Applying the Performance Pyramid Model in STEM Education

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Abstract

The purpose of this paper was to give a demonstration of the primary materials and methods we used in learning communities (LCs) for biology students. The LCs were based on the performance pyramid theoretical structure. The objectives were to show the pedagogical links biological and mathematical concepts through co-curricular projects; assess students' perceptions of the performance pyramid model, and demonstrate a method for assessing LC efficacy directly related to General Biology I and College Algebra course content. Forty-eight students were recruited into the LCs with 39 students completing the LCs. The participants completed co-curricular projects that linked biology and mathematics course content with guidance from a peer leader. The LC participants completed the Augmented Student Support Needs Scale (SSNS-A) to assess perceptions of performance pyramid elements, as well as separate biology and mathematics quizzes related to their General Biology I and College Algebra courses, respectively. It was found that all co-curricular projects had biology and mathematics learning objective and outcomes. The SSNS-A had adequate internal consistency for appraising multiple aspects of the performance pyramid in general. However, some aspects and student responses might need more clarification. The quizzes had adequate internal consistency and LC students had large gains in biology ($d = 1.88$) and mathematics ($d = 2.62$) knowledge and skills from the beginning to end of their General Biology I and College Algebra courses. Promising aspects and limitations the LC activities and assessments are discussed.

Key terms: *STEM education, learning communities, performance pyramid, course knowledge assessment*

Retention of African-American students remains a persistent problem at Historically Black Colleges and Universities (HBCUs). The most recent survey of HBCUs indicated that only five institutions had a 50% or greater retention rate, half of the HBCUs reported rates of less than 34% and as low as 12% (Research & Studies, 2014). There are similar enrollment and retention issues for African-American students in biology programs. Ten-year trends indicate that African-American students account for 12% of undergraduate enrollment, but 7% of the bachelor's degrees conferred in biology (National Science Foundation, National Center for Science and Engineering Statistics [NSF], 2019). A greater disparity exists for African-American student retention in biology, where 14% intend to major in biology, yet 4% a bachelor's degree in biology (NSF, 2019). However, African-American students' probability of degree completion improves three to five times when mathematics preparation and socioeconomic barriers are removed (Ma & Liu, 2017).

X University is an HBCU, where some of these realities are reflected. The *X University's* Office of Admissions indicated that 35% of incoming students wish to pursue a biology major, but 12% of graduates completed a biology degree. Students in biology at *X University* switch to non-STEM disciplines due to difficulty completing the required math courses related to foundational and upper division biology courses. This reflects what has been previously found in the literature. Where African-American students have strong interests and aptitudes in biology as a major. Nonetheless, these early skills deficits might lead to academically capable African-American students to switch to non-STEM majors (May & Chubin, 2003). Therefore, the development of theory- and research-based models to promote biology course work persistence and success are needed. In this paper, we propose an intervention to enhance the academic performance of African American students in STEM disciplines, using biology majors as an example.

Learning Communities

Learning communities (LC) are created when groups of students are connected deliberately as a cohort course work and specific learning experiences (Han et al., 2018). Previous literature has demonstrated the efficacy of LCs that include collaborations between peer-leaders and faculty to increase STEM retention (Minor, 2007; Astin 1996; Kuh et al., 2005). More recently, LCs that integrate course work across disciplines have been found to increase student's program satisfaction and course work performance (Dagley et al., 2016; Lee et al., 2019; Salomon et al., 2015).

STEM-based LCs have been found to predict academic achievement and increase persistence rates (Carrino & Gerace, 2016; Kuh, 2008; Heaney & Fisher, 2011; Inkelas, 2012). LC participants earned higher grade point averages than non-LC participants (Baker & Pomerantz, 2001), have higher graduation rates, report higher levels of satisfaction with college experience (Zhao & Kuh, 2004), have higher levels of academic self-confidence (MacPhee et al., 2013), and are overall more academically engaged (Rocconi, 2011). More specifically, biology centered LCs in a university setting have positive impacts on course grades, retention, and sense of belongingness (Xu et al., 2018). LCs are also aligned with recommended supports for African-American STEM students (Freeman et al., 2008), as they foster peer and faculty connections (Xu et al., 2018), as well as provide peers to complete common course tasks with (Love, 2012).

