ARTICLES

Utilizing Quantitative Analyses of Active Learning Assignments to Assess Learning and Retention in a General Biology Course

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Abstract: Numerous studies have examined the use of active learning methods in undergraduate courses, suggesting that these methods increase learning and retention as well as student engagement. In order to investigate the benefits of particular active learning assignments involving presentations of 3-dimensional simulations in an introductory biology course for science majors, quantitative analyses of the effects of these assignments on learning and retention as assessed by unit and final exam scores were performed. Same student populations and varying student populations across multiple semesters were compared using t-test analyses, single factor ANOVA analyses, and Pearson correlation coefficients. These statistical analyses determined the simulation assignments as compared to other active learning assignments resulted in no consistent significant increase in learning or retention of material covered by these assignments for same student populations and varying student populations across multiple semesters. Based on these results, the simulation assignments were replaced with other active learning assignments and additional assessment found no significant difference in the learning and retention of course material. The approach described in this study can be used for other assignments in introductory majors' biology courses, as well as other courses to assess the effectiveness of course assignments for student learning and retention.

Key words: active learning, general biology, assessment, quantitative analysis

INTRODUCTION

Moving beyond standard lecture format in undergraduate biology classrooms has been an area with much focus over the past several years (Couch et al., 2015; Waldrop, 2015). This may manifest in many different formats, from flipped classrooms to blended methods incorporating multiple approaches (Jensen et al., 2015; Sadeghi et al., 2014). Increasing both student engagement with material and overall retention and learning has long been the goal of good pedagogy, often achieved through an increase in overall active learning techniques employed in the classroom (Jensen et al., 2015; Tanner, 2013). An analysis of over 200 studies of active learning in the STEM fields found that student failure rates were 12% higher in traditional lecture style classes versus ones utilizing active learning environments (Freeman et al., 2014). A study comparing performance on ETS® Major Field Tests in Biology administered to senior students having completed a two-course sequence with or without active learning as freshmen found significant increases in overall scores for those that completed the active-learning courses (Derting & Ebert-May, 2010). Often these methods are incorporated into introductory or first-year courses, but active learning has also led to increases in exam performance in upper-level biology courses, indicating these methods can be incorporated across curricula to improve understanding and course performance (Knight & Wood, 2005).

Beyond increased student learning and retention of material, a switch to group-based, active-learning classrooms generally leads to increases in positive student attitudes toward material and courses (Goldberg & Ingram, 2012; Aguilera et al., 2017; Obialor et al., 2017; Tal & Tsaushu, 2017). However, not all instructors have perceived significant improvements in overall performance compared to standard lecture formats, indicating there is still more work to be done to consistently engage students and increase overall learning and retention (Sadeghi et al., 2014; Miller & Metz, 2014). Even without measuring increases in student performance following group-based creative activities, a recent study found improved student confidence of material after employing active learning activities (Bentley & Connaughton, 2017). Improvements in overall confidence and satisfaction of students has been shown to increase retention in biology programs, suggesting that active learning methods have impacts on students beyond potential increases in learning and assessment performances (Jeno et al., 2017).

An essential learning outcome outlined by the Association of American Colleges and Universities is “creative thinking” and their VALUE rubric on creative thinking can be utilized by schools to examine curricula for creative thinking (https://www.aacu.org/value-rubrics). Because creative thinking and activities are important features of active learning that have historically increased engagement and retention of course content, we employed creative three-dimensional simulations completed in groups in selected units of our first semester introductory biology course for biology majors. This course aims to set a foundation for future courses in the curriculum with a focus on basic biological concepts of molecules, cells, genetics, and energy. In the course, two units utilized a group simulation activity, whereas the other two units employed different types of active learning assignments. We compared test scores among same student populations over the course of a semester. In addition, comparisons were done between all sections of the course in a semester, over multiple semesters, as well as between the different instructors teaching the course over the same time period(s). Overall, exam scores did not significantly vary between topics with simulations and topics without. However, in the absence of group simulation assignments, other active learning assignments were used to provide students opportunities to work with the material, suggesting that the various active learning assignments employed in this General Biology I course were equivalent in terms of their effects on student learning and retention. Though no consistent differences were observed for the active learning assignments utilized in this course, continual quantitative assessment of assignments in biology courses and other subjects will allow for informed decisions about pedagogical methods and active learning assignments to be made in efforts to improve student learning outcomes and understanding of material presented in undergraduate courses.

