Georgia Journal of Science

Volume 78 *No. 2 Scholarly Contributions from the Membership and Others*

Article 5

2020

A Transdisciplinary Laboratory Course Increases STEM Retention

Caroline A. Brown
University of North Georgia, cabrow9816@ung.edu

Royce Dansby-Sparks
University of North Georgia, royce.dansby-sparks@ung.edu

Sarah Formica
University of North Georgia, sarah.formica@ung.edu

Margaret (Meg) Smith
University of North Georgia, margaret.smith@ung.edu

A Transdisciplinary Laboratory Course Increases STEM Retention

Acknowledgements

This research was supported by a grant from the Complete College Georgia STEM Innovation Initiative. The authors would like to thank Marcus Brewer from the UNG Office of Institutional Effectiveness for providing student retention and GPA data. In addition, the authors would like to thank the UNG College of Science & Mathematics for their support of this work and Gregg Velatini from the Department of Mathematics for his help in designing the course. Author Caroline Brown is a student who was also part of the initial STEM treatment group but did not participate as a student in the qualitative survey. This research was supported by a grant from the Complete College Georgia STEM Innovation Initiative.

A TRANSDISCIPLINARY LABORATORY COURSE INCREASES STEM RETENTION

Caroline A. Brown[a,1], Royce N. Dansby-Sparks, PhD[a], Sarah P. Formica, PhD[b], and Margaret Smith, PhD
[a]Department of Chemistry & Biochemistry, University of North Georgia, Dahlonega, Georgia, 30597, USA
[b]Department of Physics and Astronomy, University of North Georgia, Dahlonega, Georgia, 30597, USA
[c]Department of Biology, University of North Georgia, Dahlonega, Georgia, 30597, USA

ABSTRACT

STEM retention is a national challenge. Recent literature suggests that students leave STEM for many reasons, including lack of context, lack of academic preparedness for entering college, and challenges with quantitative reasoning. These observations compelled us to design an introductory, transdisciplinary STEM lab course which we describe herein. This course was designed to integrate the disciplines of biology, chemistry, physics, and mathematics with activities that engage students in real-world, inquiry-based exercises and help students develop quantitative reasoning skills. Assessment showed that students in this STEM lab have higher STEM retention rates than those in equivalent disciplinary courses. The largest gains in STEM retention were seen in the 4th semester for students who took the lab as underclassmen. Additionally, student surveys indicated that students found the context of the lab compelling. In contrast, there were no significant differences in gains in quantitative literacy and reasoning or GPA among STEM lab students and students in discipline-specific labs. These results suggest that students' engagement in applications of STEM with context might be more important for increasing retention than just focusing on academic ability alone.

Keywords: retention, STEM, transdisciplinary, quantitative reasoning

INTRODUCTION

Retention of students in STEM majors is a challenge that many undergraduate institutions face, especially as colleges and universities strive to educate the future workforce. The creation of STEM jobs is outpacing the production of graduates, making the retention of these students a major focus (Brewer and Leschner 2011; Olson and Riordan 2012). In Georgia, this issue prompted the University System of Georgia to enact a STEM initiative in 2007 (USG STEM Initiative 2007).

Over the past several decades, it has become clear that there are many factors that affect STEM retention, and it would be challenging to simultaneously address them all here (Astin and Astin 1992; Seymour and Hewitt 1997; Whalen and Shelley 2010; Xu

[1] Caroline Brown's current affiliation is Department of Cell Biology, Yale School of Medicine, New Haven, Connecticut, 06520, USA.

2016). Instead, we have chosen to focus on the impacts of academic ability and educational experience on retention of students.

STEM retention is affected by the academic ability of students. Part of academic ability in college is determined by the academic preparedness with which students arrive on campus, or what Astin and Astin (1992) call *inputs*. Academic ability also encompasses preparedness of current college students for future college courses. Xu (2016) showed that STEM students with lower cumulative GPAs had a significantly higher intention to drop out than students with higher GPAs.

However, academic ability alone cannot fully explain STEM retention patterns. Seymour and Hewitt (1997) found that the academic abilities of quitters (those that left STEM majors) and non-quitters (those that persisted in STEM majors) are relatively the same. There is also evidence suggesting that educational experiences affect retention in STEM majors. One kind of educational experience that is important for retention is establishment of a clear context for the content covered in a class. Specific classroom experiences that establish content context affect student awareness of the applicability of course material and student engagement in class (Canning et al. 2018; Xu 2016; Schneider et al. 2015). For example, participation in course-based research experiences has been shown to increase retention by contextualizing material (Hanauer et al. 2017).

Moreover, academic ability and educational experience are not mutually exclusive categories. Interplay between these areas also impacts retention. For example, Stinebrickner and Stinebrickner (2013) showed that some students leave STEM because they are initially overly optimistic about their prospects of completing a STEM degree while also maintaining a high GPA, but the students' actual academic achievement is not as high as they initially thought it would be. Therefore, differences between students' perception of their ability and actual ability in STEM also impact retention.