Intrusive learning could be a beneficial addition to LCs. Intrusive learning is the use of repeated mentor-mentee interactions to foster academic and personal growth of students (Earl, 1998; Yarbrough, 2002), through focusing on student's scholastic needs and motivation (Heisserer & Parette, 2002). These intrusive interaction could be delivered through peer-mediated and structured interventions that directly address specific academic goals (Grandstaff-Beckers et al., 2013), which could lead to increased retention and degree completion (Michael et al., 2010). Within a LC, there are structures for social interactions between students, peer leaders, and faculty members. This is reflective of sociocultural perspective (Tobin, 2015), which states that social forces related to how students learn from each other, as well as how social network are formed contribute to individual academic outcomes (Scott & Palincsar, 2014). This conceptualization of how to support students has driven pedagogical shifts in universities to include peer-assisted learning, problem-based learning, collaborative learning, and active learning (Bishop & Verleger, 2013; Jonassen & Easter, 2012). This could improve LCs by assuring they are student-centered.

Outcomes assessment for LCs

Outcomes measures used to detect success or progress related to STEM LCs have consisted of quantitative and qualitative methods. These have consisted of objective-type measures such as course grades, overall grade point average (GPA), retention in STEM major, institutional persistence, and graduate school admission test scores. Subjective measures or ratings of student perceptions have been collected for self-efficacy and motivation, understanding of course content, confidence in academic skills, learning community satisfaction, and engagement with courses (Baker & Pomerantz, 2001; Heaney & Fisher, 2011; MacPhee et al., 2013; Xu et al., 2018). Qualitative assessments consisting of coding student reflection assignments and interviews (Carrino & Gerace, 2016), as well as open-ended questions asking what was helpful during the semester (Heaney & Fisher, 2011) have been examined, too.

Overall, the measures tend to be global measures of student performance or progress. That is, outcomes such as GPA, course grades, or retention give an overall summary of student success, but could be influenced by factors outside of targeted courses. For instance, course grades reflect an aggregate of assignments, and performance on a few assignments could skew course grades due to the number and weighting of the assignments. Therefore, it might be advantageous to have a cumulative assessment of course content. This would provide a direct, summative appraisal of course specific knowledge. Further, limitations to self-report assessments have been well documented (Paulhus & Vazire, 2007), but they can still be valuable tool for assessing outcomes if they are theoretically grounded in a cohesive theory (Pike, 2011). Previous studies have used rating scales to appraise student perceptions of programs; however, these measures have not been linked through a comprehensive theory. A measure that appraises student perceptions of a program with theoretically linked elements could help determine if students are aware of program procedures and speculated benefits.

Need for LCs

Approaches to specifically promote African-American student STEM success emphasize environmental support. It is found that when these students have connections to peers and faculty beyond the classrooms, they have greater academic success. This includes observing other African-Americans STEM students succeed, forming an identity around academic success, and seeing value in their academic pursuits (Arroyo & Gasman, 2014). Peer-led teams have been useful for facilitating faculty developed STEM enhancement programming, while allowing faculty to provide feedback and mentoring over projects and professional development (Gasman et al., 2017). LCs are a manner to address connections to peers and facilitate faculty designed projects to prevent course work difficulties or address academic needs.

At *X University*, the high interest in completing a bachelor's degree in biology has regularly ended with high attrition rates. Institutional data and biology faculty have identified that the one area of difficulty lies in applying mathematical concepts to biology. For instance, a survey of biology students that switch to non-STEM majors indicated that they switched due to challenges related to math courses (38% of respondents) and instructors' failure to connect concepts between mathematics and biology (47% of respondents). This is consistent with prior research that indicated African-American students tend to struggle with relating mathematics to other STEM discipline when compared to international student peers (Treisman, 1992). Being part of a LC that helps bridge biology and mathematics could address this issue, and improve performance across biology and mathematics.

Considerations for LC Theory

Research shows that individuals with high STEM self-efficacy perform better and persist longer in STEM disciplines relative to those lower in STEM self-efficacy (Bandura & Locke, 2003; Rittmayer, 2008). Self-efficacy beliefs may be developed through positively appraised task outcomes and environmental support, such as LCs. Self-efficacy beliefs are based on four primary sources of information: mastery experience, vicarious experience, social persuasion, and physiological reaction (Bandura, 1997; Pajares, 2005). These are likely interconnected in substantial student support systems.

