)(\cancel{mm})}\cancel{Pa}$$

Where,

r = radius of cylindrical vessel, units of distance (mm)
μ = viscosity of fluid, units of pressure*time
L = length of vessel, units of distance (mm)
ΔP = pressure drop along the vessel, units of pressure
Q = flow rate of fluid within the vessel, ***units of volume/time***

Calculate the pressure drop per unit length (in Pa/cm):

a). In the aorta (ALL Groups)
b). A terminal artery (Groups 1-8)
c). An arteriole (Groups 9-16)
d). A capillary (Groups 17-24)

Vessel	Diameter (cm)
Aorta	2
Terminal Artery	0.12
Arteriole	0.004
Capillary	0.0016

Assumptions:
- 5L/min flow rate through single vessel
- Viscosity of blood is 3.5 mPa*sec
- Dimensions of vessels given in table

Remember: 1L = 1000cm³

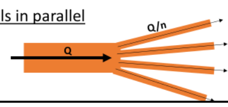
$$Q = \frac{\pi r^4}{8\mu L}\Delta p$$

How many vessels need to have same CSA as aorta? Repeat calculation for each vessel

a). In the aorta (ALL Groups)
b). A terminal artery (Groups 1-8)
c). An arteriole (Groups 9-16)
d). A capillary (Groups 17-24)

Vessel	Diameter (cm)
Aorta	2
Terminal Artery	0.12
Arteriole	0.004
Capillary	0.0016

Assumptions:
- 5L/min flow rate through system of vessels in parallel
- Viscosity of blood is 3.5 mPa*sec
- Dimensions of vessels given in table



Hands-On

Activity

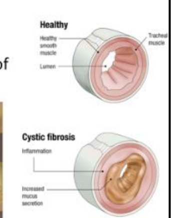
- Your group will be given a set of notecards – **DON'T LOOK AT THEM!**
- When the time starts you will take turns grabbing a card from the stack and describing the item on the card to the rest of your group
  - You cannot say any part of word
  - Keep describing the item until you can get your team to guess the word/phrase on the card
- Once someone on the team correctly identifies what you are describing, place the card face-up on the table and the next group member grabs a card
- Once all of the cards have been identified, organize them on the table as appropriate (some items may be associated with each other and/or a process)

Each set of notecards contained: DNA, DNA helicase, DNA polymerase, Okazi fragment, DNA ligase, RNA, mRNA, tRNA, Amino acid sequence/protein

Research

Disease/Disorder Report out

- Describe the disease/disorder
  - Symptoms, known causes, etc.
- Which organ system(s) affected? What components of the organ system affected? How does the disease impair function?
  - Nervous
  - Endocrine
  - Immune
  - Musculoskeletal
  - Respiratory
  - Renal
  - Integumentary (skin)
  - Reproductive



Assigned diseases included Epilepsy, Stroke, Multiple Sclerosis, Asthma, Cystic Fibrosis, Acid Reflux, and Guillain-Barre Syndrome

Figure 2. Examples of each of the three types of learning activities used in BIOM-101

Five-point Likert-scale surveys administered at the mid-point and conclusion of the semester asked students the extent to which they agreed the following statement: "[Name of Specific Learning Activity] helped me understand or apply course material or learn more about biomedical engineering". They were also asked to indicate their level of agreement with the following statements on the overall structure and value of the active learning as implemented with the responses from the mid-point and final surveys averaged together for each student:

1.) "Overall, I have enjoyed the active learning class periods"
2.) "Overall, the active learning class periods have been valuable to my learning"
3.) "I wish we had more active learning class periods"
4.) "I wish we had active learning during "regular lectures" instead of only during active learning classes"

Completion of each survey was requested of each student, but it was not required or rewarded. They were conducted through Google Forms with student ID number or email address used to match responses across the initial, mid-semester, and final surveys. The student responses from Fall 2016 and Fall 2017 were pooled and analyzed using JMP (13.0.0, SAS Institute Inc.). Specifically, to determine significant differences between the three activity types, mixed modeling was used with student ID treated as a random effect; a post-hoc Tukey HSD p-value adjustment was then used for the three pairwise comparisons. To determine the factors which significantly affect student responses, ordinal logistic modeling was used with all measured effects included. A threshold of 0.05 was used to determine statistical significance. For qualitative reporting, the negative average responses were designated as "(Strongly) Disagree", zero average responses were "Neutral" and positive average responses were designated as "(Strongly) Agree".