This overview is not an exhaustive list of all factors affecting STEM retention that have been considered in the literature but rather suggests that retention of students in STEM majors is a complex, multifaceted issue for which there is likely no single, simple solution. Therefore, a variety of ways to address STEM retention are needed so that solutions can be tailored based on instructor, institutional priorities, and financial constraints. Our four-year, primarily undergraduate institution in Georgia is growing rapidly and has limited space and resources to meet the needs of our STEM students. To address STEM retention with these kinds of constraints, we developed a one-semester, freshman-level, transdisciplinary, lab-based course. We define transdisciplinary broadly following Wickson et al. (2006) and consider this course transdisciplinary because it brings together introductory topics and methodologies in biology, chemistry, and physics in a context that focuses on collaboratively solving real-world problems, advancing quantitative reasoning, and enhancing science communication skills. Because this course provides a clear context for material across STEM disciplines and because it focuses on quantitative skills that may enhance academic ability, we expected that the class would increase retention. In assessing this course, we had two questions: (1) Does this course increase STEM retention? (2) What aspects of this course, academic content or educational experience, have the greatest impact on retention? To answer these questions, we compared outcomes for students who took this STEM lab with students in traditional, discipline-specific labs. We measured retention to address the first question. We tracked GPA and measured quantitative reasoning learning gains as measures of academic impact and gave a student survey to measure students' perception of engagement to address educational experience.

Our results show that retention is increased for underclassmen who took the STEM lab relative to those who took traditional, discipline-specific labs. Moreover, student surveys indicated that students found the context of the labs compelling and relatable. However, there were no gains in quantitative reasoning and no long-term differences in GPA. Thus, in terms of retention in STEM majors at our institution, our findings suggest that student enjoyment of and engagement in lab could be more important than academic preparedness for STEM retention.

MATERIALS & METHODS

Course Development and Structure

To increase the number of STEM graduates at our institution, we developed a course that seamlessly blends the disciplines of biology, chemistry, mathematics, and physics in experiments that are exciting and relevant to students. When we were creating the course, the current science labs were single-discipline, one-credit-hour courses with experiments focused on reinforcing lecture course concepts with a heavily guided procedure. Henceforth we refer to these labs as traditional labs. With support from a Complete College Georgia STEM Innovations grant, faculty designed laboratory experiments that use empirical, analytical, and transdisciplinary research methodologies for students to collect and analyze real-world quantitative information. These experiments were organized into three units with broad themes: (1) harnessing light's energy and investigating alternative energy sources, (2) gel electrophoresis and molecular biology, and (3) enzymatic reactions and the efficiency of biofuels. The transdisciplinary experiments were then implemented in a 3-credit-hour laboratory course, STEM 1002L, which we will refer to henceforth as the STEM lab.

The STEM lab was designed to meet twice a week for a total of six hours and was taken in place of the laboratory courses for second semester general biology, chemistry, and physics. Each of the traditional labs are one-credit hour courses that each meet for two or three hours weekly for a combined total of seven hours. Therefore, the time spent in lab per credit hour is similar for both STEM lab and traditional lab students. In practice, most students were not concurrently enrolled in the corresponding three lecture classes. Most students were enrolled in a single corresponding lecture class. In place of lab handouts and worksheets for reporting results used in the traditional, comparison lab groups, STEM lab groups collect quantitative data and organize it independently for all labs. Multiple labs made up each unit. Upon completion of each unit, student groups wrote a research paper on a specific topic of their choice based on the unit's theme, synthesizing their own laboratory results and current primary literature. Not all data collected in lab were ultimately used in the research paper; students decided which data were relevant to the argument of the paper. We focused on quantitative literacy and reasoning extensively throughout the semester by requiring correct computational analysis of numerical results and expression of the results in meaningful graphs, tables, and statistical statements. Oral and written communication of quantitative results was emphasized by group presentations and research papers contextualizing each theme, one after each unit, culminating in an academic research poster session at the end of the semester. More detailed information about the course can be found in Appendix I (see the *additional file* here https://digitalcommons.gaacademy.org/gjs/vol78/iss2/5).

Institutional Demographics

This study was conducted at a primarily undergraduate, four-year institution that has around 20,000 students. There are slightly more females (53%) than males (43%) at our institution, and diversity is relatively low with only 17% of students identifying as non-white. Class sizes are typically 24 students. The four, five and six-year graduation rates for were 31.7, 49.5, and 54.4% respectively, based on the most recent available data (2012 cohort).

Student Populations Assessed

The treatment groups were enrolled in the STEM lab in spring 2016, fall 2016, spring 2017, and spring 2018. The STEM lab has no pre- or corequisites, however, most students were enrolled in or had completed at least one of the companion lecture courses. A majority (73%) of students were early in their academic careers, either freshmen or sophomores. Students were encouraged to take the class through academic advising or other means of advertising but ultimately self-selected the course. Class sizes ranged from 10 to 23 students divided into lab groups of three or four people. The treatment group was composed of a total of 67 students across all four semesters, of which 26 were biology majors, 17 were chemistry majors, 18 were physics or physics/engineering majors, and six were undeclared or non-STEM majors. Of the students in the treatment group, 54% were female and 46% were male. This is consistent with the control group and representative of the institution overall which is 57% female and 43% male.