However, developing self-efficacy in STEM students at HBCUs might have particular nuances. Increasing self-confidence in STEM students at HBCUs is associated with increased effort to complete course work, class participation, enjoyment of courses, and decreased feels of being discouraged or worried for their academic success. Relatedly, experiencing comfort and acceptance within courses can promote increased effort at course work and class participation (Wilson et al., 2015). This aligns well with using LCs as they create support networks and promote STEM course material engagement, as well as self-efficacy in the course material. It is would be reasoned that as HBCU students would build self-efficacy as they participate in LCs. For instance, underrepresented minority (URM) students, who participated in a LC are more likely to persist in a calculus-based major (e.g. STEM disciplines; Murphy et al., 1998).

LC Model a*t X University*

It has been found that successful STEM program have used integrated approaches that included a variety of activities, such as financial support, faculty-student research and mentoring, recruitment, and supplementary education for underrepresented students (e.g., the Minority Engineering Program, the Meyerhoff Program; Tsui, 2007). Indeed, an integrated approach might be needed as URM low participation rates might be caused by multiple factors. These factors consist of poor mathematics and science preparation, as well as issues related to motivation and potentially other psychological factors (Maton & Hrabowski, 2004; Tsui, 2007). Broad supports are likely indicated for academically talented URM students to choose STEM careers (Malone & Barabino, 2008). Given that STEM students at HBCUs usually have high rates of attrition from STEM disciplines and *X University* has struggled to retain biology majors, the use of LCs could be helpful to address academic and psychological needs, and promote success.

Performance Pyramid

The LC program that we developed was based on the theoretical foundations of the Performance Pyramid model (PPM), which has been successfully applied to educational settings (Wedman 2009; Wedman & Diggs, 2001; Wedman 2011). The PPM identified six major systems that support STEM participation and persistence: (a) Knowledge and Skills; (b) Performance Capability; (c) Rewards, Recognition and Incentives; (d) Tools, Environments and Processes; (e) Expectations and Feedback, and (f) Motivation, Values, and Self-efficacy. We employed the PPM as a strengths-based approach (Maton & Hrabowski, 2004), which assumes that URM students will have success in STEM disciplines, when they have adequate academic and social support. The PPM provides six types supports that are theorized to increase performance when they are employed together.

The learning communities were led by peer leaders (PL), who held weekly, small-group study sessions in order to help participating students develop course knowledge and effective study skills through activities and prescribed projects. The LCs addressed the intersecting learning objectives of the courses College Algebra and General Biology I. These projects are from course projects related to General Biology Lab with related mathematics integrated into them. These projects were designed to be completed over a two session span. This structure, which incorporates small communities, collaborative interactions, accountability, and peer-support for course work completion, is likely to normalize the social and academic skills learning process and improve degrees completion (Michael et al., 2010). In addition, the course faculty maintain high levels of communication with PLs for training purposes and students for progress monitoring and performance feedback, to increase academic success (Yarbrough, 2002). Each LC meeting was structured to address elements of the performance pyramid (see Author, 2019a). Moreover, we integrated outcomes assessments that directly appraised participant knowledge of biology and mathematics course content in the form of comprehensive quizzes. We also directly assessed student perceptions of performance pyramid elements.

Performance Pyramid Element: Knowledge and Skills

Knowledge and Skills refers to adequate academic preparation prior to and during courses and degree programs (Allen & Saparova, 2015; Park & Ertmer, 2008; Watkins et al., 2012). The PLs reviewed the key concepts in the General Biology and College Algebra courses, and connected the biology lecture material and lab skills with the underlying mathematics concepts. Then a biology-based, applied mathematics project was completed by the group.

Performance Pyramid Element: Performance Capacity

Performance Capacity is an individuals' environmental, interpersonal, and intrapersonal resources to complete necessary work (Park & Ertmer, 2008; Schaffer & Richardson, 2004; Wedman, 2010). The PLs had students review and record their own scores on weekly assessments in a grade log, and participate in a short duration (≤ 10 minutes) team building exercise. The PLs had the students in the LC review places and characteristics of places that are optimal for studying and completing course assignments during each session.

Performance Pyramid Element: Rewards, Recognition and Incentives

The Rewards, Recognition, and Incentives element is related to receiving acknowledgements and incentives for adequate academic performance (Park & Ertmer, 2008; Watkins et al., 2012; Wedman & Diggs, 2001). Each week's LC projects were evaluated by the instructors and PLs. The participants whose project had the highest score received recognition as the week's winner. For completing each project, students earned in their respective biology and college algebra courses: (a) one extra credit unit, (b) two extra credit units for actively participating the group discussion, and (c) one extra credit unit for completed project submission.