Results

Across all students, the active learning class periods were well received. 67% of respondents agreed that the active learning periods were enjoyable compared to only 16% who disagreed. Of the total respondents, 71% agreed that the active learning periods were valuable while only 18% disagreed. The assessment of the specific implementation was more split however; slightly less than half of the respondents wanted more active learning class periods and slightly more than half reported a preference for incorporating active learning into the lectures (Figure 3).

Of the three types of learning activities implemented, the problem-solving activities were scored significantly higher in the degree to which they helped the students understand/apply course material or learn more about biomedical engineering compared to the research-based ($p < 0.01$) and hands-on activities ($p < 0.01$, Figure 4). Examining individual learning activities, students responded the highest to the problem-solving activity shown in Figure 2, which was introduced after lectures on the circulatory system. The equation to be used for the activity had been introduced in class, but the students had not worked with the equation or explored its meaning until the activity. A brief dimensional analysis was performed as a class to refamiliarize the students with each of the variables and their units. Then each group was assigned a blood vessel of varying diameter to calculate the pressure drop per unit length and compare the result to that of the large diameter aorta. Once each group had completed their calculations, they confirmed their answers with another group assigned the same vessel. Errors often resulted from incorrect unit conversions. Once there was agreement for each assigned vessel (as assessed by iClicker responses from a representative on each team), the class was brought back together and a table of answers was created. A brief discussion was then held on the effect of the decreasing vessel radius with an emphasis on the units of pressure (Pa, MPa, GPa) and scientific notation. The students were then asked to determine how many of their assigned vessels it would take to match the cross-sectional area of the aorta and then calculate the pressure drop for a single vessel in the system. The same procedure was followed and after the table of answers was assembled as a class, the engineering advantages of the branching system seen in the circulatory and respiratory system were discussed.