Students in the comparison groups were from concurrent, traditional biology, chemistry, and physics classes with corequisite labs. The biology comparison group, BIOL, was generally composed of biology and chemistry majors. The chemistry comparison group, CHEM, was composed of chemistry, biology, physics, and physics/engineering majors. The physics comparison group, PHYS, consisted of students in a calculus-based physics class with mostly physics, physics/engineering, and chemistry majors. We received IRB approval and complied with all institutional and federal guidelines (IRB 201601). All available data from all students in the treatment and comparison groups were used for retention and GPA analysis because these data were provided in aggregate by the Office of Institutional Effectiveness. Only data from students with paired pretest-posttest data was analyzed for the quantitative reasoning study.

Retention and GPA Evaluation

Retention and GPA information was compiled independently by the institution and in aggregate by course number and semester for all students enrolled, including those that were not included in the quantitative reasoning study. GPA averages are straightforward, but retention data are more complex. For retention data analysis, students fell into three categories: (1) students retained by the institution in STEM majors (STEM retention); (2) students retained by the institution in any major (institutional retention) and (3) students who left the institution. We were unable to track what happened with students who left the institution, and data for these students are not directly presented. In addition, we focused on underclassmen data for the purposes of tracking long-term retention because junior and seniors will leave the institution before they reach five semesters posttreatment, and because the course was designed specifically to improve retention for underclassmen. For the purpose of this study, STEM majors were defined as students within the departments of biology, chemistry, mathematics, physics, and kinesiology (as many pre-physical therapy students at our institution regularly switch between biology and kinesiology. Data for STEM retention (Table IA) were calculated by dividing the number of students still in a STEM major at the institution (n) by the total number of students (n_{total}) in a given cohort (STEM lab for treatment; traditional BIOL, CHEM, PHYS for comparison). Institutional retention values are the weighted averages of all cohorts with data that can be included (Table IB) and were calculated by dividing the number of students remaining in any major at the institution (n) by the total number of students (n_{total}) in a given cohort (STEM lab for treatment; traditional BIOL, CHEM, PHYS for comparison).

Quantitative Reasoning Learning Assessment and Analysis

To assess quantitative reasoning skills, we administered the Quantitative Literacy and Reasoning Assessment (QLRA) instrument (Gaze et al. 2014) in a pretest-posttest manner to all groups. The QLRA is a 20-question multiple-choice exam that focuses on quantitative literacy, using numbers in meaningful sentences, tables, and graphs rather than in simple computation. The pretest was administered the first week of class and the posttest was administered the last week. To measure student learning gains in quantitative reasoning we compared the QLRA pretest and posttest scores with two methods: (1) normalized change which is calculated for individual students and averaged for the class (c; Marx and Cummings 2007; Hake 1998), and calculated according to:

$$c = \frac{\text{Post-test} - \text{Pre-test}}{100 - \text{Pre-test}} \text{ for Posttest Score > Pretest Score}$$

or

$$c = \frac{\text{Post-test} - \text{Pre-test}}{\text{Pre-test}} \text{ for Posttest Score < Pretest Score,}$$

and (2) Cohen's d, an estimate of effect size based on class means (Cohen 1988), and calculated by:

$$d = \frac{\text{Post-test} - \text{Pre-test}}{\text{SD}_{\text{pooled}}}$$

where SD_{pooled} is the standard deviation pooled across both data sets being compared.

Qualitative Survey of Student Perception

To gain an understanding of student perception of the STEM lab, we generated a survey (Appendix II; see the *additional file* here https://digitalcommons.gaacademy.org/gjs/vol78/iss2/5/) and sent it to all students who had completed the STEM lab when the questionnaire was administered, which excludes the spring 2018 cohort. The survey was anonymous and consisted of questions falling into three categories: (1) questions specific to the STEM lab, (2) questions asking students to compare their STEM lab experience to traditionally taught lab experiences and (3) questions where students were asked to specifically state what was enjoyable or not enjoyable about the course. Questions in categories one and two were measured on a scale of 1–5 with five being strongly agree and one being strongly disagree. The third category questions were free, written response questions. Student response was on a completely volunteer basis, and a total of 28 student responses (62.2% response rate) were recorded and analyzed.

RESULTS

Retention Evaluation

STEM major retention values (Table IA) and institutional retention values (Table IB) were higher for treatment over comparison groups across all semesters measured when considering only students who took the class as underclassmen. Just looking at underclassmen, as opposed to including upperclassmen, provides a clearer picture of the total number of students that are retained in STEM by the institution and provides a valuable way to interpret the gains in retention in an absolute way because students who took the class as underclassman are not likely to have yet graduated. STEM retention rates generally decrease with time because students (1) leave STEM majors or (2) transfer or otherwise leave the institution and are no longer counted. Of particular interest is the 4th semester STEM retention rate because post-STEM lab retention rates are statistically significantly higher relative to the comparison groups in the 4th semester, 58.9% versus 42.9% (p = 0.039; Table IA). In the 5th semester the differences are no longer statistically significant, likely because students start to graduate and are no longer included in retention data. Institutional retention values were not significantly different among the treatment (STEM lab) and comparison (discipline-specific lab) groups. Because of national conversations about STEM diversity, the STEM retention rates were further broken down into subgroups based on male, female, and minority status and these data are available in Appendix III (see the additional file here https://digitalcommons.gaacademy.org/gjs/vol78/iss2/5/).