METHODS

Course description

The course examined in this study was BL1250 General Biology I, an introductory course for biology majors at Rockhurst University in Kansas City, Missouri. This course, along with BL1300 General Biology II, examines basic biological concepts that will be required for upper level courses in the biology curriculum. The course goals are for students to be able to explain basic cellular and molecular structures and processes, apply knowledge to answer important biological questions, demonstrate effective study habits for learning about science, and to work successfully in groups upon the completion of the course. Though General Biology I is considered a foundation course for biology and other natural science majors, students from other fields of study are also included in this course, including a considerable number of exercise science and engineering majors and students opting to take this course as a Core requirement for degree completion. General Biology I consists primarily of freshman level students, although all levels of students can enroll in the course. The class size is typically restricted to 48 students, which also includes honors students (included in this study) that enroll in a separate course number, BL1260 Honors: General Biology I, with the classroom experience between these two courses being equivalent and shared.

Course structure

The structure of the course includes 4 units based on content, including Units: I – cell division and genetic inheritance; II – molecular genetics; III – cellular structure, function, and communication; and IV – energy, cellular respiration, and photosynthesis. Each unit is assessed through a combination of in-class activities, assignments, quizzes, presentations, and unit exams. Additionally, a comprehensive final exam is given at the end of the semester to determine understanding and retention of knowledge. Teaching approaches for this course include lecturing, in-class activities, group problem solving, case studies with associated exercises, simulations and modeling of biological processes, quizzes, problem-based discussions, group assignments, and reading reviews. Unit and final exam questions varied by semester and section of the course and were comprised of a mixture of question types written and graded by the instructors for the individual sections of the course, including multiple choice, essay, true or false, fill in the blank, matching, draw or fill in a diagram, and biological problem solving questions. Unit and final exams were assessed based on revised Bloom’s taxonomy levels independently by two instructors to determine the percentage of lower (revised Bloom’s taxonomy levels of remembering and understanding) and higher (revised Bloom’s taxonomy levels of applying, analyzing, evaluating, and creating) order cognitive skills questions on each exam (Krathwohl, 2002).

Simulation assignment description

To increase student understanding and learning, 3-dimensional simulation assignments were included to display the dynamic and 3-dimensionality of the biological processes being examined and to integrate other disciplines and student interests with biology. In these simulation assignments, student groups of 3 or 4 were instructed to create and perform a 4 to 5 minute creative and accurate presentation, either live in class or via multimedia, related to a given topic that incorporates the 3-dimensionality of the process assigned. Detailed rubrics for the simulation assignments were given to the students in advance (see sample rubric). For each assignment, students were instructed to incorporate a creative approach (e.g. interpretive dance, Claymation, etc.) to explain a particular process or topic (e.g. cell division, genetic inheritance, DNA synthesis, RNA transcription, protein synthesis, cellular structure and enzymatic function, cellular respiration, or photosynthesis) that was covered within particular units. For unit 1 and 3 simulations, students were assigned specific genetics problems or enzymes to ensure different approaches and information was being conveyed in the simulation presentations. The students were graded on biological process accuracy, inclusion and movement of 3-dimensional molecules, uniqueness and creativity involved in particular artistic approaches, delivery of the presentation, and inclusion of all group members in the presentations. A detailed outline of the project was due in advance of performances to ensure that the student groups had effectively incorporated the assigned biological topic with another discipline or field of study before continuing with the project. This allowed for students to receive constructive feedback before presenting to attempt to ensure understanding of the biological process and that students have met the requirements outlined for this project in the rubric.

Data collection and analysis

The data collected for this study were based on student performances on General Biology I simulation assignments, unit exams, and final exams at Rockhurst University for students enrolled in the fall 2013-2016 semesters among different sections of the course taught by three specific instructors that were consistently involved in the course throughout the period being examined. Sections of the course taught by other instructors were excluded so that the data included in this study came from sections of the General Biology I course that were taught in a similar manner during the period being examined. For each section of the course included in the study, overall performances on unit exams and questions over specific topics from the comprehensive final exams were compared to the inclusion of simulation assignments for the topics being covered. The combined number of students included in this study was 513 students, though numbers vary slightly for particular assignments and exams as not all students completed every assignment or exam and 2013-2014 final exam data was not available for one instructor.