Performance Pyramid Element: Expectations and Feedback

The Expectations and Feedback area is related to explicit information regarding courses or degree requirements, and how to successfully complete these requirements (Park & Ertmer, 2008; Watkins et al., 2012; Wedman & Diggs, 2001). The PPL leaders provide student participants information about actions that lead to succeed in both courses as well as individual feedback to improve academics. The PLs have student participants set a goal score prior to completing a course task, complete an individual grade log for their task score, and then compare the scores to the goal after the grades are provided.

Performance Pyramid Element: Tools, Environment and Processes

Tools, Environment, and Processes refers to availability of physical resources, areas to engage in degree related tasks, and other supports of course work completion at the institution (Park & Ertmer, 2008). The PLs study guides, online tutorial videos, and other supporting materials for LC participant use. The PLs led student discussions that emphasized the quantitative elements of biology content from co-curricular projects, and met monthly with faculty members regarding student support needs. Further, the location of LC space is designed for individual and group learning activities.

Performance Pyramid Element: Motivation, values, and self-efficacy

Motivation, Values, and Self-efficacy is sustaining effort for academic tasks because students see benefits for completing academic tasks (Park & Ertmer, 2008; Watkins et al., 2012). The PLs had students rate their desire (1 = *almost never* to 5 = *almost always*) to (a) continue to learn biology, (b) continue to learn mathematics, and (c) report if they can identify one STEM role model or person. The PLs had students rate their perceived skill level (1 = *completely disagree* to 5 = *completely agree*) for biology and mathematics, respectively. The PLs had the students write two things they learned regarding the relationship between biology and mathematics.

Purpose of this Paper

The goal of the LCs was to increase biology student academic performance in General Biology I. The purpose of this paper is to provide an accounting of the primary materials and methods we used. We developed PL led LCs that used cross-course concept reinforcement through co-curricular assignments and structures based on the performance pyramid model. The objectives of this paper are to (a) demonstrate the pedagogical linkages between biological and mathematical concepts through co-curricular projects, (b) identify an instrument to assess students' perceptions of the performance pyramid model, and (c) show a method for assessing knowledge directly related to General Biology I and College Algebra course content.

Method

Participants & Setting

The LC in this project solely focused on students at an HBCU, who took a College Algebra and General Biology I during the same semester. There were two cohorts that participated in the LCs in consecutive fall semesters (Table 1 for demographics). There were five PLs for the first cohort and four PLs for the second cohort. Each PL was assigned five or six participants per LC. PLs were selected from STEM majors who completed College Algebra and General Biology I with an "A" grade. Across both cohorts, 48 students enrolled as participants in the LC intervention. Thirty-nine (81%) of the LC participants completed the LC and all program assessments.

	M (SD)
Age	18 (0.47)
	N (%)
Gender	
Woman	41 (85%)
Man	4 (8%)
Other	3 (6%)
Race	
Black/African-American	47 (98%)
American Indian/Native American	1 (2%)
Primary Language English	47 (98%)

Table1. Learning Community Participant Demographics

Personnel

The Project team consists of three primary faculty members and five and four PLs for the first and second cohort, respectively. The PI was the primary instructor for sections of College Algebra related to the program. He is an associate professor of mathematics at *X University* with focus on math biology, has 15 years of experience in providing mathematics instruction, and is a mathematics instructor for the program. A Co-PI was the primary instructor for sections of General Biology I related to the program. She is an instructor at *X University* in the biology department, as well as has over 40 years of experience with providing instruction in college biology courses. Other *X University* biology and mathematics instructors were recruited to teach students in the program, when necessary.

PLs in the LCs were peer mentors. The PLs were identified one semester in advance to allow for training. Each PL worked with a group of five students in the learning community and took on six roles. PLs provided orientation to group tasks, which consisted of familiarizing student participants with the biology and math concepts and modeling required lab skills. Further, the identified informational resources including study guide and tutorial videos, key personnel, tools and processes to succeed in these courses. PLs provided instruction to LC participants by offering student participants a 1 hour LC weekly meeting. These were held in conference rooms with access to instructional technology (e.g. Smart Boards) and could be arranged for one-on-one and group discussions. PLs also offered additional help outside class time.

