JOURNAL OF MICROBIOLOGY & BIOLOGY EDUCATION, December 2016, p. 360-369
DOI: http://dx.doi.org/10.1128/jmbe.v17i3.1071

Research

The Use of Group Activities in Introductory Biology Supports Learning Gains and Uniquely Benefits High-Achieving Students †

Gili Marbach-Ad[1]*, Carly H. Rietschel[2], Neeti Saluja[1], Karen L. Carleton[3], and Eric S. Haag[3]
[1]College of Computer, Mathematical and Natural Sciences, University of Maryland, College Park, MD 20742,
[2]Counseling, Higher Education and Special Education, University of Maryland, College Park, MD 20742,
[3]Department of Biology, University of Maryland, College Park, MD 20742

This study describes the implementation and effectiveness of small-group active engagement (GAE) exercises in an introductory biology course (BSCI207) taught in a large auditorium setting. BSCI207 (Principles of Biology III—Organismal Biology) is the third introductory core course for Biological Sciences majors. In fall 2014, the instructors redesigned one section to include GAE activities to supplement lecture content. One section (*n* = 198) employed three lectures per week. The other section (*n* = 136) replaced one lecture per week with a GAE class. We explored the benefits and challenges associated with implementing GAE exercises and their relative effectiveness for unique student groups (e.g., minority students, high- and low-grade point average [GPA] students). Our findings show that undergraduates in the GAE class exhibited greater improvement in learning outcomes than undergraduates in the traditional class. Findings also indicate that high-achieving students experienced the greatest benefit from GAE activities. Some at-risk student groups (e.g., two-year transfer students) showed comparably low learning gains in the course, despite the additional support that may have been afforded by active learning. Collectively, these findings provide valuable feedback that may assist other instructors who wish to revise their courses and recommendations for institutions regarding prerequisite coursework approval policies.

INTRODUCTION

This study describes the implementation and effectiveness of small-group active engagement (GAE) exercises in a large-enrollment introductory biology course, BSCI207 (Principles of Biology III—Organismal Biology) taught in a large auditorium setting. In research-intensive universities, introductory biology courses are commonly taught in large lecture halls. Given the challenges to engage students in large-enrollment classes, researchers across the US have begun implementing new strategies to try and restructure large classes to enhance student engagement (13, 14, 20, 21). Evidence shows that student classroom engagement through group work and problem solving can enhance learning (6–8, 12, 19, 33) and foster critical thinking (10, 21). Furthermore, working collaboratively on group assignments in science classes is fundamentally important for preparing students for the collaborative nature of the workplace (17). Nevertheless, students have shown resistance to group work (31, 35), which seems to also increase faculty resistance to implementing group-work activities (18, 31).

Transitioning from traditional lecturing to student-centered teaching styles (e.g., GAE) is characterized by challenges such as opening the classroom to faculty-student interaction (34), managing small-group work within the constraints of the lecture hall (i.e., dense rows), and assuring that students are not straying from the task (24, 25). This is especially difficult since the number of teaching assistants assigned to large-enrollment classes is typically insufficient to support active learning instruction. Additionally, it is challenging to develop thought-provoking activities that necessitate collaboration between groups of students (25, 26, 32). These challenges encourage further research on the transition process from instructor-centered teaching to student-centered teaching in large-enrollment courses. In fall 2014, we took advantage of the two sections taught by the same team of instructors to do a comparative study. One section was taught, as in previous semesters, through three weekly 50-minute lectures only. The other section replaced one lecture per week with a GAE class whose content matched the corresponding lecture in the other section. The goal was to explore the effectiveness of implementing active learning exercises, while maintaining consistency in content coverage.

*Corresponding author. Mailing address: 1328 Symons Hall, University of Maryland, College Park, MD, 20742. Phone: 301-405-2075. Fax: 301-405-1655. E-mail: gilim@umd.edu.
†Supplemental materials available at http://asmscience.org/jmbe

We also investigated how diverse groups of students differentially responded to the active and traditional learning conditions. The student population in BSCI207 is very diverse with regard to prior learning and prerequisite courses (e.g., Advanced Placement (AP) biology courses, courses transferred from two- and four-year institutions). It is important to observe the impact of prior knowledge obtained from prerequisite coursework on improvement in learning outcomes, as the diversity of material coverage and skill acquisition in prerequisites can impact students' experiences in subsequent courses and their ability to improve (11, 15, 22).

In addition to prerequisite coursework experiences, students in BSCI207 are varied in terms of major, race/ethnicity, gender, and other demographic characteristics. This situation (i.e., heterogeneous student population) is common in large research universities nationwide and is also important to consider. For example, research has shown that women generally collaborate, and have more positive attitudes towards collaborative work than men (23). It has also been documented that active learning strategies in higher education science, technology, engineering, and mathematics (STEM) classes best support underrepresented populations, in particular, African American students (9). However, it is still unclear which types of active learning interventions work best for which students. Therefore, it is important to observe the impact of different student-centered teaching approaches on unique groups of students.

This study addresses the following research questions (RQs):

- RQ1: Were student learning outcomes associated with class treatment (GAE versus traditional class), demographic characteristics, and/or prerequisite coursework?
- RQ2: What are students' and instructors' perspectives on the GAE and the traditional classes?

