The Impact of Participation in Biology Boot Camp, a Collaborative, Peer-Led, Active Learning Program, on Academic Performance in Freshman Biology Students

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Abstract

While a growing body of research supports active, student-centered approaches to teaching, the implementation of such methodologies in the undergraduate STEM classroom has not been widespread. In an effort to increase student success in an introductory course for biology majors, we developed Biology Boot Camp, a peer-led program based on active, collaborative learning. Program participants attended weekly study sessions led by Boot Camp Coaches who had been trained extensively in both course content and pedagogy. During Boot Camp sessions, Coaches engaged students in activities designed to encourage the development of higher-order cognitive skills represented by the upper levels of Bloom's taxonomy (analysis, evaluation, and synthesis). A primary goal of the program was to transform students into active, engaged learners who understand the difference between superficial and deep, meaningful learning. Biology Boot Camp strove to cultivate motivated learners, to promote biology content mastery, and to develop problem-solving skills necessary for future leaders and visionaries in rapidly evolving STEM fields. In this study, we examined the impact of Boot Camp on student success, and we determined that participation in Biology Boot Camp improved academic performance as demonstrated by exam grades, pre-test/post-test gains, and final course averages.

Keywords: collaborative learning, peer-based instruction, active learning, engagement, higher-order cognitive skills

Introduction

Low retention rates in the fields of science, technology, engineering, and math (STEM) are an ongoing national problem. In a study published by the President's Council of Advisors on Science and Technology, less than 40% of US college students who begin their academic careers with an interest in STEM finish with a STEM degree (PCAST, 2012). The PCAST report called for the implementation of evidence-based educational strategies, such as active learning, to mitigate this problem. Active learning can be defined as students constructing new knowledge, building scientific skills, and "doing something other than taking notes" (Handelsman et al, 2011). More specifically, active learning strategies focus on the development of higher order cognitive skills (analysis, evaluation, and synthesis) rather than on rote memorization. A growing body of research supports active, student-centered approaches to teaching (Ebert-May et al., 1997; Prince, 2004; Michael, 2006; McLaughlin et al., 2014; Freeman et al., 2014; Dolan and Collins, 2015). Active learning strategies increase student performance, and decrease withdrawal rates (Prince, 2004; Ruiz-Primo et al., 2011; Freeman et al., 2014). Despite a large body of evidence supporting the effectiveness of active learning strategies, their adoption among STEM faculty has not been widespread (Friedrich et al., 2008; PCAST, 2012; Stains et al., 2018) thus creating a disconnect between scientific evidence and classroom practice. Several barriers such as lack of training in pedagogical strategies, extensive preparation time required for implementation, class time required to employ active learning, and student resistance challenge the widespread implementation of active learning in the college science classroom (Tanner, 2012; Shadle et al., 2017). In an effort to address these challenges, we created an innovative, peer-based instructional program called Biology Boot Camp to equip biology students to become active, engaged participants in their learning process.

Biology Boot Camp provides students with an opportunity to participate in a learning environment that encourages transformational learning, or deep constructive learning that goes beyond the acquisition of knowledge. It serves as a supplement to the traditional, lecture-dominant classroom model as students attend small, peer-led study sessions designed to build both critical-thinking and metacognitive skills as students engage in a wide variety of active learning pedagogies. In addition to transforming students from passive to active, engaged learners, the Boot Camp program might provide a steppingstone to bridge the gap between the typical classroom lecture based on transmittal learning theory and a more active approach to teaching based on constructivist learning theory. During Biology Boot Camp study sessions, students participate in learning activities in order to construct a fundamental knowledge base that will serve as a foundation for their future studies in biology. Students discuss, analyze, summarize, predict, and explain content (Anderson et al., 2001) as they build relationships between new and existing knowledge. When students engage in such a collaborative learning environment, they are able to perform at higher intellectual levels than possible if they worked alone (Vygotsky, 1978; Gokhale, 1995; Freeman et al., 2014; Gorvine and Smith, 2015). Therefore, Biology Boot Camp strives to cultivate motivated learners, to promote biology content mastery, and to develop problem solving skills necessary for future leaders and visionaries in rapidly evolving STEM fields. In order to assess the effectiveness of Biology Boot Camp in promoting content mastery, we conducted a two-semester study (Spring 2018 – Summer 2018) with students taking majors biology (Biology 1107K - Principles of Biology I). We predicted that participation in Biology Boot Camp would increase the academic performance of these students as measured by lab practical exam scores, pre-test/post-test gains, and final course averages earned.