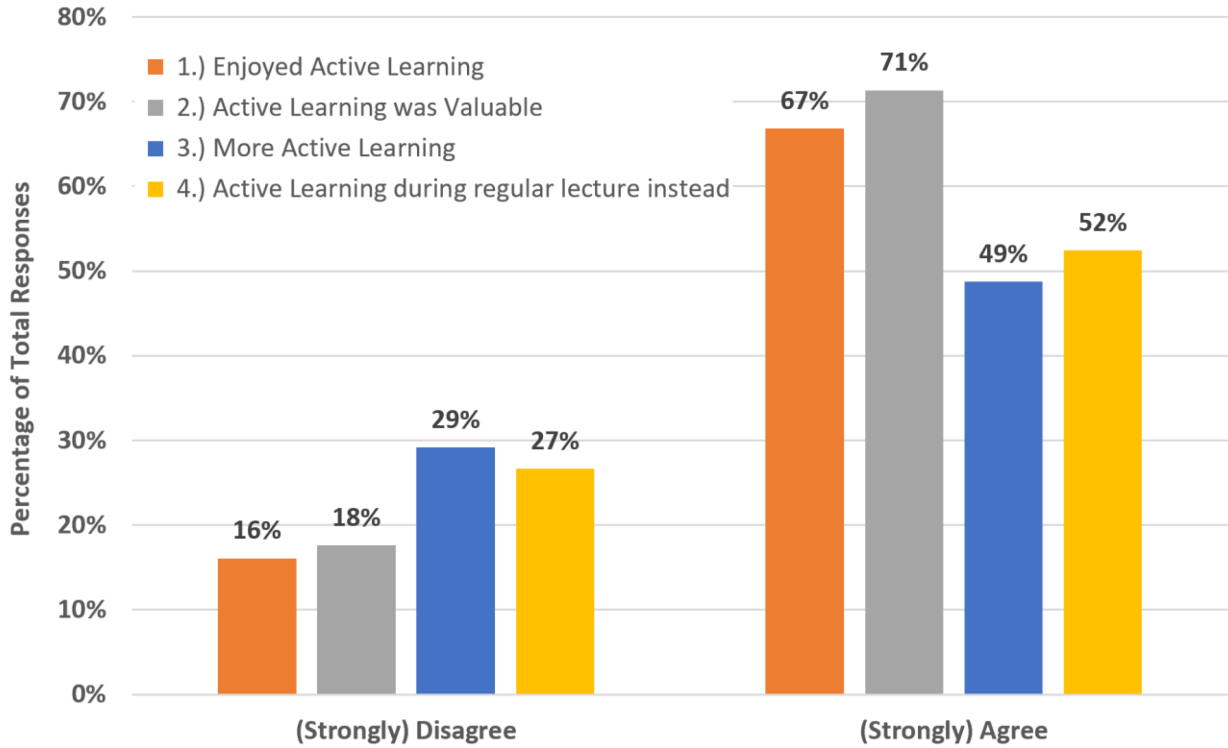


Figure 3. Student responses showed the majority thought the active learning sessions were valuable and enjoyable, but the opinion on the implementation model used was less positive

Of the 3 research-based activities, the students thought the activity presented in Figure 2 was most useful. After completing the physiology portion of the textbook, each group was assigned a disease or disorder to research out-of-class. The following week, each group was expected to be prepared to discuss any of the aspects listed on the slide. As multiple groups were assigned the same disease, the instructor randomly chose which groups presented which information. The students found the “Jeopardy”-style competition between groups to be the most helpful of the hands-on activities, followed by the “Password”-style competition on the molecules and processes involved in DNA replication and protein synthesis described in Figure 2.

Table 2 displays the significant effects for each of the four general statements above as well as the learning activities. The most common finding was that older students (based on date-of-birth, not class standing) were less likely to respond positively to the active learning model. Students score on the visual/verbal learning style scale was also a significant predictor of their response to wanting more active learning classes. Students with a higher verbal score also reported significantly more positive reactions to the hands-on activities overall, while the other increases were not found to be significant. How students did the majority of their homework/studying for the class was also a significant indicator of their reaction to the active learning model. Those students who continued to work with their activity group outside of class or those who worked with other classmates had a significantly higher response than those who worked with students who had taken the class previously. Interestingly, male students had a more positive reaction to the active learning model and the learning activities themselves. Male students were significantly more likely to report that the problem-solving activities and the activities overall helped them understand/apply course material. They also were significantly more likely to disagree with incorporating active learning during the lectures instead of dedicated classes.