METHODS

Course description

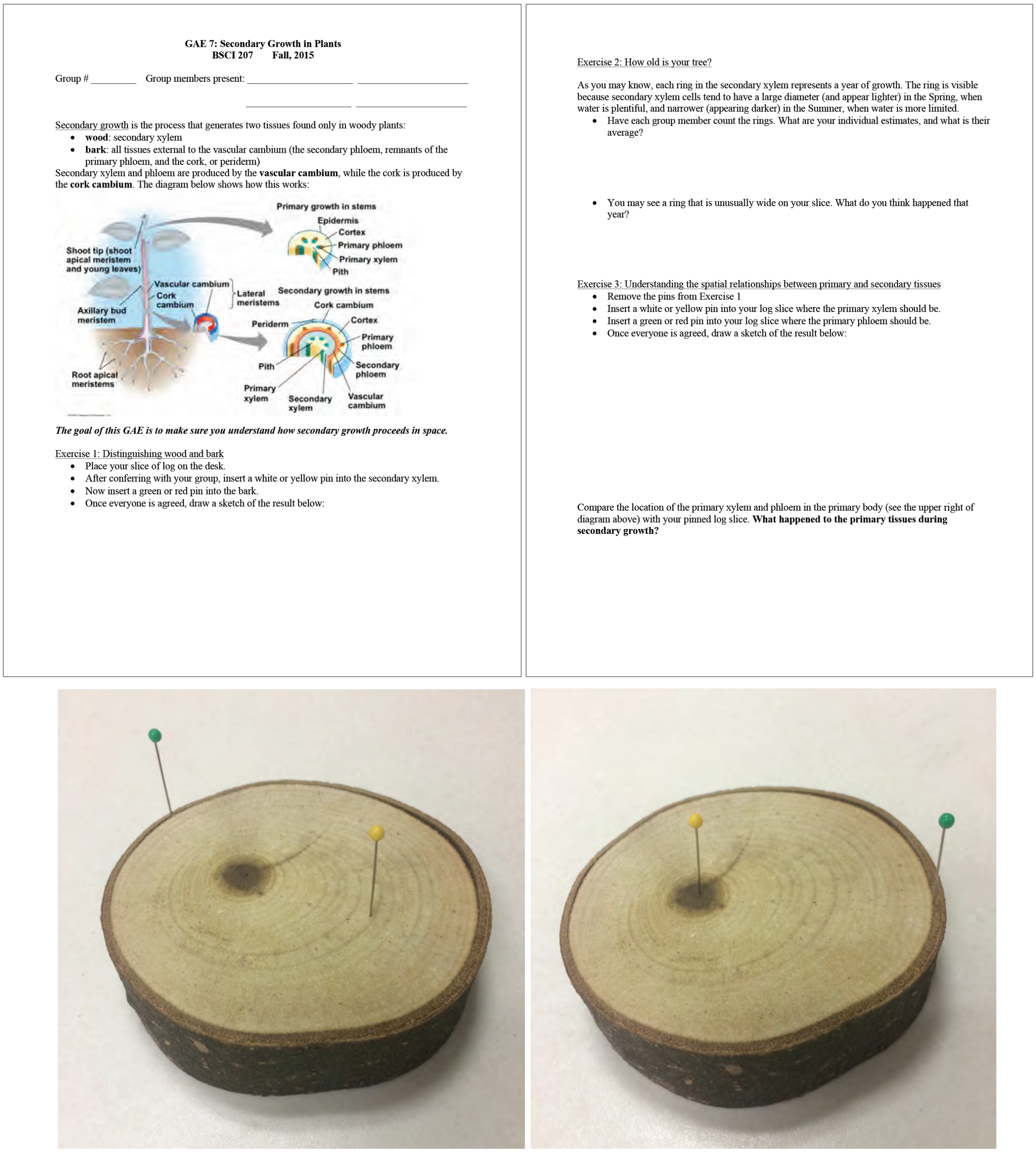
Prior to 2005, the biology curriculum at the University of Maryland included courses that covered the diversity of organisms but did not emphasize unifying biological principles. Many faculty members felt that this traditional approach neither led to a clear picture of the major branches of the evolutionary tree of life nor prepared students for upper-level courses in physiology. The BSCI207 course curriculum was created in 2005 to promote understanding of biological principles that apply across major groups of organisms, as well as an appreciation for the physical, chemical, and evolutionary principles governing the function and diversity of all life, especially in multicellular organisms (29). BSCI207 was designed to follow BSCI105 and BSCI106, with a goal of showing students the unity and diversity of all life and infusing connections between biology and mathematics, physics, and chemistry. The prerequisite courses provide students with fundamental biology knowledge needed for the higher-level learning goals of BSCI207. BSCI105 covers molecular and cellular biology, while BSCI106 covers ecology, evolution, and diversity. BSCI106 and BSCI207 display some similarities with regard to content (e.g., evolution). BSCI207 requires students to synthesize the concepts learned, apply them across contexts in biology, and generally engage in higher-order learning (e.g., interdisciplinarity, conceptual understanding, quantitative reasoning). These learning goals are consistent with current national recommendations to strengthen interdisciplinary reasoning, conceptual understanding, and critical thinking skills in undergraduate science education (1–3, 27, 28, 33, 36).