Measurements of Academic Ability

Grade Point Averages: Student GPA data were evaluated for underclassmen only to assess the impact of student self-selection into the treatment groups and influence on academic preparedness and success pre- and posttreatment (Table II). When only underclassmen students are considered, the pre- and post-GPAs for the treatment group are slightly higher than comparison groups. However, when looking at individual cohort data, the pre-GPAs and post-GPAs are very similar. Some individual treatment cohort GPAs are at—or even below—the comparison groups. The increases in retention rates presented above for the treatment group are occurring despite GPAs that are very similar to the comparison groups, especially in later semesters where retention rates are most statistically significant. This seems to suggest that students are likely not more or less successful, in terms of GPA in their major, due to being part of the treatment group, and therefore other factors are leading to the increases in retention.

Quantitative Reasoning Learning Assessment: For all groups, there was no statistically significant difference on the QRLA between the pretest and posttest (Table III). To control for preexisting differences and quantify learning gains, pretest and posttest scores (Table II IA) were used to compute the normalized change in the treatment

Table I. Retention results.[1] (A) STEM retention represents the percent of students in each semester's cohort that are in STEM majors at the institution for underclassmen only. (B) Institutional retention rates represent the percent of students in each semester's cohort that are still enrolled at the institution for underclassmen only.

(A) Group/statistics	STEM retention rates (%) by semester [1]			
	2nd	3rd	4th	5th
Treatment (n/n_{total})	**80.4 (45/56)**	**66.1 (37/56)**	**58.9 (33/56)***	**54.3 (19/35)**
Comparison (n/n_{total})	**72.0 (116/161)**	**60.9 (98/161)**	**42.9 (69/161)***	**42.5 (65/153)**
X^2 statistic	1.53	0.478	4.269	1.604
degrees of freedom	1	1	1	1
p-value	0.216	0.489	0.039	0.205

(B) Group/statistics	Institutional retention rates (%) by semester[1]			
	2nd	3rd	4th	5th
Treatment (n/n_{total})	**91.1 (51/56)**	**87.5 (49/56)**	**75.0 (42/56)**	**68.6 (24/35)**
Comparison (n/n_{total})	**88.2 (142/161)**	**82.6 (133/161)**	**64.6 (104/161)**	**61.4 (94/153)**
X^2 statistic	0.36	0.74	2.04	0.63
degrees of freedom	1	1	1	1
p-value	0.551	0.391	0.153	0.427

[1]The data represent are weighted averages (bolded) by semester for all cohorts with data available for that particular semester. The total number of students starting in each group with available retention data is represented as n_{total}. The number of students still in each group is represented by n. Percent (%) retention is n/n_{total} by semester. Statistical analysis for the comparison of weighted average data is presented. The value of n_{total} for the 5th semester is lower than in earlier semesters because this cohort had not yet had a 5th semester.

and comparison groups. There was no significant difference among treatments, in general, for normalized change. However, normalized change may be skewed in favor of higher pretest scores (Nissen et al. 2018). Because of this, it may be better to use effect size rather than normalized change when quantifying learning gains. There was no significant difference among groups for effect size.

Measurement of Educational Experience

Qualitative Survey of Student Perception: To help understand the contribution of educational experience to retention, student feedback was solicited through an online questionnaire after students had completed the STEM lab (Figures 1 and 2, Table IV). Answers to the free response survey questions were varied, but some common ideas were repeated in student responses (Table IV). Students found the experiments engaging, responded well to the transdisciplinary approach, and valued the opportunities to communicate their work. A frequent negative comment was that students felt unprepared to deal with some of the material but that, in the end, it was worth it. The questionnaire and all the student feedback are available in supplemental information (Appendix II: see the *additional file* here https://digitalcommons.gaacademy.org/gjs/vol78/iss2/5/).

Table II. Student grade point average (GPA) on a four-point scale for underclassmen students in treatment and comparison groups.

Group/cohort	GPA By cohort and semester[1]					
	Pre	Post	2^{nd}	3^{rd}	4^{th}	5^{th}
Treatment	**3.33**	**3.07**	**2.97**	**2.95**	**2.95**	**2.92**
Spring 2016 (n = 21)	3.57	3.32	3.12	3.08	3.12	3.12
Fall 2016 (n = 6)	2.91	3.05	2.90	2.73	2.65	2.48
Spring 2017 (n = 8)	3.11	2.78	2.67	2.67	2.71	2.71
Spring 2018 (n = 21)	3.30	2.93	2.96	2.99-	-	
Comparison (n=152)	**2.89**	**2.78**	**2.78**	**2.79**	**2.74**	**2.75**
Spring 2016 (n = 91)	2.84	2.79	2.80	2.81	2.83	2.83
Spring 2017 (n = 62)	2.86	2.76	2.76	2.75	2.61	2.64
Spring 2018 (n = 8)	3.62	3.23	3.27	3.21	-	-

[1]Data are representative of all students enrolled in the treatment or comparison classes and is not limited to students in the comparison classes who agreed to be in the QRLA study. Data in black (bold) are the weighted average, and GPA by cohort is indicated in blue below the averages. *Pre* indicates the GPA for the cohort before taking either STEM or traditional labs. *Post* indicates the GPA at the end of the semester in which the STEM or traditional labs were taken. Second, 3^{rd}, 4^{th} and 5^{th} are the semesters following when the STEM or traditional lab was taken for a given cohort.