Materials and Methods

Location

This study was conducted on the Gainesville campus of the University of North Georgia, a regional four-year university, and one of six senior military colleges in the US, located northeast of Metro Atlanta, Georgia. The Gainesville campus is a commuter campus with no residential housing. Most of the students on this campus work part-time or full-time jobs. There is a large population of non-traditional students (23 and older), part-time students, military reservists, veterans, and dual-enrolled students.

Boot Camp Coach Recruitment and Training

The Boot Camp faculty directors recruited students who had previously participated in Boot Camp, had successfully completed Biology 1107K, and had demonstrated an excitement for learning to serve as Boot Camp Coaches. While a majority of these recruits had earned an A in the course, demonstration of a growth mindset - believing that effort and attitude determine abilities - was a more important criterion than grade earned. Coaches underwent intensive pedagogy and content training during workshops conducted prior to the start of the semester as well as during weekly training sessions throughout the semester. Pedagogy training focused on how to implement active learning strategies designed to facilitate deeper, more meaningful learning, while content training focused on reviewing key concepts in biology.

Student Recruitment

During the first lab meeting of the semester, Boot Camp Coaches delivered an “Introduction to Biology Boot Camp” presentation to all sections of Biology 1107K. This presentation outlined the pedagogical basis of the program as well an overview of how the program works. Additionally, the Coaches shared their own experiences as Boot Camp participants as well as their reasons for becoming Coaches. Following the presentation, one of the Coaches informed the students of the research study being conducted to assess the effectiveness of the Boot Camp program and explained the IRB process. Students opting to participate in the study were asked to sign the IRB form, while those students choosing not to participate in the research study were still eligible to participate in Boot Camp.

The Program

Boot Camp Coaches attended 1107K lectures, assisted in a lab section, and conducted at least two or three Boot Camp study sessions throughout the week beginning with the second week of the semester. We offered multiple sessions each week at different times of the day and on the weekends to accommodate student schedules. Participation in Boot Camp was voluntary, and students could attend one or more sessions each week. Two Coaches (one experienced and one new) led each study session, providing new Coaches with a peer mentor to assist them as they began to develop their teaching skills. Each session involved specific content review in addition to a collaborative activity designed to facilitate active learning. Boot Camp participants were taught the difference between passive and active learning as they were challenged to engage with the course content. Boot Camp sessions were not instructor-specific, covered the same key concepts, and utilized similar active learning strategies. This provided a familiar structure for each session.

Experimental Design

We used a quasi-experimental design. During the first scheduled lab period, students in all Biology 1107K sections took a 33-question multiple choice pre-test to assess their current biology knowledge. Sixty percent of these questions, obtained from the Campbell Biology 11/e (Urry et al. 2017) test bank, were classified as higher-order thinking questions (application, analysis, synthesis, or evaluation) based on Bloom's updated taxonomy (Krathwohl, 2002). In addition to pre-test/post-test gains, we also used two standardized, departmental lab practical exams (midterm and final) to evaluate student performance. We used Freshman Index (FI) scores, calculated using high school GPA and SAT or ACT scores, in our analysis to control for differing student abilities.

Data Collection and Analysis

We pooled data from all Biology 1107K courses during the spring and summer semesters of 2018 (15 sections: 325 total students). These courses represented a variety of instructional modalities including the lecture-heavy transmittal model, hybrid classes, classes with elements of the constructivist approach, and short-session summer classes. Several individuals had to be discarded from the complete data set due to missing IRB forms, final letter grades of Withdrawal (W) or Withdrawal Fail (WF), being under the age of eighteen years old, or being a student repeating the course. We considered the complete data set to include freshman index (FI) score, total sessions attended, Lab Practical 1 grade, Lab Practical 2 grade, pre/post-test improvement, final grade percentage, and final letter grade.

Pre-tests were collected and scored during the first week of lab. Personal identifying information was removed, and each student was assigned a unique identification number. At the end of the semester, instructors provided scores for midterm lab practicals, final lab practicals, post-tests (questions embedded within course final exam), as well as final course averages. Additionally, instructors reported if they award extra credit points for Boot Camp participation so that any extra credit given could be removed from the final course average prior to analysis using Excel© (2016).