Presently, BSCI207 is a three-credit class (three 50-minute lectures) with no required out-of-class discussion sections or labs. The GAE classroom sought to more effectively promote these learning goals through the addition of active learning methods. Prior to this study, instructors successfully piloted some of the GAE activities in a small-class setting (~40 students). In fall 2014, the instructors decided to scale up the implementation, and the class was offered in two large-enrollment sections (traditional lecture class and GAE class). Students were told about the different class styles in the first session of class and had the option to switch out from their pre-registered class section into the other section. One student elected to move from the GAE section to the other section. The same three faculty members collaboratively taught both sections. Each of the faculty members was in charge of teaching one third of the course, including lecture and GAE content. Each instructor was in charge of teaching five consecutive weeks of class. In order to facilitate GAE exercises, at least two instructors were present on GAE class days. The GAE class replaced one traditional lecture per week with a content-matched GAE session. In total, 12 GAE sessions were held during the semester (see syllabus in Appendix 1). Both GAE and traditional classes were taught in large lecture auditoriums. For each GAE session, students divided themselves into groups of three to four students of their choice. Four graduate teaching assistants (GTAs) circulated between the groups to facilitate group work. To allow GTAs to move among the groups, students were asked to leave empty rows around their respective groups.

GAE class examples. The GAE activities were focused predominantly on content areas that are likely to be those with the greatest potential to lose students in the lecture format. One of the core skills introduced in BSCI207 is the use of simple mathematical models of biological processes or relationships. For example, instead of presenting lecture slides on fitness effects of gamete size, students in the GAE class worked in groups on an activity in which they used Excel to calculate the fitness effects of gamete size, gamete number, and gamete mobility. Student groups compared their findings with other peer groups in the class. Another GAE session facilitated students' understanding of secondary growth in trees. Each group received a horizontal slice of wood and an activity sheet with instructions (Fig. 1). The instructors organized lecture topics, GAE class activities, and homework assignments by content area (Appendix 1). Homework assignments consisted mainly of textbook reading and computer-based modules to reinforce required math skills.

Participants

Nearly half of BSCI207 students are "conventional" sophomores, having taken both of the prerequisite courses we offer, BSCI105 (Principles of Biology I: Cellular and Molecular Biology) and BSCI106 (Principles of Biology II: Ecology,



GAE 7: Secondary Growth in Plants
BSCI 207 Fall, 2015

Group # ________ Group members present: ________________ ________________

________________ ________________

Secondary growth is the process that generates two tissues found only in woody plants:

- **wood**: secondary xylem
- **bark**: all tissues external to the vascular cambium (the secondary phloem, remnants of the primary phloem, and the cork, or periderm)

Secondary xylem and phloem are produced by the **vascular cambium**, while the cork is produced by the **cork cambium**. The diagram below shows how this works:

The goal of this GAE is to make sure you understand how secondary growth proceeds in space.

Exercise 1: Distinguishing wood and bark

- Place your slice of log on the desk.
- After conferring with your group, insert a white or yellow pin into the secondary xylem.
- Now insert a green or red pin into the bark.
- Once everyone is agreed, draw a sketch of the result below:

Exercise 2: How old is your tree?

As you may know, each ring in the secondary xylem represents a year of growth. The ring is visible because secondary xylem cells tend to have a large diameter (and appear lighter) in the Spring, when water is plentiful, and narrower (appearing darker) in the Summer, when water is more limited.

- Have each group member count the rings. What are your individual estimates, and what is their average?
- You may see a ring that is unusually wide on your slice. What do you think happened that year?

Exercise 3: Understanding the spatial relationships between primary and secondary tissues

- Remove the pins from Exercise 1
- Insert a white or yellow pin into your log slice where the primary xylem should be.
- Insert a green or red pin into your log slice where the primary phloem should be.
- Once everyone is agreed, draw a sketch of the result below:

Compare the location of the primary xylem and phloem in the primary body (see the upper right of diagram above) with your pinned log slice. **What happened to the primary tissues during secondary growth?**

FIGURE 1. An example for a GAE worksheet to facilitate students' understanding of secondary growth in trees. The figure that appears in the worksheet is from REECE, JANE B.; URRY, LISA A.; CAIN, MICHAEL L.; WASSERMAN, STEVEN A.; MINORSKY, PETER V.; JACKSON, ROBERT B., CAMPBELL BIOLOGY, 9th, ©2011. Reprinted by permission of Pearson Education, Inc., New York, New York. Each group received a horizontal slice of wood and an activity sheet with instructions.

Evolution and Diversity). The remaining students were heterogeneous with regard to prerequisite coursework, including AP coursework and courses taken in other two- or four-year institutions. The GAE class had an enrolment of 136 students (56% female; 32% underrepresented minority [URM]; 49% biology majors; average GPA = 3.15), while 198 students enrolled in the traditional class (54% female; 32% URM; 48% biology majors; average GPA = 3.19).

The instructor team was comprised of one female and one male with tenure track positions from the biology department, and one male lecturer from the entomology department. Two of the three instructors were interviewed for the present study. The study was approved by the Institutional Review Board (IRB protocol #601750-2).

Student characteristics

Students' characteristics and demographic data were obtained from the registrar's office. These included major (biology versus non-biology), gender (male versus female), underrepresented minority status (URM: yes/no), and cumulative GPA. URM student status was defined as African-American, Hispanic, and Native American. We also documented the students' prerequisite coursework completed prior to taking BSCI207. Due to the similarity in course content between the prerequisite course BSCI106 and BSCI207, we included student performance in BSCI106 as a potential predictor of performance in BSCI207. In our analyses, we recorded students' prerequisite coursework as falling into one of five categories: 1) Advanced Placement Biology (only students who scored a 5 on the AP examination) [AP students], 2) transfer from four-year college [four-year transfers], 3) transfer from two-year college [two-year transfers], 4) prerequisite biology course (BCSI106) completed at our university with grade A or B, [A or B students], and 5) prerequisite biology course completed at our university with grade C or below [C or below students].