Table III. Analysis of QRLA scores for each group for all semesters during which STEM lab was taught. (A) Raw values and (B) statistical analysis.

(A) Group	**Normalized change (%)**	**Effect size**		**Pretest**	**Posttest**
STEM lab (n = 66)	13.4 ± 3.7	0.244		0.58	0.63
PHYS (n = 12)	14.4 ± 8.8	0.221		0.67	0.71
CHEM (n = 35)	14.1 ± 4.7	0.326		0.42	0.49
BIOL (n = 63)	1.1 ± 3.6	0.107		0.4	0.42
(B) Basis for comparison	**Group**	***F***	***t***	**Degrees of freedom**	***p*-value**
Pretest vs posttest	STEM		1.43	130	0.156
	PHYS		0.54	22	0.593
	CHEM		1.36	68	0.177
	BIOL		0.6	124	0.550
Normalized change	All	2.66		3, 172	0.062
Effect size	All	2.66		3, 172	0.472

Table IV. Some student answers to the free-response survey question where students were asked to specifically state what was enjoyable or not enjoyable about the course.

Student engagement
"...The labs were engaging and the Lab was setup perfectly in that the professors would guide us an assist us when we needed them, however, we were able to understand and learn on our own as well, which is invaluable in my opinion." *"I enjoyed it and did not enjoy it for the same reason. I was a freshman taking the STEM course and was very overwhelmed. I had never written a research paper or did any chemistry experiments and it was very stressful. However, I appreciate it now because I have been more prepared for my upper level biology classes than most of my peers."* *"I also enjoyed how we could branch off an[d] make decisions on our own."*
Learning in Context
"The main take away [from STEM lab] was being able to relate all the different areas (Biology, Chemistry, Physics, Mathematics, etc) together [to] make stronger arguments, understand concepts easier, and . . . explain things to others with the other fields in mind." *"I enjoyed the interdisciplinary aspect. It truly prepared me for other courses and made traditional labs seem easy."*
Scientific Communication
"I loved the small aspect of the class. I hated presentations, but I know it was good for me. Its important to be able to speak to others about your research." *"the presentations were enjoyable, and comparing our own findings to those of scientific articles gave me some insight into just how useful the techniques we used are."* *[I enjoyed] "Having the opportunity to present a small research project involving multiple disciplines in front of peers."*