In order to determine if the simulation assignments increased learning and retention of material covered in these assignments, unit and final exam scores were compared within same course sections and semesters; within same semesters across all course sections for all students and for the bottom performing 25% of students; based on simulation assignment topics across multiple semesters; based on instructor; and based on simulation assignment performance. Comparisons of exam scores based on simulation assignments were analyzed in Excel using paired and unpaired t-test analyses or single factor ANOVA and p values were used to determine any significant differences (using a cutoff of $p < 0.05$ for significance) with respect to the use of simulation assignments in General Biology I courses at Rockhurst University that occurred during the fall semesters from 2013-2016. Correlations between simulation assignment and exam performances were analyzed in Excel using Pearson product-moment correlation coefficient analysis. This methodology allowed for comparisons of student performance with and without simulation assignments using same student populations, as well as among multiple semesters to determine whether these assignments increase learning and retention in larger populations of multiple groups of students.

RESULTS AND DISCUSSION

Analysis of unit exam scores within same student populations with and without simulation assignment

Previous studies have indicated that active learning and creative thinking enhance student learning and retention, and therefore, two creative three-dimensional simulation assignments were added to a General Biology I course in attempts to increase student engagement with material covered in this course, as well as enhance understanding of basic biological processes. The biological topics covered in the simulation assignments corresponded to information from two of the four units of the course, with the other two units of the course not implementing these simulation assignments but rather including other types of active learning.

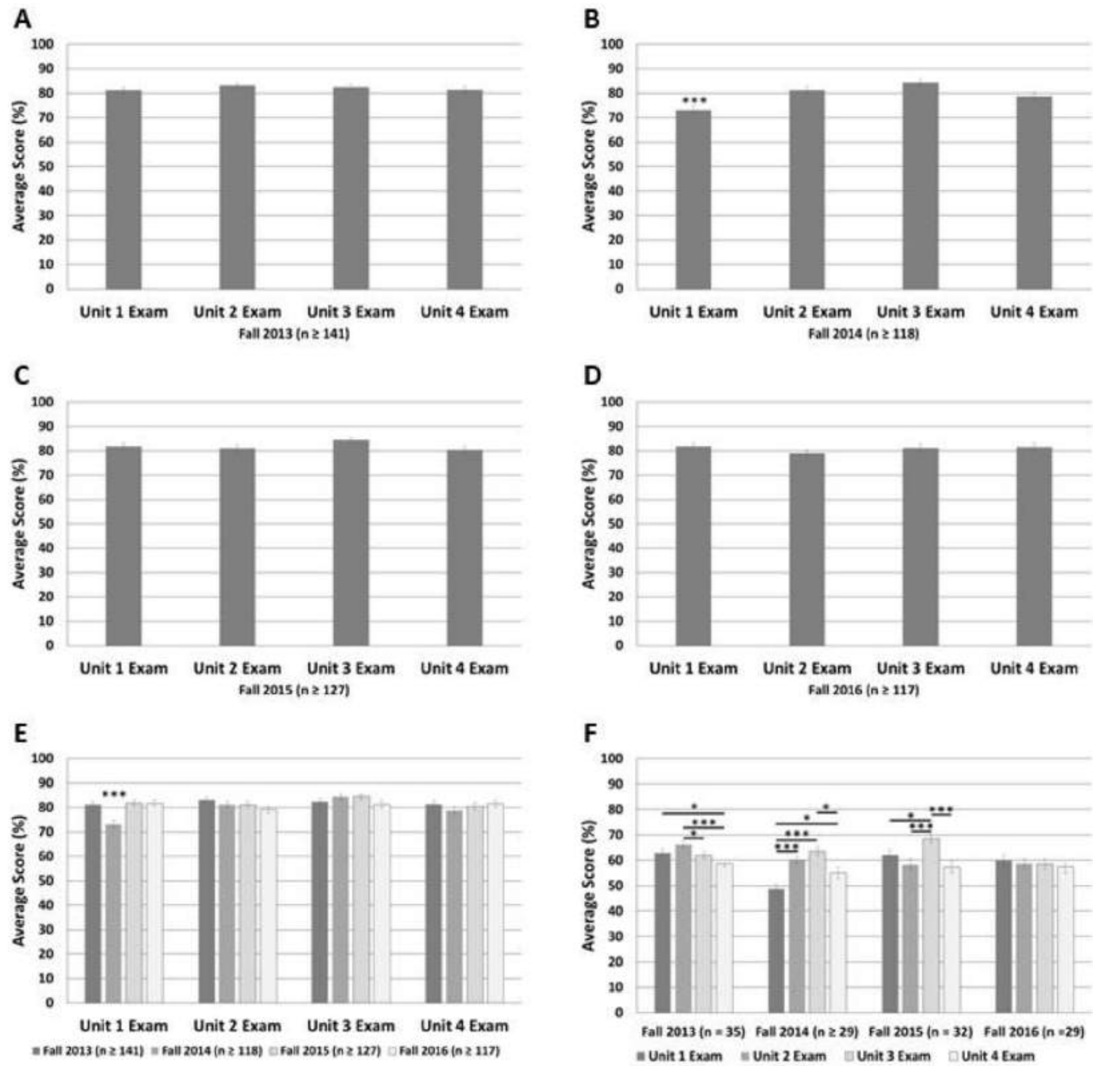
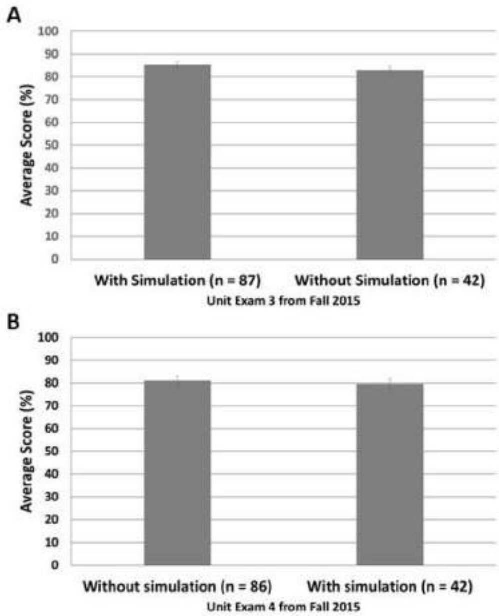