Satisfaction survey

At the end of the semester, students completed a written course satisfaction survey comprised of multiple-choice and open-ended questions. The survey was face validated by a science educator, two instructors of the course, and a graduate student from Information Studies. Students were asked about the meaningfulness of the GAE class activities and to provide suggestions to improve the course. They were also probed about their reactions to the course structure, teaching methods and instructors. Survey responses were analyzed using frequencies and percentages. For qualitative analysis of open-ended questions, we used a modified content analysis strategy (30), in which we grouped related responses into quantifiable subcategories. A graduate student from the College of Information Studies and a science education faculty member categorized the responses separately and then discussed their categories until they came to agreement. Their inter-rater agreement was 90%.

Interviews, class observations, and notecards

Qualitative data on student experiences of the GAE class were obtained from a small subsample of students (*n* = 5; four female, one male) through individual interviews. At the end of one GAE class, we invited students to stay after class to participate in brief, tape-recorded interviews about their experience in the class. The interview protocol was semi-structured and included questions such as, "Do you enjoy learning through exercises in small groups?" and "Is there enough coverage of the syllabus?" In the Results section, we provide illustrative examples of answers from the student interviews.

Qualitative data were also obtained from instructors (*n* = 2). A graduate research assistant transcribed the instructor interviews and reviewed each transcription for the predominant themes. A science educator then reviewed the transcriptions and themes in order to refine the themes. Both individuals then discussed and reviewed the themes until they came to 90% agreement.

Two independent raters conducted class observations. Raters observed six GAE class sessions in the GAE class and the six parallel, content-matched sessions in the traditional class. This procedure allowed the raters to compare the class sessions covering the same material taught using the differing teaching approaches (i.e., student-centered learning versus instructor-centered). The two raters attended each class session together. Once in the class, the raters used a rubric to evaluate the class based on a previously constructed rubric (http://cmns-tlc.umd.edu/observations/). The rubric used for the present study was modified to include five observable areas rated on five-point Likert-type scales, a) student participation (1 = no participation, 5 = extremely high participation), b) reinforcing students' conceptual understanding (1 = no reinforcement, 5 = extremely high reinforcement), c) teacher interaction with the students (1 = no interaction, 5 = extremely high interaction), d) energy level of the class (1 = no energy, 5 = extremely high energy), and e) alternative teaching methods used (1 = no alternative methods used, 5 = extremely high number of alternative methods used). Following each class, the raters compared content.

Finally, we recorded student feedback data using notecards. Following three GAE sessions, students were asked to reflect on the activity of the day on blank notecards. A graduate research assistant transcribed these data, and these responses were linked with participants' characteristics (e.g., GPA, course grades). To examine the relationships between GAE attendance and participants' characteristics, we performed a series of *t*-test analyses. Participation in the GAE activity, as recorded by the notecard (yes/no), was treated as the independent variable, and students' characteristics were treated as the dependent variable.

We also qualitatively examined the notecard feedback to understand students' perspectives on recommendations for future course improvement.

Examinations

Students completed several learning assessments throughout BSCI207. The present study examined grades from two examinations to quantify students' improvement in learning outcomes. These exams included a pretest (see Appendix 2), which consisted of 20 multiple-choice questions that evaluated students' preexisting knowledge, and a final exam (see Appendix 3) consisting of 44 multiple-choice questions, some of which were identical to pretest questions, as well as six short-answer questions.

The GAE class students had higher average scores on the final exam than the traditional class students, but this difference was not significant. Traditional class students performed significantly ($p < 0.05$) better on the pretest than GAE class students. Although examinations are informative metrics of student performance, normalized gain scores provide objective measures of student learning, allow for statistical control of any preexisting differences between groups, and are commonly used in science education research (8, 21). Therefore, pre- and posttest examinations were used to calculate Hake's $\langle g \rangle$, a relative improvement index of student learning improvement or gain (16), defined as follows:

$$\langle g \rangle = \frac{\%Correct_{post-test} - \%Correct_{pre-test}}{100 - \%Correct_{pre-test}}$$

We compared the *g* class averages using multiple linear regression (MLR) in SPSS v22. Independent variable predictors included class section (GAE vs. traditional class), cumulative GPA, major (biology major vs. non-biology major), gender (male vs. female) and underrepresented minority status (yes/no).

RESULTS AND DISCUSSION

Adherence to course redesign conditions

We used class observation protocols to document the instructors' adherence to the class treatment conditions (see Table 1 for an illustrative example). Instructors generally adhered to the class teaching protocols. Overall, students were substantially more engaged with the instructor (e.g., asking more questions) and with their peers in the GAE class section than in the traditional section. Raters provided several specific examples of class characteristics related to the categories listed in Table 1. For example, one observer recorded an instance where the same lecture material (i.e., two slides) was presented over a 16-minute period. In the GAE class session, eight student questions were posed to the instructor compared with one question in the lecture session.