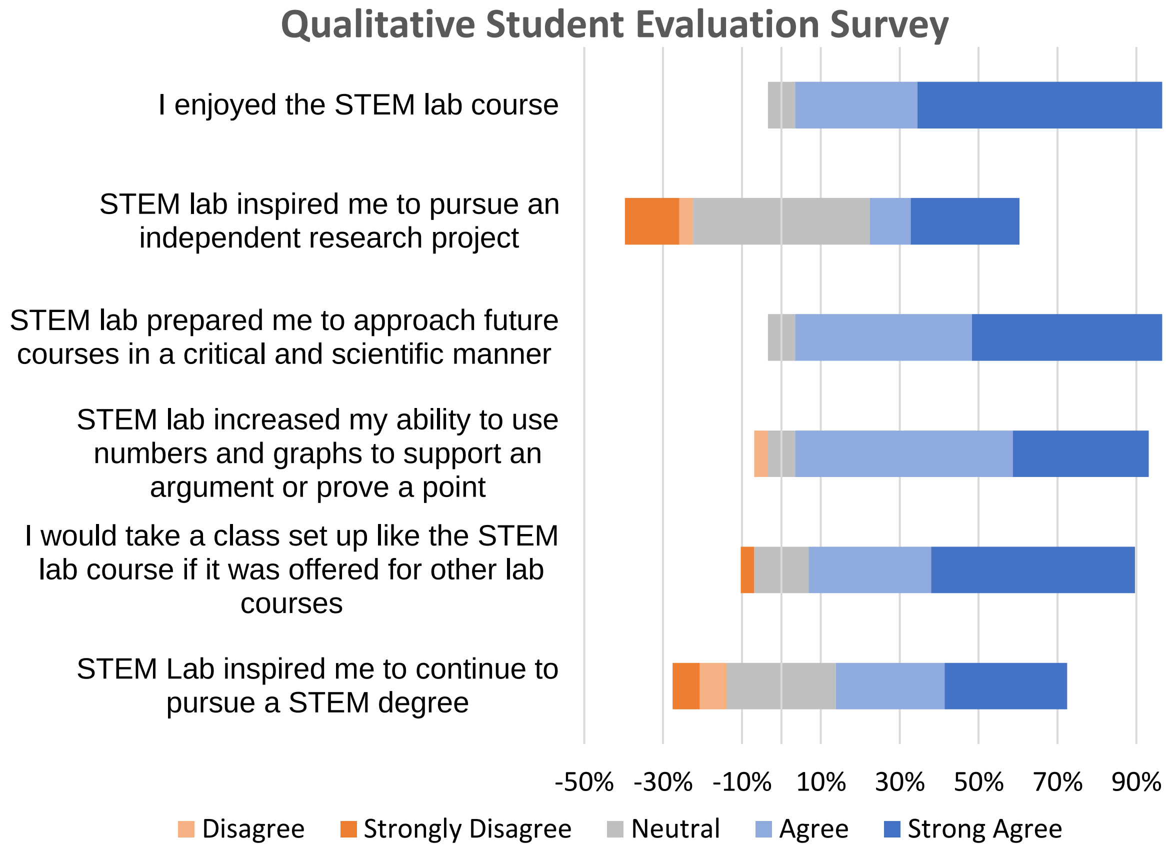

Figure 1. Qualitative survey responses of STEM students for questions specific to the STEM lab. Negative and positive signs on percentages indicate the percentage of responses that was unfavorable and favorable respectively. *N* = 28, response rate = 62.2%.

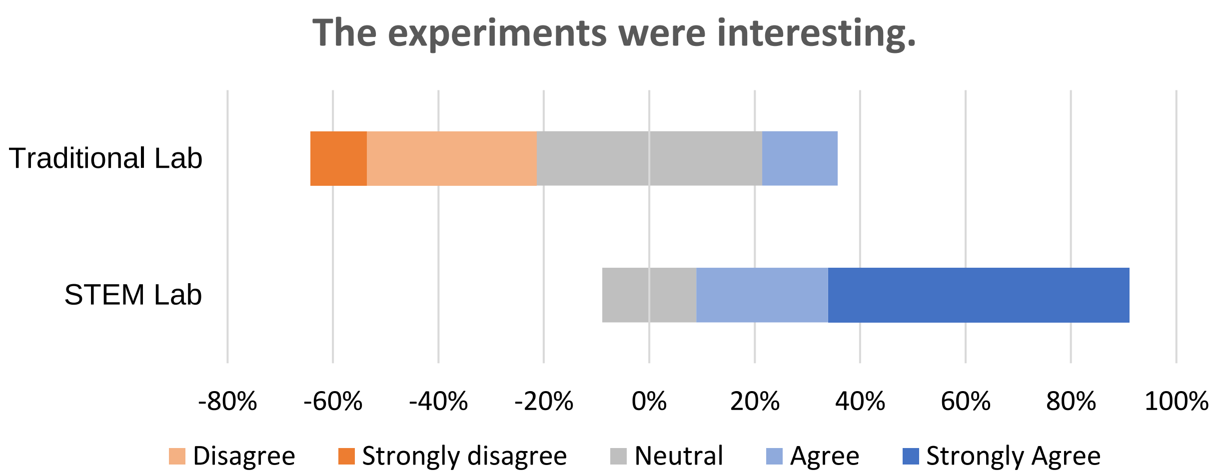

Figure 2. Qualitative survey responses of STEM students for questions comparing the experience in a traditionally taught lab and STEM lab. Negative and positive signs on percentages indicate the percentage of responses that was unfavorable and favorable respectively. *N* = 28, response rate = 62.2%. This figure is continued on the next page.