Fig. 1. Comparison of average unit exam scores in General Biology I by year for: A. Fall 2013; B. Fall 2014; C. Fall 2015; D. Fall 2016; E. Fall 2013-2016 combined; and F. Fall 2013-2016 combined for bottom 25% performing students. Asterisks indicate a significant difference between exam scores, with (* $p < 0.05$; ** $p < 0.005$; and *** $p < 0.0005$). The asterisk in B indicates a significant difference between exam scores for unit 1 and units 2-4 for fall 2014. The asterisk in E indicates a significant difference in unit 1 exam scores when comparing 2014 to all other years examined. Error bars indicate standard error of the mean (SEM).

To assess the effectiveness of these simulation assignments, unit exams for the course were used as a measure of understanding of material covered in the simulation assignments, as well as material that was not covered in the simulation assignments. Student performance on unit exams were compared for same student populations for the fall 2013, 2014, and 2015 semesters. Unit exams that assessed material covered in the simulation assignments were compared to unit exams that assessed material not covered in the simulation assignments within each semester using a one factor ANOVA analysis.

When comparing units of the course with simulation assignments (units 2 and 4) versus units without simulation assignments (units 1 and 3) for the fall 2013 semester, no statistical difference was observed between unit exam scores for units 1 through 4 of the course (Fig. 1A). For the 2014 semester, a significant decrease in unit exam percentages was observed for unit 1 of the course as compared to the other 3 unit exams (Fig. 1 B). As unit 1 of the course for the fall 2014 semester did not contain a simulation assignment, this finding led to a change in the units of the course that contained the simulation assignments, with all 4 sections of the course including a simulation assignment for unit 1 in fall 2015. However due to instructor preference, the second simulation assignment from the fall 2015 semester covered material from unit 3 of the course for 3 of the 4 sections of the course and unit 4 for the remaining section of the course. Comparison of fall 2015 unit exam scores determined that there was no statistical difference between unit exams (as observed in fall 2013), regardless of which units of the course included simulation assignments covering the material (Fig. 1C). Dividing the unit 3 and 4 exam

Fig. 2. Comparison of average unit exam scores in General Biology I in fall 2015 for content covered by a simulation assignment and content not covered in a simulation assignment for: A. Unit 3; and B. Unit 4. Error bars indicate standard error of the mean (SEM).