RQ1. Were student learning outcomes associated with class treatment, demographic characteristics, and/or prerequisite coursework?

Association between learning outcome and class treatment. To control for preexisting differences and quantify learning improvement, pre- and posttest scores were used to compute Hake's $\langle g \rangle$ (18), an index of normalized gain (see "Methods"). Students in the GAE section exhibited a significantly ($p < 0.01$) greater average score of improvement ($\langle g \rangle = 0.55$) than those in the traditional class ($\langle g \rangle = 0.50$), holding constant major, gender, URM status, and cumulative GPA (Table 2). No significant differences were associated with gender, URM, or major.

Association between learning outcome and GPA. We observed that undergraduate GPA significantly ($p < 0.0001$) predicted improvement across class sections. To further explore this relationship, we conducted separate regression analyses for high achievers as indexed by cumulative GPA (GPA ≥ 3.2; $n = 164$) and low achievers (GPA < 3.2; $n = 169$) on improvement. We included the same predictor variables (i.e., gender, GPA, URM, major, section) in each of these regression analyses as in the primary regression analysis. Section (GAE vs. traditional) significantly predicted improvement ($p = 0.008$) in the high-achieving group ($F(5,158) = 10.53$, $p < 0.001$). However, in the analysis examining the low-achieving group only ($F(5,163) = 1.626$, $p = 0.156$), section (GAE vs. traditional) did not significantly predict improvement ($p = 0.101$). In other words, high-achieving students experienced more gains than low achievers from the active learning section relative to the traditional learning section.

One plausible explanation for these results is that the high-achieving students were more motivated to attend GAE sessions, thereby gaining the additional value afforded

TABLE 1.
Rating of one class session (course topic: isogamous vs. anisogamous reproduction).

Observable Areas	Traditional Class	GAE Class
Student participation	2.5	4.5
Reinforcing students' conceptual understanding	3.5	4.5
Teacher interaction with the students	4	5
Energy level of class	3	5
Alternative teaching methods used	3.5	4.5

GAE = small-group active engagement exercises.
Ratings are averages from two independent raters who rated rubric areas from low (1) to high (5) on Likert-type scales.

TABLE 2.
Regression analysis of students' improvement scores (Hake's <g>), controlling for selected student characteristics.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.129	0.079		1.618	0.107
Section	-0.001	0.000	-0.137	-2.810	0.005
Cumulative GPA	0.168	0.019	0.441	8.763	0.000
Biology majors/other	-0.019	0.020	-0.048	-0.960	0.338
Gender	-0.023	0.019	-0.058	-1.186	0.236
Underrepresented minority	-0.024	0.210	-0.057	-1.162	0.246

GPA = grade-point average.
$F (5,327) = 19.021$; $R^2 = 0.23$, $p < 0.0001$.

by active learning. Data obtained via notecards provided support for this explanation. For example, students who were present at the stress and strain GAE activity ($n = 65$; as recorded by handing in a notecard at the end of the GAE session) had significantly ($p < 0.002$) higher cumulative GPAs (mean ± standard deviation [SD] = 3.32 ± 0.47) and higher scores on the final exam (73.36 ± 13.45) than students who were absent ($n = 69$; GPA: 2.98 ± 0.54; final exam: 66.45 ± 11.21). Notably, participation in GAE activities was not required for course grades. Another explanation could be that the nature of the activities employed in the course redesign played a role. For instance, given the interdisciplinary teaching goals of the course, the GAE activities required students to integrate skills from physics, chemistry, and mathematics. Low-achieving students may have lacked the background knowledge in these areas and, consequently, did not improve to the same degree as high achieving students.

Association between learning outcome and prerequisite coursework. We analyzed the association between learning outcome and prerequisite coursework (BSCI106) in the GAE class using one-way ANOVA. The overall ANOVA test was significant ($F(4,130) = 3.889$, $p = 0.005$). Tukey's honest significant difference (HSD) pairwise comparisons showed that this result was mainly due to greater improvement of AP students (<*g*> = 0.64) relative to C students (<*g*> = 0.47) and transfer students from two-year colleges (<*g*> = 0.44). Students obtaining A or B grades in BSCI106 (<*g*> = 0.56) and transfer students from four-year colleges (<*g*> = 0.58) were undifferentiated from one another (Table 3). The same trend was observed in final exam grades.

The significant relationships between prerequisite coursework and learning outcomes are in accord with research documenting a relationship between prior knowledge and learning improvement (4, 22). It is common in large universities for students to enter introductory science courses with diverse prerequisite coursework. Results indicate that, in the GAE class, AP students improved the most. We speculate that AP students have the study skills and/or intrinsic motivation to improve in their courses to compensate for

TABLE 3.
Differences in learning gains between student groups in the GAE class as defined by prerequisite coursework.

Student Group Based on Prerequisite Course Experience	*N*	Average Gain in BSCI207
AP students	25	0.64*
Four-year transfers	11	0.58
A or B students	65	0.56
C and below students	22	0.47*
Two-year transfers	12	0.44*

GAE = small-group active engagement exercises; AP = advanced placement.
*Tukey's pairwise comparison significant at $p < 0.05$.

any differences in coverage of material between AP biology and university biology courses. Students who earned C or below in the prerequisite at our university and students from two-year transfer colleges had comparably very low improvement in the course. These students may have lacked the study skills and/or prior knowledge required to adequately improve in the course.