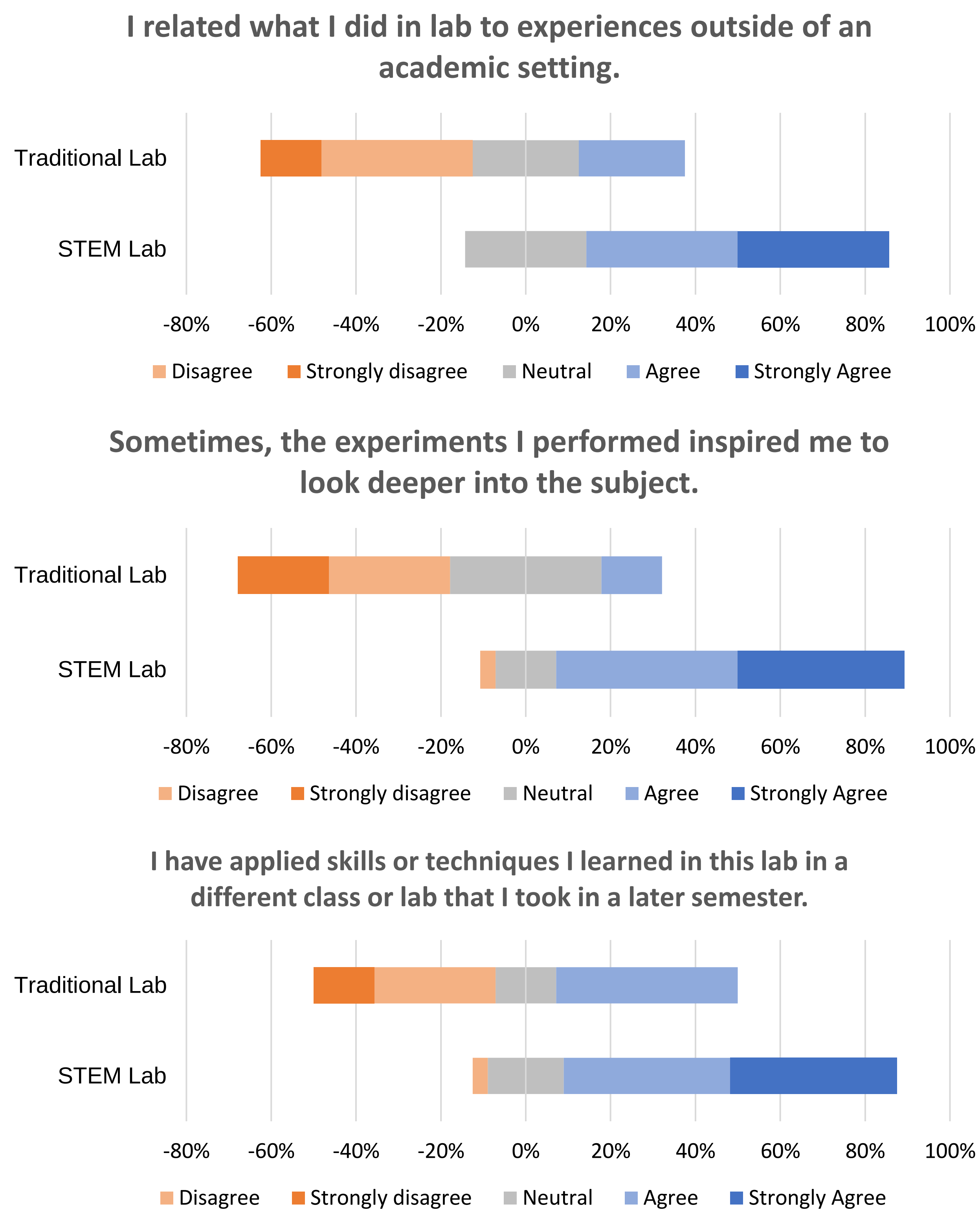

Figure 2 *(Continued)*

DISCUSSION

The STEM lab was developed to increase STEM retention at a rapidly growing, primarily undergraduate teaching institution in a way that required no additional facilities or program restructuring. We aimed to assess the course's impact on retention and investigate what factors of the class might be responsible for changes in retention. Our results show that the class did positively impact both STEM and institutional retention. Our transdisciplinary approach to introductory science labs for science majors increases retention in STEM for some students. The effect is most pronounced for retention in the 4^{th} semester for students who took STEM lab as underclassmen.

One of the areas we intentionally focused on when developing this lab was quantitative reasoning skills. However, we observed no difference in quantitative reasoning gains between treatment and comparison groups. In addition, GPA data do not indicate substantial differences in the academic abilities or success of treatment versus comparison students. These two findings seem to suggest that academic ability alone is not enough to explain the increases in STEM retention that we see for the underclassmen in our treatment group at our institution.

The specific factors outside of academic ability and success that lead to increases in STEM retention are hard to pinpoint and quantify as they relate to student beliefs and perceptions of their educational experiences. Nonetheless, we suggest that the benefit to retention of exploring broad ideas in STEM, which provides context that is often lacking in traditional introductory science labs, is supported by student survey feedback (Figures 1 and 2). The survey data support the idea that the STEM lab established how concepts in distinct disciplines are interconnected within the field of science. Student perspectives shifted from viewing the scientific world as delineated fields to relating the different disciplines together as an integrated whole (Table IV and Appendix II). This realization of interrelatedness in turn may have enabled students to understand concepts that could be more difficult to fully grasp without transdisciplinary knowledge. The student survey feedback for questions asking students to compare STEM lab to their educational experiences in traditional labs supports this reasoning (Figure 2). Students also commented on the benefit of the independence of STEM lab in comparison to traditional labs where experiments are often very prescriptive. In the STEM lab, it was understood that professors would guide and assist when needed, but students were able to explore the material on their own and were ultimately responsible for their own success. The independent nature of this course may have fostered a responsibility for learning resulting in 92% of students feeling as if STEM lab effectively prepared them for future lab courses (Figure 1). The student independence together with the context provided from the integrated nature of the course may have helped motivate students to continue in a STEM major.

Our findings that STEM retention is affected by context and not likely academic ability alone is consistent with the findings of others. Specifically, Seymour and Hewitt (1997) suggest that students who leave STEM are not necessarily leaving because they are academically underprepared or unsuccessful in the major. Instead, students expressed concerns about their academic abilities in STEM at the same rate of frequency, regardless if they were retained in STEM or not and that the most common reasons for leaving STEM majors relate to structural and cultural sources within institutions or student beliefs about their prospects for careers in STEM fields (Seymour and Hewitt, 1997). Seymour and Hewitt suggest that students who persist did so because they had developed coping mechanisms to deal with concerns as they arise or had interventions by faculty at critical points in their development. We suggest that our transdisciplinary course is one such way to mitigate the concerns that might cause a student to leave a STEM major and believe that the model presented here is one such way to change the culture of our institution, especially early in the tenures of our students.