scores into students that performed simulation assignments versus students that did not perform simulation assignments over the material in a particular unit of the course for fall 2015 did not display any significant difference between student populations (Fig. 2A and 2B). As mean exam performances were typically near 80%, differences for particular groups of students, such as low-performing students, could potentially be difficult to observe. To determine if the simulation assignments were resulting in an increase in performance for the lower-performing students in the course, we compared average unit exam scores for the students that performed in the bottom 25% on the exams (Fig. 1F). Though some variation was observed in lower-performing students' scores, no consistent differences were observed that varied with the inclusion of the simulation assignments, suggesting that simulation assignments were not leading to an improvement in performance for those that had the most potential for improvement. With the exception of one unit exam for the fall 2014 semester, overall these results suggest that the simulation assignments did not result in significant increases in understanding of material covered by these assignments when assessed by course unit exams (Fig. 1E).

Differences among unit exams could potentially confound any observed effects of the simulation assignments. Therefore, unit and final exams were compared based on revised Bloom's Taxonomy

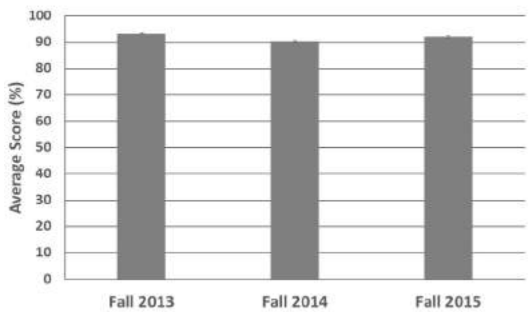
Table 1. Comparison of the percentages of points allotted to lower order cognitive skills (LOCS) and higher order cognitive skills (HOCS) questions on each unit and final exam for General Biology I for fall 2013-2016 semesters.

		Fall 2013	Fall 2014	Fall 2015	Fall 2016
Unit 1 Exam	LOCS	0.447	0.476	0.414	0.398
	HOCS	0.553	0.524	0.586	0.602
Unit 2 Exam	LOCS	0.706	0.794	0.754	0.742
	HOCS	0.294	0.206	0.246	0.258
Unit 3 Exam	LOCS	0.816	0.759	0.916	0.751
	HOCS	0.184	0.241	0.084	0.249
Unit 4 Exam	LOCS	0.889	0.973	0.948	0.893
	HOCS	0.111	0.027	0.052	0.107
Final Exam	LOCS	0.672	0.699	0.724	0.701
	HOCS	0.328	0.301	0.276	0.299

levels (Krathwohl, 2002) by determining the amounts of lower order cognitive skills (LOCS) and higher order cognitive skills (HOCS) questions on each exam. Though the levels of LOCS and HOCS questions differed between the different unit exams within the same semester, the percentage of points allotted to LOCS and HOCS questions on same unit (e.g. unit 1 exams) and final exams across different semesters were fairly consistent with the exception of the fall 2014 unit 4 and fall 2015 unit 3 exams (Table 1). However, it is important to note that increased percentages of HOCS questions on particular exams do not always correlate with increased difficulty (Dunham et al., 2015), as shown in our data with average unit 1 exam scores (with the exception of fall 2014) not significantly different than the other unit exams though unit 1 exams contained a higher percentage of HOCS questions. Additionally, differences between instructors of course sections could result in differences in student performance on unit exams, as each individual instructor wrote and graded exams for the sections separately. However, comparisons between average student performances on unit exams based on the instructor of the course section were performed for each individual unit exam, with no consistent statistical difference based on instructor observed (data not shown).

Though average performances on unit exams did not vary significantly with the inclusion of the simulation assignments, it is possible that individual student unit exam scores may vary with individual performance on the simulation assignments (Fig. 3). Therefore, performance on simulation assignments were compared with individual unit exam performances using Pearson correlation coefficient. For fall 2013-2015, no strong correlation was observed between performance on simulation assignments and performance on unit exams ($r \leq 0.205$ for all simulation and unit exam pairs). These

Fig. 3. Comparison of average performance on simulation assignments in General Biology I for fall 2013, 2014, and 2015. Error bars indicate standard error of the mean (SEM).



results suggest that higher scores on simulation assignments did not correlate with increased unit exam scores. However, since the simulation assignments were performed in groups and all group members received the same grade on the simulation assignment, some group members could have benefited more from the simulation assignments, possibly through the process of leading the group, which may have resulted in increased unit exam performances for particular students and not for other students. As efforts of individual group members on simulation assignments were not individually measured, this analysis cannot distinguish between these possibilities.