RQ2: What are students' and instructors' perspectives on the GAE and the traditional classes?

Students' perspectives. On the satisfaction survey administered on the last day of class, students were asked to rate various approaches to improving the course (Table 4). Most of the students in the GAE class were satisfied with the number of GAE class activities included in the course (72.2% reported that they did not want fewer activities; 83.3% reported that they did not want more activities). In the traditional class, most of the students (72.7%) reported that they did not want more activities included in class time. It is difficult to speculate on why most traditional class students felt that activities would not improve the course. It is possible that students' past experiences and/or general resistance to in-class activities played a role. Conversely, given that traditional class students did not experience GAE exercises, they may have been unable to conceptualize the possible benefits of activities. Students in both classes felt that the courses could be improved in the area of connecting the material to everyday life (GAE: 72.2%; traditional: 64.5%). Across sections, the majority of students were comfortable with the room setting (GAE: 94.5%; traditional: 86.1%) and the TA involvement in class (GAE: 76.4; traditional: 71.8). However, the majority of students across sections (GAE: 63.9%; traditional: 65.5%) wished that they had discussion sessions supplementary to lecture time.

Seventy-one GAE students responded to the question, "Did you feel that the GAEs were relevant to the course material and why?" Of the 61 students who responded positively (yes), 45 students added open-ended explanations, stating that GAE activities were relevant to the course material for the following reasons (Table 5): clarity (28), for example, "[the GAE] provided scientific facts that were explained in lecture in an understandable way"; visualization (10), for example, "the GAEs provided visual and more tangible examples as to why biological processes occur and it was easier to remember"; application (4), for example, "they made us apply our knowledge to real life or semi real life situations"; and engagement (3), for example, "I though[t] [the] GAE [activities] were insightful and engaging but may have [been] better in smaller groups." These data show that students felt that the GAE activities were relevant to material presented in the course because they added clarity, opportunities to visualize material, and an environment where they could engage with peers. These student perspectives are consistent with published literature showing the benefits of peer engagement in class (34). Research also shows that when students visualize material and manipulate it through exercises, learning outcomes are enhanced (12). The GAE exercises provided an environment in which students could engage in such higher-level learning processes.

Ten students responded that they felt the GAE exercises were irrelevant to the course material, and only three of these students provided reasons, which included a sense that GAE activities were oversimplified, confusing, and time consuming.

Recommendations for improvement. Student feedback (n = 46) for improvement of the GAE activities pertained to the nature and the structure of GAE activities and to group work (Table 6). In general, students wished for more feedback from instructors during GAE exercises and for better time management of activities. Some students felt that the integration of activities with lecture content could be improved, while others expressed frustration with the difficulties of some tasks involved in the exercises (e.g., technical/software difficulties). Comments regarding group work included suggestions to make smaller groups. Finally, others suggested incentivizing group work, which may have been related to a frustration with fellow group members' lack of preparation, and/or a desire to be rewarded for group work efforts.

Instructors' perspectives. Both instructors reported that they perceived the GAE exercises as effective methods for engaging students in the learning process, and that they plan to continue teaching with GAE activities in future semesters. Regarding specific themes, instructors reported that the principal benefit afforded by the GAE activities was the opportunity to model real science in the classroom. In particular, students were able to experience scientific endeavors such as collaboration, critical thinking, and problem solving. Another theme was the changed role of the instructor. Both instructors discussed how their role

TABLE 4.
Percentages of students' responses to the question, "What do you think could improve the course?" by checking a box (Yes or No) for each item.

What Do You Think Could Improve the Course (Check All that Apply)?	GAE Class (N = 72)		Traditional Class (N = 110)	
	No	**Yes**	**No**	**Yes**
More activities included in the class time	83.3	16.7	72.7	27.3
Fewer activities	72.2	27.8	—	—
Working in small groups in the classroom	75.0	25.0	80.0	20.0
Connecting the material to everyday life examples	27.8	72.2	35.5	64.5
Connecting the material to scientific research	68.1	31.9	80.0	20.0
More intervention from the TAs in the class time	76.4	23.6	71.8	28.2
Discussion sessions	36.1	63.9	34.5	65.5
Different room setting	94.5	5.5	86.1	13.9

GAE = small-group active engagement exercises; N = the number of students in each section who responded to the satisfaction survey; TA = teaching assistant.

TABLE 5.
Students' responses to the question, "Did you feel that the GAEs were relevant to the course material and why?"

Category	Number of Responses (*N* = 45)	Illustrative Examples of Students' Open-Ended Responses
Clarity	28	• It helped in understanding the difficult concepts that were discussed during lecture • Provided scientific facts that were explained in lecture in an understandable way • Some examples/topic were better explained through GAE • Some topics were helpful learning through GAE, the ones where we actually worked with objects like K'NEX, [or] levers
Visualization	10	• They helped me understand course material, in visual and sometimes hands-on way • They provided visual and more tangible examples as to why biological processes occur, and it was easier to remember concepts
Application	4	• It allowed me to better understand the concept and relate to everyday life • Learned how to apply what we learn in lecture class to actual problems • They made us apply our knowledge to real life or semi real life situations
Engagement	3	• They really did put a hands-on approach to figuring out concepts • GAE[s] were insightful and engaging but may have [been] better in smaller groups

GAE = small-group active engagement exercises.

TABLE 6.
Students' responses to the open-ended question regarding ways to improve GAE activities.