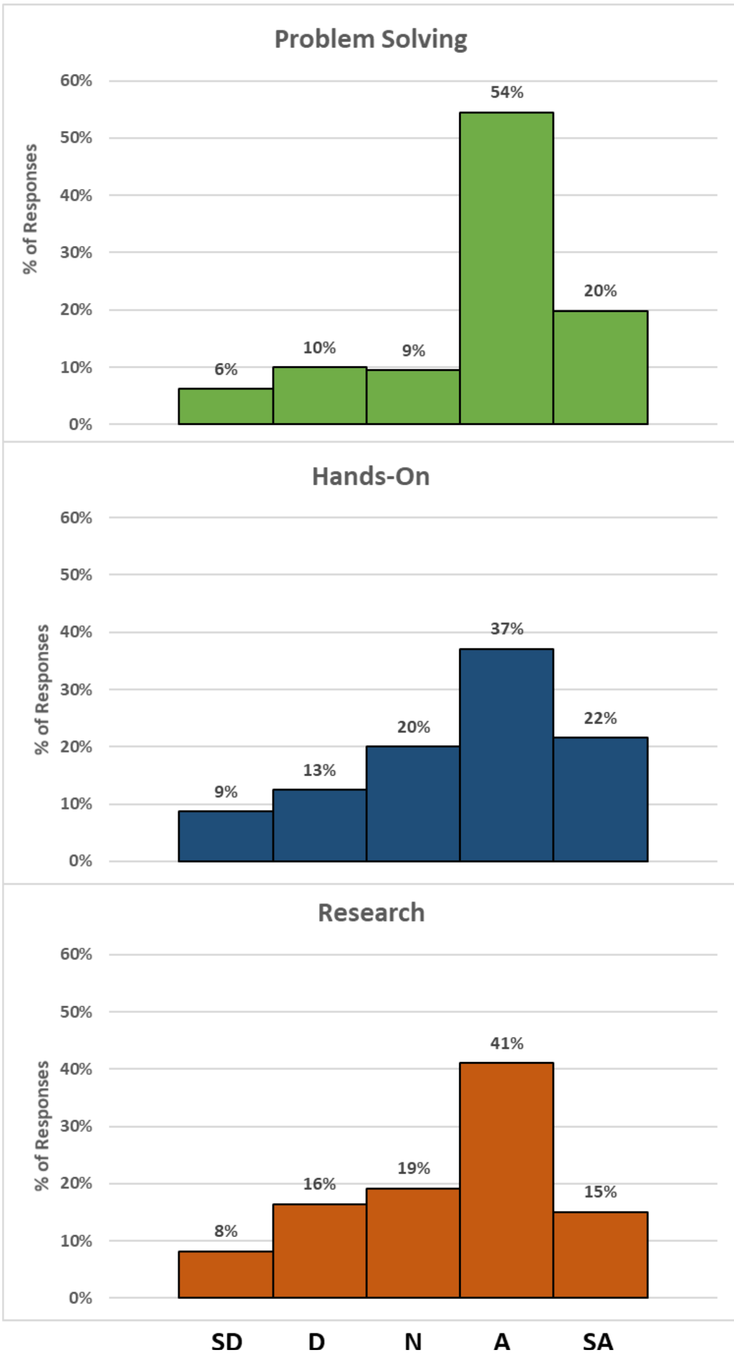


Figure 4. The problem-solving type of learning activity was rated significantly higher than the hands-on and research type (SD = Strongly Disagree, D = Disagree, N = Neutral, A = Agree, SA = Strongly Agree)

Discussion

STEM higher education, including that of biomedical engineering, has benefited from the research surrounding high impact practices. The “flipped” classroom has emerged as a well-researched model for incorporating active or collaborative learning across many disciplines and educational levels [9], [12], [15], [19], [21], [22], [25], [29]. Despite the research on the positive effect of "flipping" on student engagement and success, adoption of the technique has been relatively low in undergraduate STEM courses [12], [15], [18], [21]. One of the most commonly reported reasons instructors give for their hesitancy to employ the "flipped" model is the amount of time and planning required to restructure their course [12], [15], [18]–[21]. This is an especially poignant concern at large research universities where this time may take away from research activities critical to promotion and tenure [15]. Reviews of the "flipped" classroom model have reported the time, effort, and resources required to create effective out-of-class instructional materials as "intense" [19], "significant" [21], and "considerable" [24]. Another of the most commonly reported instructor concerns is that of student resistance. Traditional lecture models require little active student participation and place little responsibility on the student for their own learning out-of-class, and some students find the transition to a "flipped" class frustrating [12], [18], [19], [21], [24]. Specifically, instructors who have tried to implement the model often report that students do not utilize the out-of-class resources and come to class unprepared for the learning activities [12], [21], [24].

The method chosen by our School of Biomedical Engineering for improving the Introduction to Biomedical Engineering course was based on our belief that it would have the same positive effects of active/collaborative learning while avoiding the two major challenges of fully "flipping" the course. It allowed the instructor to continue to use previously prepared lecture materials (i.e., PowerPoint presentations) with little to no modification, and the students were exposed to all new instructional content in the familiar traditional lecture format. The schedule of regularly spaced class periods devoted entirely to active learning was thought to allow important aspects of the lecture material to be emphasized with students knowing what to expect from each instructional class period. Furthermore, the development of the in-class learning activities was a relatively easy initial step towards "flipping" the course, with the next being the conversion of in-class lecture content to out-of-class videos.

The results of our study show that the learning activities were well received by the majority of the students; 71% considered the active learning class periods valuable to their learning and 67% considered them enjoyable. Scores for the specific learning activities revealed that the problem-solving type was seen as the most helpful in understanding biomedical engineering or applying course material, followed by the hands-on activities, then the out-of-class researched based activities. The lower scores for the research based activities may be due to the same student resistance to and attitudes about out-of-class learning responsibilities. This is supported by the comments some students gave with their survey responses, which included the following from a 1st year, 18-year old male student: "A problem with [the research-based activities] was that most students just showed up to the day of presentation with maybe one person having read about the topic, and then that person would present on behalf of the group." The issue of variability in student preparation has been discussed in the literature, and has been a common theme in studies of "flipped" first-year engineering courses [12], [19]. Clark et al. reported that their freshman engineering students expected to be taught during class and may not have the maturity to be successful in a fully "flipped" curriculum [12]. However, they felt that exposure to "flipped" instruction is valuable as it helps "instill in the freshman a tendency to arrive to class prepared to use their skills and ask questions – versus arriving the with expectation of being given information" and "promotes behavioral changes…including teaching them how to learn and research problems initially on their own" [12].