Analysis of unit exam scores across multiple semesters to allow for comparison of same units of assignments

Comparison of unit exam scores across semesters did not find any significant differences between unit exam scores, with the exception of the fall 2014 unit 1 exam score that was lower as compared with the fall 2013 and fall 2015 unit 1 scores (Fig. 1E). Though an increase in unit 1 exam scores was observed between fall of 2014 (no simulation) to fall 2015 (simulation), the observation that there was no significant change in unit 1 exam scores when comparing fall 2013 (no simulation) to fall 2015 (simulation) would suggest that the increase in scores between fall 2014 and 2015 might not be due to the inclusion of the simulation assignment in fall 2015 for unit 1 of the course. All other unit exam percentages did not significantly vary between the fall 2013, 2014, and 2015 semesters in this course.

With analyses of unit exam scores as compared to inclusion of the simulation assignments not suggesting significant increases in performances on unit exams, the simulation assignments were removed in the fall 2016 semester due to time constraints inside and outside of the class, in lieu of other active learning components in all units of the course. No significant difference was observed between performances on unit exams in fall 2016 when no simulation assignments were assigned (Fig. 1D). Comparison of unit exams from the fall 2016 semester with unit exam scores from fall 2013-2015 semesters found no significant difference in exam scores for all units of the course, with the exception of the fall 2014 semester for unit 1 of the course (as previously described) (Fig. 1E). These findings indicate that the specific simulation assignments utilized were not likely having a large impact on student learning of the material in each of the units of the course that included these assignments.

Analysis of material retention within same student populations with and without simulation assignments

In order to examine retention of material, performances on final exam questions from each unit of the course were compared based on the inclusion of simulation assignments for the fall 2013 through 2015 semesters. For fall 2013, no significant difference was observed between performances on questions from various units on the final exam (Fig. 4A). For the fall 2014 and 2015 semesters, differences were observed between performances on specific units of the course (Fig. 4B and 4C). However, significant differences were also observed between the four units of the course in fall 2016 when no simulations were assigned (Fig. 4D). Therefore, the differences in performances on questions from various units of the course seem to vary, but these variations might be due to factors other than the presence of the simulation assignments.

When comparing performances on questions from the final exams that assessed material from units with simulation assignments as compared to those without simulation assignments, again no significant difference was found for fall 2013, but significant differences were observed for the fall 2014 and 2015 semesters (Fig. 5). Interestingly, performance on questions assessing topics covered by the simulation assignments was significantly lower in 2014 and higher in 2015 as compared to questions assessing material not covered by simulation assignments (Fig. 4B, 4C, and 5). Therefore, we did not observe a consistent increase in retention of material covered by simulation assignments to the final exam as compared with material not covered by these simulation assignments. As this analysis is comparing retention in same student populations, these results could suggest that the simulation assignments might improve retention in some groups of students, but not in others. However, no strong correlation was