How Do You Think the GAE Could Be Improved? What Changes Would You Suggest?	Responses (*N* = 46)
Better feedback for the GAE during and following the activities	14
There was not enough or too much time allocated for the activities	12
Specific assignments should be more relevant to the lecture	7
Technical reasons and in particular the activities with Excel were too complicated	5
The need to incentivize group work	3
Other (e.g., changes relating to group structure)	5

changed from a lecturer on facts to a leader or guide, which they perceived as beneficial for helping students take charge of their own learning. This assisted students in moving away from rote learning to meaningful learning.

For faculty wishing to revise their courses, the instructors provided several recommendations and lessons learned. First, for group work to function effectively, students must come prepared with the content knowledge and skills required to perform the task. Such preparatory activities could take the form of online tutorials, videos, lecture slide presentations, or reading assignments with associated online quizzes. Second, the instructors noted the importance of setting aside time for summary and wrap-up of the core concepts of the GAE. One instructor noted, "you want them to see the forest, and all they see is the shrubs and the trees and the weeds; they're so fixated on carrying out the mechanics of the exercise that they don't realize what it is pointing towards."

Finally, the instructors recommended strategies for improved management of small-group activities within the rigid constraints of the large lecture hall. One instructor noted, "It's still tricky to think about how you actually stage all of this… there is a bit of theatre to running a large class with 200 students; how do you move from one aspect of the process to another quickly, without losing people, without too much noise and disturbance?" The instructors emphasized the contribution of GTAs or undergraduate teaching assistance (UTAs) in successful implementation of active learning in large lecture hall settings. UTAs and GTAs should receive training in small-group facilitation in order to learn skills to facilitate group work.

CONCLUSION

The present study was limited in that students were not randomized to study conditions due to environmental constraints of the student population (e.g., course schedules). Strengths of this study include its large sample size and comparison group with a traditional class. Brownell and colleagues (5) noted that when evaluating active learning interventions, comparison with a traditional course is critical for purposes of deciding whether or not differences in learning outcomes are worth the cost (e.g., time and preparation) of implementing novel course redesign. Overall, this study provides valuable data that may assist other instructors who wish to implement active learning activities in large auditorium settings. Findings show that supplementing lecture content with active learning activities benefits student learning overall. In this study, high-achieving students obtained maximal benefits from the active-learning activities. This may have been related to high-achieving students' more frequent attendance at GAE class sessions. One option to encourage greater participation across student groups would be to incentivize group work. It could also be that low-achieving students benefited less from the group activity exercises because of the complexity of the activities (e.g., requirements to engage in interdisciplinary and quantitative thinking). In future implementations of BSCI207, the instructors plan to provide more preparation assignments before group activities to familiarize students with the mathematical principles and technical skills required to complete the activities.

Students with AP biology credit as a prerequisite for BSCI207 showed the greatest learning improvement in the active learning section. This suggests that students who pass AP biology examinations are well prepared for the challenges of higher-level, university biology coursework. These findings provide support for university decisions to allow acceptance of AP credits in lieu of university prerequisites. Conversely, students with low grades in prerequisites in our university and community college students showed very low improvement in the active learning section. These findings suggest that supplementary academic supports should be provided for at-risk students.

SUPPLEMENTAL MATERIALS

Appendix 1: Schedule of GAE exercises and course topics
Appendix 2: Principles of Biology III – pre examination
Appendix 3: Principles of Biology III – final examination

ACKNOWLEDGMENTS

This research was supported in part by a grant from the University of Maryland provost (Elevate Fellows Program) to support the development and assessment of active learning exercises in the classroom. The authors would like to thank Todd Cooke (Department of Cellular Biology and Molecular Genetics, University of Maryland) and Kristi Hall (College of Behavioral and Social Sciences, University of Maryland) for their assistance in planning this study. The authors declare that there are no conflicts of interest.