PLs had the primary responsibility of facilitating student's participation in the LCs by delivering the co-curricular projects that supplement in-class instruction and meeting monthly with faculty members to update student support needs. The PLs also provided student participants individualized feedback for projects and assignments. Additionally, they provided guidance for how to perform well in the target courses. The PLs served as role models for dedication to learning for the STEM students in the LCs. Further, they were a point of contact for providing socialization into the community of biology students. The PPLs coordinated weekly LC meetings, developed interpersonal bonds with the LC participants, and acted as advocates for LC participants' concerns when meeting with project faculty members.

Assessments

Co-curricular projects

Seven co-curricular project were developed using General Biology I and College Algebra content. Each project was completed over the course of two weeks. The projects included: (a) Calculating BMI value; (b) Metric System and Unit Conversion; (c) Dilutions; (d) Diffusion and Osmosis; (e) Enzymes; (f) Solutions and pH Value; and (g) Mitosis. Each project was completed by paper-and-pencil and had biology and mathematics learning objectives and outcomes (click for projects). Treatment fidelity was collected via a direct observations checklist (click for fidelity forms).

Augmented Student Support Needs Scale (SSNS-A)

The SSNS-A is and adaption of the SSNS (Hardy & Aruguete, 2013), where the original 36 items were used to develop a revised 35-item scale with seven subscales (for scale development see Author, 2019b). For the SSNS-A, additional items were created to better fit the performance pyramid model, and items on scales were refined based on internal consistency coefficients. The SSNS-A has seven subscales: (a) Knowledge, (b) Performance, (c) Motivation, (d) Tools/Environment, (e) Feedback-Procedural Expectations (Feedback-PE), (f) Feedback-Rewards, Recognition, and Incentives (Feedback-RRI), and (g) Self-efficacy (Table 2). Items that are rated on a six-point scale (1 = *Strongly disagree*, 2 = *Mostly disagree*, 3 = *Slightly disagree*, 4 = *Slightly agree*, 5 = *Mostly agree*, 6 = *Strongly agree*). Higher item mean scores indicate greater presence of each element. The SSNS-A was piloted at *X University* and had adequate internal consistency based on Cronbach's alpha (.71 to .93) and McDonalds omega (.67 to .94) for the subscales, yet had variable convergent validity (Author, 2019b).

Subject Quizzes

A biology quiz was developed based on the General Biology I course content and related applied mathematical concepts. The quiz had 20 multiple-choice items and 5 points were given for each correct answer and 0 points for each incorrect answer, with a maximum of 100 points. Items covered content from converting units of measurement to applying concepts to simulated laboratory data. Higher scores indicated greater knowledge of course related biology content.

An algebra quiz was developed based on the College

Scale	Items
Knowledge	I have a strong enough math background to do well in my major
	I have a strong enough science background to do well in my major
	I have good academic preparation for my major.
	I continue to develop knowledge to perform well in my major.
	I continue to develop knowledge from other courses that help me to do well in my major.
Performance	Conflicting responsibilities sometimes make me miss classes. (reverse scored)
	I have enough time to devote to my studies.
	I receive passing grades from instructors on exams in my major.
	I typically cooperate with peers to do well on group assignments in my major.
	I complete assignments on or before their due date.
Motivation	I have clear career goals related to my major.
	I am proud to tell people about my major.
	I am fascinated by the material in my major.
	I see that doing well in my major courses will help me in my career.
	I see the benefit of doing well in courses that are related to my major.
Tools/ Environment	If I have a question about my major, the university provides the resources to get the answer quickly.
	The university has many institutional processes that promote success in my major.
	Academic tutoring is available to me in my major.
	I have a place to where I can study on campus on my own if I need to.
	My university provides me with a space to work with peers on assignments related to my major.
Feedback-Procedural	I get enough feedback about my performance in my major.
	My major instructors give me the feedback I need to correct my performance problems when they occur.
	I have a lot of contact with faculty members in my major.
	My major instructors clearly identify what is expected on assignments.
	My major instructors let the class know how they did as a group.
Feedback-RRI	In my major, instructors reward good performance.
	My instructors recognize my accomplishments.
	I understand how come other students earn awards for their performance.
	I am recognized by my major instructors when I do well in class.
	Grades in my major courses are given based on level of performance.
Self-Efficacy	I am capable of completing tasks related to my major.
	I am confident that I will pass all tests in my major courses.
	I am likely to do well on majors courses' assignments.
	As major courses become more difficult, I believe I will do well.
	I can figure out how to correct assignments in my major courses

Table 2. Augmented Student Support Needs Scale (SSNS-A) Items by Scale.