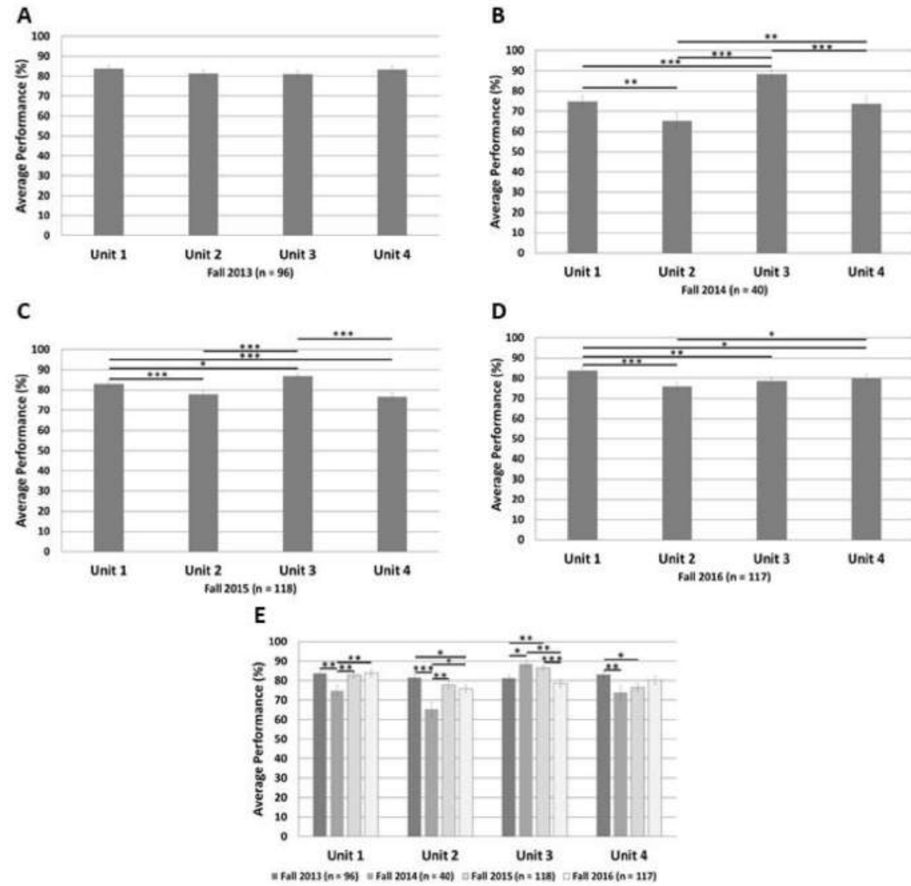


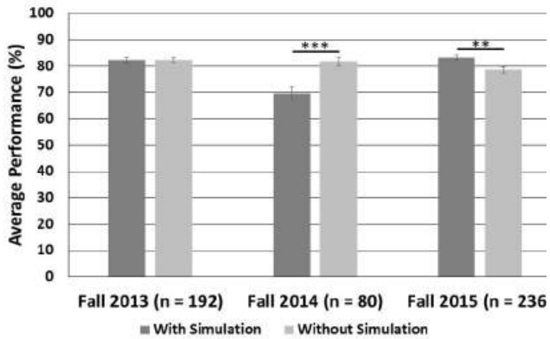
Fig. 4. Comparison of average performance on final exam questions covering material from each unit of the course in General Biology I for: A. Fall 2013; B. Fall 2014; C. Fall 2015; D. Fall 2016; and E. Fall 2013-2016 combined. Asterisks indicate a significant difference between exam scores, with (* $p < 0.05$; ** $p < 0.005$; and *** $p < 0.0005$). Error bars indicate standard error of the mean (SEM).

observed between simulation performance and final exam performance ($r \leq 0.185$ for all simulation and final exam pairs). Alternatively, the simulation assignments may have no effect on retention of material to the final exam for each population of students examined. Though no consistent improvement was observed in retention through the completion of the course, it is important to note that this study did not assess long term retention, as it is possible that students completing the simulation assignments may retain the information covered in these creative assignments longer than individuals that did not participate in these presentations.

Analysis of material retention across multiple semesters to allow for comparison of same units of the course with and without simulation assignments

After removal of the simulation assignments from all sections of the course, retention of material between the time at which the material is covered and final exam were examined again. Comparison of performances on questions from individual units of the course with the presence or absence of the simulation assignments from the fall 2013-2016 semesters did not find any significant difference, with the exception of unit 3 of the course (Fig. 6). Interestingly, comparison of unit 3 with and without simulation assignments did not display a significant difference for the 2013-2015 semesters (data not shown). Though overall final exam performance in fall 2016 was not statistically different from the fall 2014 and fall 2015 semesters (Fig. 7), the average performance specifically on unit 3 questions from the fall 2016 final exam was significantly lower as compared to the fall 2014 and 2015 semesters (Fig. 4E). There was no significant difference between average performances on unit 3 questions from the final exam when comparing the fall 2013 and 2016

Fig. 5. Comparison of average performance on final exam questions covering material from units of the General Biology I course from fall 2013-2015 that contained simulation assignments and did not contain simulation assignments. Asterisks indicate a significant difference between average performances, with (* $p < 0.05$; ** $p < 0.005$; and *** $p < 0.0005$). Error bars indicate standard error of the mean (SEM).