REFERENCES

1. **AAMC-HHMI Scientific Foundation for Future Physicians.** 2009. AAMC/HHMI committee defines scientific competencies for future physicians. Washington, DC. [Online.] http://www.hhmi.org/grants/sffp.html.
2. **American Association for the Advancement of Science [AAAS].** 2011. Vision and change in undergraduate biology education: a call to action: a summary of recommendations made at a national conference organized by the American Association for the Advancement of Science, July 15–17, 2009. Washington, DC. [Online.] www.visionandchange.org/VC_report.pdf.
3. **Association of American Universities [AAU].** 2011. Undergraduate education STEM initiative. [Online.] https://stemedhub.org/groups/aau. Accessed 2 October 2015.
4. **Belzer, S., M. Miller, and S. Shoemake.** 2003. Concepts in biology: a supplemental study skills course designed to improve introductory students' skills for learning biology. Am. Biol. Teach. **65**(1):30–40.
5. **Brownell, S. E., M. J. Kloser, T. Fukami, and R. J. Shavelson.** 2013. Context matters: volunteer bias, small sample size, and the value of comparison groups in the assessment of research-based undergraduate introductory biology lab courses. J. Microbiol. Biol. Educ. **14**(2):176.
6. **Crouch, C. H., and E. Mazur.** 2001. Peer instruction: ten years of experience and results. Am. J. Phys. **69**(9):970–977.
7. **Deslauriers, L., E. Schelew, and C. Wieman.** 2011. Improved learning in a large-enrollment physics class. Science. **332**(6031):862–864.
8. **Dori, Y. J., and J. Belcher.** 2005. How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? J. Learn. Sci. **14**(2):243–279.
9. **Eddy, S., and K. Hogan.** 2014. Getting under the hood: how and for whom does increasing course structure work? CBE Life Sci. Educ. **13**:453–468.
10. **Finn, K., and J. Campisi.** 2015. Implementing and evaluating a peer-led team-learning approach in undergraduate anatomy and physiology. J. Coll. Sci. Teach. **44**:38–43.
11. **Fisher, K. M.** 2004. The importance of prior knowledge in college science instruction, p 69–83. *In* Sunal, D. W., E. L. Wright, and J. Bland (eds.), Reform in undergraduate science teaching for the 21st century. Information Age Publishing, Charlotte, NC.
12. **Freeman, S., et al.** 2014. Active learning increases student performance in science, engineering, and mathematics. PNAS **111**(23):8410–8415.
13. **Freeman, S., D. Haak, and M. P. Wenderoth.** 2011. Increased course structure improves performance in introductory biology. CBE Life Sci. Educ. **10**:175–186.
14. **Freeman, S., E. et al.** 2007. Prescribed active learning increases performance in introductory biology. CBE Life Sci. Educ. **6**:132–139.
15. **Hailikari, T., N. Katajavuori, and S. Lindblom-Ylanne.** 2008. The relevance of prior knowledge in learning and instructional design. Am. J. Pharm. Educ. **72**(5):113.
16. **Hake, R. R.** 1998. Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. Am. J. Phys. **66**(1):64–74.
17. **Hart Research Associates.** 2015. Falling short? College learning and career success. Hart Research Associates, Washington, DC.
18. **Henderson, C., and M. H. Dancy.** 2007. Barriers to the use of research-based instructional strategies: the influence of both individual and situational characteristics. Phys. Rev. ST Phys. Educ. Res. **3**(2):020102.
19. **Injaian, L., A. C. Smith, J. G. Shipley, G. Marbach-Ad, and B. Fredericksen.** 2011. Antiviral drug research proposal activity. J. Microbiol. Biol. Educ. **12**(1):18.

20. **Kitchen, E., J. D. Bell, S. Reeve, R. R. Sudweeks, and W. S. Bradshaw.** 2003. Teaching cell biology in the large-enrollment classroom: methods to promote analytical thinking and assessment of their effectiveness. CBE Life Sci. Educ. **2**:180–194.
21. **Knight, J. K., and W. B. Wood.** 2005. Teaching more by lecturing less. CBE Life Sci. Educ. **4**:298–310.
22. **Marbach-Ad, G., et al.** 2010. A model for using a concept inventory as a tool for students' assessment and faculty professional development. CBE Life Sci. Educ. **9**(4):408–416.
23. **Martinho, M., P. Albergaria-Almeida, and H. T. Dias.** 2015. Cooperation and competitiveness in higher education science: Does gender matter? Proc. Soc. Behav. Sci. **191**:554–558.
24. **Michaelsen, L. K., and R. H. Black**. 1994. Building learning teams: the key to harnessing the power of small groups in education. Collaborative learning: a source book for higher education II. National Center on Postsecondary Teaching, Learning, and Assessment. The Pennsylvania State University, State College, PA.
25. **Michaelsen, L. K., A. B. Knight, and L. D. Fink.** 2004. Team-based learning: a transformative use of small groups in college teaching. Stylus Publishing, Sterling, VA.
26. **Michaelsen, L. K., M. Sweet, and D. X. Parmelee (eds.).** 2008. Team-based learning: small group learning's next big step. New Directions for Teaching and Learning, Number 116. John Wiley & Sons, San Francisco, CA.
27. **National Research Council (US). Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century.** 2003. BIO2010: transforming undergraduate education for future research biologists. The National Academies Press, Washington, DC.
28. **President's Council of Advisors on Science and Technology (PCAST).** 2012. Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. [Online.] www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf.
29. **Redish, E. F., and T. J. Cooke.** 2013 Learning each other's ropes: negotiating interdisciplinary authenticity. CBE Life Sci. Educ. **12**(2):175–186.
30. **Ryan, G. W., and H. R. Bernard.** 2000. Data management and analysis methods, p 769–802. *In* Denzin, N., and Y. Lincoln (eds.), Handbook of qualitative research. Sage, Thousand Oaks, CA.
31. **Shekhar, P., et al.** 2015. Development of an observation protocol to study undergraduate engineering student resistance to active learning. Int. J. Engin. Educ. **31**(2):597–609.
32. **Sibley, J., and P. Ostafichuk.** 2014. Getting started with team-based learning. Stylus, Sterling, VA.
33. **Singer, S. R., N. R. Nielsen, and H. A. Schweingruber (eds.).** 2012. Discipline-based education research: understanding and improving learning in undergraduate science and engineering. The National Academies Press, Washington DC.
34. **Smith, K. A.** 2000. Going deeper: formal small group learning in large classes. New Direct. Teach. Learn. **81**:25–46.
35. **Weimer, M.** 2013. Learner-centered teaching: five key changes to practice. Jossey-Bass, San Francisco, CA.
36. **Woodin, T., C. Carter, and L. Fletcher.** 2010. Vision and change in biology undergraduate education, a call for action—initial responses. CBE Life Sci. Educ. **9**(1):71–73.