Adapting our current model to include courses that truly seek to develop students into cross-disciplinary thinkers and foster their personal interests in the applications of knowledge, not just knowledge itself, might enable us to retain students who are otherwise academically able but lose interest in our current system. Additionally, these changes can be implemented at minimal impact to the institution and without full programmatic overhauls if instituted only at the introductory level of the curriculum where the greatest impacts can be realized. Faculty at some institutions, including our own, will have concerns about abandoning labs that are designed to reinforce lecture content. However, recent studies suggest that these reinforcement-type labs are ineffective (Holmes and Weiman 2018) so, in practice, this may not be a valid concern. Given that the results of our study indicate that this transdisciplinary approach may be one useful way to help combat low STEM retention rates seen in the traditional model, particularly early in the curriculum, adoption of this type of lab may be more effective in reaching institutional goals. While these results are from a single semester, second-semester introductory class, expanding the number of transdisciplinary course offerings might further improve STEM retention.

ACKNOWLEDGEMENTS

This research was supported by a grant from the Complete College Georgia STEM Innovation Initiative. The authors would like to thank Marcus Brewer from the University of North Georgia's Office of Institutional Effectiveness for providing student retention and GPA data. In addition, the authors would like to thank the University of North Georgia College of Science & Mathematics for support of this work and Gregg Velatini from the Department of Mathematics for his help in designing the course. Author Caroline Brown is a student who was also part of the initial STEM treatment group but did not participate as a student in the qualitative survey. This research was supported by a grant from the Complete College Georgia STEM Innovation Initiative.

REFERENCES

Astin, A. and H. Astin. 1992. Undergraduate Science Education: The Impact of Different College Environments on the Educational Pipeline in the Sciences. Report Submitted to National Science Foundation.

Brewer, C. and A.I. Leshner. 2011. Vision and Change in Undergraduate Biology Education a Call to Action. Report submitted to American Association for the Advancement of Science. http://visionandchange.org/files/2011/03/Revised-Vision-and-Change-Final-Report.pdf

Canning, E., J. Harackiewicz, S. Priniski, C. Hecht, Y. Tibbits, and J. Hyde. 2018. Improving performance and retention in introductory biology with a utility-value intervention. Journal of Educational Psychology, 110(6), 843–849. https://psycnet.apa.org/doi/10.1037/edu0000244.

Cohen, J. 1988. Statistical power analysis for the behavioral sciences. Lawrence Erlbaum Associates.

Gaze, E., A. Montgomery, S. Kilic-Bahi, D. Leoni, L. Misener, and C. Taylor. 2014. Towards developing a quantitative literacy/reasoning assessment instrument. Numeracy, 7(2), Article 4.

Hake, R. 1998. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66, 64–74.

Hanauer, D., M. Graham, L. Betancur, A. Bobrownicki, S. Cresawn, R. Garlena, D. Jacob-Sera, N. Kaufmann, W. Pope, D. Russell, W. Jacobs Jr., V. Sivanathan, D. Asai, and G. Hatfull. 2017. An inclusive Research Education Community [sic] (iREC): impact of the SEA-PHAGES program on research outcomes and student learning. Proceedings of the National Academy of Science, 114(51), 13531–13536.

Holmes, N. and C. Weiman. 2018. Introductory physics labs: we can do better. Physics Today, 71(1), 38–45.

Marx, J. and K. Cummings. 2007. Normalized change. American Journal of Physics, 75(1), 87–91.

Nissen, J., R. Talbot, A. Thompson, and B. Van Dusen. 2018. Comparison of normalized gain and Cohen's *d* for analyzing gains and concept inventories. Physical Review Physics Education Research, 14, 010115-1-12.

Olson, S. and D.G. Riordan. 2012. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics. Report submitted to U.S. Government Office of Science and Technology.

Schneider. K., A. Bickel, and A. Morrison-Shetlar. 2015. Planning and implementing a student-centered research program for first-year STEM undergraduates. Journal of College Science Teaching, 44(3), 37–43.

Seymour, E. and N. Hewitt. 1997. Talk about Leaving: Why Undergraduates Leave the Sciences. Westview Press.

Stinebrickner, R. and T. Stinebrickner. 2013. A Major in Science? Initial Beliefs and Final Outcomes for College Major and Dropout. Working Paper 19165 submitted to National Bureau of Economic Research.

USG STEM Initiative. 2007. University System of Georgia. https://www.usg.edu/assets/academic_affairs_and_policy/alc_documents/USG_STEM_Initiative_2007-2016.pdf.

Whalen, D. and M. Shelley II. 2010. Academic success for STEM and non-STEM majors. Journal of STEM Education, 11 (1&2), 45–60.

Wickson, F., A.L. Carew, and A.W. Russell. 2006. Transdisciplinary research: characteristics, quandaries, and quality. Futures, 38, 1046–1059.

Xu, Y. 2016. Attention to retention: exploring and addressing the needs of college students in STEM majors. Journal of Education and Training Studies, 4(2), 67–76.