A one-factor analysis of variance (ANOVA) test was initially performed using basic R v.4.0.0 (R Development Core Team 2020) to determine if there was any difference in number of sessions attended for students who earned letter grades A through F. A post-hoc test using a pairwise T-Test with Bonferroni correction was then performed to determine which grades were significantly different.

Using a series of generalized linear models (GLM), we tested to see if FI scores predict success and/or if Boot Camp attendance improved student's performance in Biology 1107K. We tested a variety of performance measures in our series of GLMs: final grade percentage (FG), pre-test/post-test improvement (PPT), Lab Practical 1 (LP1), Lab Practical 2 (LP2), and Lab Practical average (LPA). For each performance measure, the first round of GLMs included both FI Score and sessions attended. The second round of GLMs included only FI Scores, while the third round of GLMs only included sessions attended.

Results

The initial one factor ANOVA test shows there is a significant difference in number of sessions attended (p = 0.02627) between students earning letter grades A through F (Figure 1). However, the pairwise T-Test with Bonferroni correction shows that only letter grade A and F were significantly different (p = 0.042). In the GLMs with both FI Score and sessions attended as predictors of final grade, both predictors were consistently significant whether we considered all students (p < 0.001 for both predictors) or only included Boot Camp attendees (p < 0.001 for both predictors; Figure 2). Higher-performing students could potentially attend Boot Camp at higher rates, leading to an apparent effect of Boot Camp attendance on student performance. Testing the relationship between FI score and attendance using a GLM revealed that there was no relationship between FI score and attendance whether considering all students (p = 0.176) or Boot Camp attendees only (p = 0.490; Figure 3). With the exception of pre-test/post-test differences, where session attendance was borderline significant (p =0.064), both session attendance and FI score were significantly associated with improved performance in Biology 1107K (p < 0.01 in all cases), for all our performance measures.

Discussion

In this study, we examined the effectiveness of an innovative program designed to improve student performance by engaging students in a collaborative, active learning environment. Participation in Biology Boot Camp improved academic performance as demonstrated by higher exam grades, pre-test/post-test gains, and final course averages. By including freshman index scores in our analyses, we demonstrated that while academic performance was influenced by both FI score and number of Boot

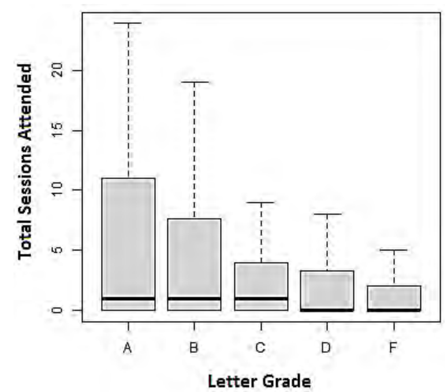

Figure 1: Letter grades as related to number of Boot Camp sessions attended.

Note. Outliers are excluded from the plot.

Probability note. Pairwise T-Test with Bonferroni correction shows a significant difference ($p < .05$) in the number of sessions attended and final letter grade for students who achieved a letter grade of an A or F.

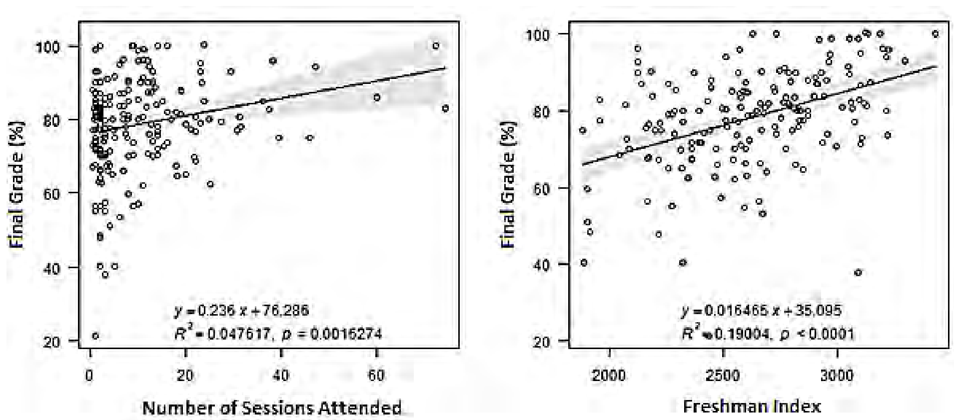

Figure 2: Linear regressions of the total number of sessions attended (left panel) and the freshman index score (right panel) versus final grade achieved in Biology 1107K.