Table 2. Significant Correlations Found Between Student Responses and Demographics
Statistical analysis revealed that age, gender, verbal/visual learning style score, and how the student did the majority of their homework/studying were all significant indicators of their response to the learning activities and course structure.

	1.) Enjoyed Active Learning	**2.) Active Learning Valuable**	**3). Want more Active Learning Classes**	**4.) Rather have Activities Incorporated into Lectures**	**Average of all Learning Activities**	**Average of Problem Solving Activities**	**Average of Hands-on Activities**	**Average of Research Based Activities**
Age, older	- $p<0.01$		- $p=0.02$	- $p=0.03$				
Gender, male				- $p=0.04$	+ $p=0.02$	+ $p=0.01$		
Verbal, higher			+ $p<0.01$				+ $p=0.03$	
Homework: with project group	+ $p=0.03$				+ $p=0.01$	+ $p=0.01$		+ $p=0.03$
Homework: with other classmates	+ $p=0.04$				+ $p=0.01$	+ $p=0.03$		+ $p=0.04$
Homework: with past students	- $p=0.02$				- $p<0.01$	- $p=0.04$		

Review of other student comments in light of relevant literature also revealed a possible cause for the elevated problem-solving learning activity scores. Many students reported they felt the problem-solving activities were the only ones of value and wished for more work with the equations presented during lecture. One 3rd-year, 20-year-old female student commented:

> "I honestly think the learning activities are busy work and only when we do problems they are of value to what we are learning, but it's almost like doing a homework problem but in class. But if the problems are similar to the ones on the test I think they are beneficial because they are questions I will see later in my life and maybe my career."

This comment underscores another theme that has been reported in the literature: the importance of well-structured collaborative activities that clearly relate to course objectives and assessment methods [12], [15], [19]. The problem-solving activities had the most direct applicability to the course's assessment methods (e.g., homework and exams) and were therefore seen as the most valuable. This also explains why the "Jeopardy"-style review competition, which was completed the week before the second exam, was the highest scored hands-on activity.

Statistical analysis revealed significant effects of verbal/visual learning style, age, gender, and social study habits on student assessment of course structure and the learning activities. As expected, students with a stronger preference for verbal learning (i.e., that from written/spoken explanations and group discussions [30], [31]) were more likely to want additional opportunities to talk through course material with their group. It is thought that introducing more in-class demonstrations, which appeal to visual learners, would reduce this discrepancy. The influence of student gender and age are interesting findings. Of the students whose average response to "I wish we had more active learning class periods" was strongly disagree to disagree, 54% were over 19 years of age and 71% were female. Similar distributions were seen for the statements on if the active learning sessions were enjoyable and if they were valuable. The negative response of older students found in this study may be related to familiarity, maturity, and/or motivational factors. Older first-year students most likely missed the boom in active learning currently seen in K12 education, while older 2^{nd}-4^{th} year students have already grown accustomed to traditional lecture formats. Clark et al. suggests that students later into their collegiate studies may have less patience towards changes in instructional methods and may find initial attempts at incorporating active learning disorganized [12]. This frustration with perceived disorganization was also reflected in the survey comments from older students, including that of the 20-year old student quoted above. They were more likely to find the active learning sessions, especially those which did not include problem-solving exercises, as "busy work" and unnecessary for their success in the class and may reflect differences in motivational factors and preferred learning environments noted by some researchers [32], [33]. The differences in gender are more puzzling and are contrary to what has been reported in studies of active learning implementation in other STEM courses [34], [35]. Comparing male and female students overall, male students had a higher verbal learning style score, higher agreement with "I enjoy working in groups of my peers", and were slightly younger; these factors may have combined to cause the differences seen between male and female students, but this requires additional research including examining the results in the context of student development theory and personality type [30], [36].