semesters (Fig. 4E). However, the fall 2013 overall final exam performance was significantly higher than all other semesters examined (Fig. 7). As student populations vary each year, it is possible that these significant variations in learning and retention of material could be due to changes in student populations or exposure of students to the material prior to covering the various topics in the General Biology I course. However, average composite ACT scores for entire populations of incoming freshmen classes (not only students enrolled in General Biology I) were similar at 25.5 for fall 2013 and 2014 and 25.6 for fall 2015 and 2016, which might suggest similarity in general academic preparation for the student cohorts for each academic year from 2013-2016. One difference that was noted was the overall

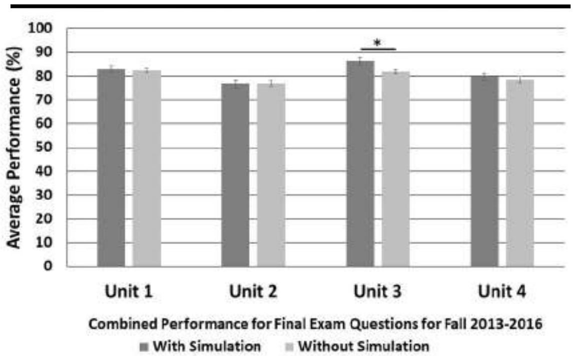


Fig. 6. Comparison of combined average performance on final exam questions covering material from each unit of the course in General Biology I for fall 2013-2016 sections based on the inclusion or exclusion of the simulation assignments. Asterisks indicate a significant difference between average performances, with (* $p < 0.05$; ** $p < 0.005$; and *** $p < 0.0005$). Error bars indicate standard error of the mean (SEM).

reception of the simulation assignments, as determined by feedback on formal student course survey questions asking students about aspects of the course that contributed to learning and aspects of the course that could be changed, varied from 2013 to 2015. In 2013, numerous students commented that the simulation assignments contributed to their learning of the material and few students provided negative feedback. However, by fall of 2015, the trends shifted some, with many students commenting that the simulation assignments did not benefit their learning or that these assignments should be removed. As active learning assignments tend to increase engagement, increases in student learning, retention, and course performance in active learning environments all might be a result of the increased engagement. Therefore, by including other active learning assignments that the students valued more as student opinions of these simulation assignments changed over time, any observable increase in performance due to including simulation assignments might have been attenuated due to the replacement of the simulation assignments with different active learning assignments that continued to engage our student population.

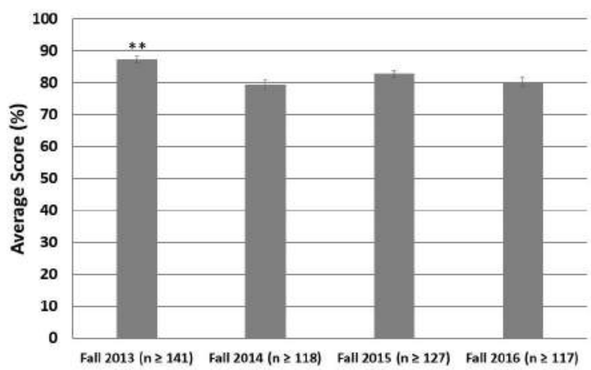


Fig. 7. Comparison of average overall final exam performance in General Biology I for fall 2013-2016. Asterisks indicate a significant difference between average performances, with (* $p < 0.05$; ** $p < 0.005$; and *** $p < 0.0005$). Error bars indicate standard error of the mean (SEM).

CONCLUSIONS

Through quantitative analyses presented in this work, we were able to determine the overall effectiveness of a specific active learning assignment in terms of learning and retention of material in a General Biology I course. Our results suggest that this particular assignment did not consistently increase overall student learning or retention of material covered by these assignments. It is important to note that these studies did not investigate whether individual students gained from the simulation exercises, as these assignments were completed in groups where participation and engagement in the simulation exercises were not directly measured. Though the particular active learning assignment in this study did not appear to increase class learning and retention, we did not examine the difference in student performance with and without active learning components in the classroom. When the simulation exercises were not assigned for units of the course, other active learning assignments were given that covered the material. Therefore, the students generally performed similarly in an environment when active learning methods were employed. As various assignments will have differential effects on student learning and retention, this study provides an example of how assignments can be assessed to ensure that we are utilizing tools that will continue to improve student learning, retention, and positive experiences in the classroom.

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This study (#2018-01) has been approved by the Rockhurst University Institutional Review Board.

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