Shaded area indicates 95% confidence interval.

Note. Both factors, freshman index score and number of sessions attended, are statistically significant predictors of final grade achieved whether considering all students or just Boot Camp attendees.

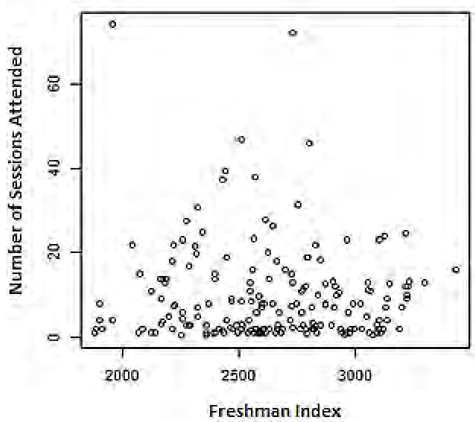

Figure 3: Scatter plot of freshman index score versus number of Boot Camp sessions attended.

Note. Only Boot Camp attendees were considered for these calculations.

Probability note. There is no significant relationship between Freshman Index score and the number of sessions a student chooses to attend ($p < .05$).

Camp sessions attended it could not be explained solely by FI scores. Nevertheless, based on attendance, levels of enthusiasm, conversations with instructors, and Boot Camp Coach feedback, we anticipated even more significant differences between Boot Camp participants and non-participants. Two major reasons for this enthusiasm-versus-performance gap may be that many excellent students do not attend Boot Camp and still do well in the course, inflating the average grades in the "never attended" group, and that some weaker students may attend Boot Camp but may fail to apply the lessons taught in sessions. In addition, in analyzing this disconnect between the expected and actual outcomes of the study, we concluded that while grades and test scores are often used to measure academic improvement, these quantitative measures do not fully measure the types of improvements that active learning strategies facilitate. The conclusions of our study corroborate what Wiltbank et al. (2019) found: grades failed to accurately measure components students considered key during their active learning experience such as enjoyment of class and the desire to learn. Effective active learning engages students in a deeper, more meaningful learning experience compared to passive learning, and it often fosters an enjoyment of learning and a more productive approach to studying. Studying becomes a path to learning rather than simply a means to a desired grade. Several studies support the hypothesis that active learning not only positively impacts higher-order cognitive skills but also student attitudes toward learning (Bonwell and Eison, 1991; Cooper, 2016). Therefore, we need to add qualitative measures to our future research strategies in order to more fully ascertain the effects of Boot Camp participation.

The Biology Boot Camp model is a potential bridge between a transmittal and a constructivist approach to instruction. With STEM instructors slow to adopt active learning strategies for many reasons including time limitations, lack of training, lack of incentives to make pedagogical changes, and perceived negative student responses to active learning, this collaborative, peer-led model provides students with an opportunity to participate in an interactive environment as they construct new knowledge based upon what they are learning in their courses and connect it to existing knowledge. As a result, they might return to their lectures and labs with an excitement for learning and a new set of skills to more effectively master course content. As instructors observe these transformational changes in their students, they may be persuaded to incorporate active learning strategies into the lecture setting. It is time that we base our teaching on current research in cognitive science, psychology, and science education rather than on tradition.

Future Directions

We plan to continue to develop Biology Boot Camp and to make necessary modifications as we continue to draw conclusions based on our assessment of its effectiveness. We will explore student perceptions of how Boot Camp participation impacts their approach to studying. Additionally, we want to follow biology majors as they complete their required major biology courses (cell biology, genetics, ecology, evolution, and senior seminar) to examine the impact of Boot Camp on academic performance in these courses. Many questions arose as we analyzed the results of the current study. Which component of the Boot Camp experience leads to improved student performance? What roles do collaborative learning, building trust, modeling active learning strategies, challenging growth mindsets, and metacognitive development play in student success? How can Boot Camp be improved to achieve our goal of inspiring an approach to learning that centers on the development of higher order cognitive skills rather than on rote memorization? Will Boot Camp participation by both students and Coaches lead to a higher retention rate in the Biology Department? Could the Biology Boot Camp model be a part of the solution to the low, national STEM retention rate? While our data show that Boot Camp participation does correlate with higher exam scores, pre-test/post-test gains, and final course grades, many questions remain concerning why such participation leads to improved academic performance and how the active, collaborative learning environment established by the program contributes to changes in student approaches to and enjoyment of the learning experience.

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