Students who regularly interacted with their project group, or even other BIOM-101 classmates, outside-of-class to complete homework or study for exams reported greater enjoyment of the active learning sessions and perceived helpfulness of almost all learning activities. On the surface, this result supports the logic that if students enjoy working with their group outside-of-class, they will have a more positive reaction to completing in-class activities. However, Vincent Tinto's Interactionalist Theory [8], [37] may provide the context for the deeper implications of this result, especially for introductory 100-level courses. Tinto's theory emphasizes the importance of both academic and social integration for student success and retention, with more contemporary research suggesting the social aspect may be even more important [8]. Specific to engineering, the use of consistent student cohorts or learning communities significantly improves social integration and retention [38], [39]. In introductory engineering classes, consistent student teams or groups as implemented here, may contribute to the social integration of first-year students. However, this is dependent on the formation of effective student teams which may involve more thought on the part of the instructor.

There are limitations of the active learning implementation method and this assessment study that should be noted. Specifically, the addition of in-class collaborative learning activities without any out-of-class videos to offset instructional content necessitated a slight reduction in the level of detail covered during lectures. Due to the structure of the curriculum in the School of Biomedical Engineering, this reduction is not expected to have any effect on future student success in the program, but concerns on content coverage have been articulated by many STEM instructors considering incorporating active learning [15], [18], [21], [24]. Also, the results of this study are based solely on student surveys and therefore it is difficult to quantify if student engagement or performance was improved with the course structure or learning activities. Unfortunately, almost all assessments (e.g., homework and exam questions) were modified for the Fall 2016 semester, which precludes the direct comparison of student scores with previous semesters. Furthermore, as the in-class activities represented additional exposure to lecture material, this comparison would not indicate if it was the active learning itself or simply increased content review which affected scores. Finally, low survey response rates (72%, 42%, and 56% for the initial, mid-semester, and final surveys, respectively) and sparse representation of certain demographic groups in the course limited the conclusions that were able to be drawn. Improved participation and further studies may provide more robust conclusions with respect to correlations for certain demographic groups. Nonetheless, the findings from this study clearly indicate an overall positive response to learning activities as implemented.

In conclusion, it is encouraging that the majority of students found the active learning class periods enjoyable and, more importantly, valuable to their learning. The problem-solving activity type was seen as the most helpful, most likely since they had the most direct applicability to course assessment methods and did not require any out-of-class work by the student groups. The significant effects of age, gender, and learning style require additional research but underscore the importance of understanding the students typically enrolled in a course when considering the implementation of active learning or a “flipped” model. The significant effect of out-of-class interaction with activity group members supports the use of consistent student teams over a semester and may contribute to social integration and improve retention. Future efforts at our university will include the improvement of the learning activities based on student feedback, including modifying the number of students in each group to increase participation, and the gradual development of out-of-class instructional content, moving towards a fully “flipped” course.

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Appendix: Complete list of Learning Activities Implemented in BIOM-101 Fall 2016 and Fall 2017 Courses (activities from each category that were rated the most helpful for students are in bold)

<u>Problem Solving: application of equations or methodologies discussed in class to real-world examples</u>

1. Estimate the number of steps taken during record-breaking mile run
2. Determine how many cycles a designed artificial heart will be expected to perform if implanted into a 30-year-old male in the United States
3. Determine the growth rate of bacteria in the lung of an immunocompromised patient
4. Use the equation of mass balance and given patient data to determine the net water generated or consumed
5. **Compare the pressure drop along a unit length of the aorta, a terminal artery, arteriole, and capillary**
6. Calculate the number of cells needed for a tissue engineered cartilage implant

<u>Hands-on: games, activities, or demonstrations that required collaboration between group members</u>

1. Group members take turns describing the molecule or process related to the central dogma of biology given to them on a flash card; once all cards are guess by the other group members, the cards must be put in the correct order to show the process of DNA replication or protein synthesis
2. Demonstrate how the circulatory system picks up and deliveries various substances by passing a bowl between group members assigned various roles (e.g. pulmonary arteries, lungs, liver, pancreas) and exchanging cards in the bowl (e.g. hormone, oxygen, nutrients)
3. **Quiz style review game in which the group must come to a consensus on the answer and submit as a team**

<u>Research: in-class reporting of what was learning from research conducted out-of-class</u>

1. Find a recent publication by a School of Biomedical Engineering faculty member and report summary of research to the class including what sub-disciple of BME it belongs it
2. **Research a given disease or disorder and report the major organ system affected and how the disease impairs its function**
3. Research a given biomedical implant and find the conditions under which it is considered successful and what complications that have been reported with its use