Algebra course content and concepts. The quiz had 20 multiple-choice items and 5 points were given for each correct answer and 0 points for each incorrect answer, with a maximum of 100 points. Items covered content, such as advanced algebraic equations and functions, as well as exponential and logarithmic functions. Higher scores indicated greater knowledge of course related mathematical content.

Procedures

PPL Recruitment and Training

A flyer and an application form were distributed to all students at *X University* through the student email listserv. Application forms were also available for pick-up outside the PI's and Co-PI1's offices. After a pool of applications was gathered, applicants were interviewed by the PI and a Co-PI. The criteria for the consideration included: (a) an A or B grade for both College Algebra (or had received and exemption from College Algebra) and General Biology I; (b) 3.00 or above cumulative GPA; and (c) a STEM major. All of the PPLs were required to attend a mandatory two-day training the week before the fall semester started. Clear guidelines about acceptable and unacceptable behavior by PPLs were established and communicated at initial training and monthly, thereafter. During this training, the PPLs were given an introduction to the LC project, the roles and responsibilities of PPL position, and training related to the College Algebra and General Biology project delivery and content. In addition, the PPL leaders were also trained on how to enter data for the surveys, check-in questionnaires, attendance record, and program biology and mathematics quizzes.

LC Activities

Each week the participants and PLs met as a LC. During the first week of each project, the participants would review their performance in course assignment via a course log. They would then engage in a PL facilitated team building exercise, which typically included icebreaker type games. Next the PL would review places to study or complete course work on campus; for instance, benefits of using spaces in the library. Specific to the project, the PLs would review related biology and math concepts, and provide instruction in how to connect the biology and math concepts. This would include activities like reviewing equations and how they reflected biological phenomena, as well as procedures for solving the equations. They would conclude the meeting with syllabi reviews and goal setting for up-coming assignments. For example, achieving an 80% or greater on an upcoming quiz or exam.

In the second week of the project, the participants would start with a review their performance in course assignment via a course log. They would then complete the project as a group. This was done by the PL providing instruction, modeling, and feedback for each question or problem and the related procedures to solve them. After the project was complete, the PL would review an academic skill topic that related to the LCs current needs, such as study skills or time management. They would conclude the meeting with syllabi reviews and goal setting for upcoming assignments, and complete a check-in questionnaire.

Each week the program faculty would meet with the PLs to review student progress, LC strengths, and needs. These meetings generally focused on how participants were responding the group projects. PLs would give an account to the faculty regarding if the participants needed more or less instruction to complete various tasks related to the project. Additionally, the faculty would also adjust or provide support needs for PLs based on their reports.

Post-test Data Collection

At the end of the semester, on the last regular course meeting date, students who consented to participate in the program received a post-test packet that included the SSNS-A, and biology and mathematics quizzes. The pre- and post-test packets were completed as paper-and-pencil assessments. They were distributed and collected by program faculty.

Analysis Conceptualization

To address the first objective of this evaluative paper, we examined each co-curricular project to detect if they had at least one learning objective for each the biology and college algebra course. It was expected that if there were pedagogical links between courses, then learning objective form each course would be present. For addressing the second objective, we examined pre- and post-test SSNS-A subscales for LC participants to determine if they were more aware of performance pyramid elements at the end of the semester. That is, if there were increases on subscale scores. The third objective was appraised by examining mean changes in the biology and mathematics course quizzes from pre- to post-test. Increased scores would indicate that the quizzes were potentially sensitive to instruction. See figure 1 for linkages of objectives to expected outcomes.

Participant Recruitment and Consent

Prior to forming the LCs, students who enrolled in General Biology I and College Algebra were sent a request to participate in the LCs. Students were convenience sampled based on interest in receiving the intervention. The primary and a co-investigator would enter the classroom at the beginning of the semester when the courses met, explain the LCs and related activities, and distribute the informed consent form. Student who were interested in participating would sign the informed consent and complete a pre-test packet that included the SSNS-A and biology and mathematics quizzes. Participants were randomly assigned to one of four LCs.

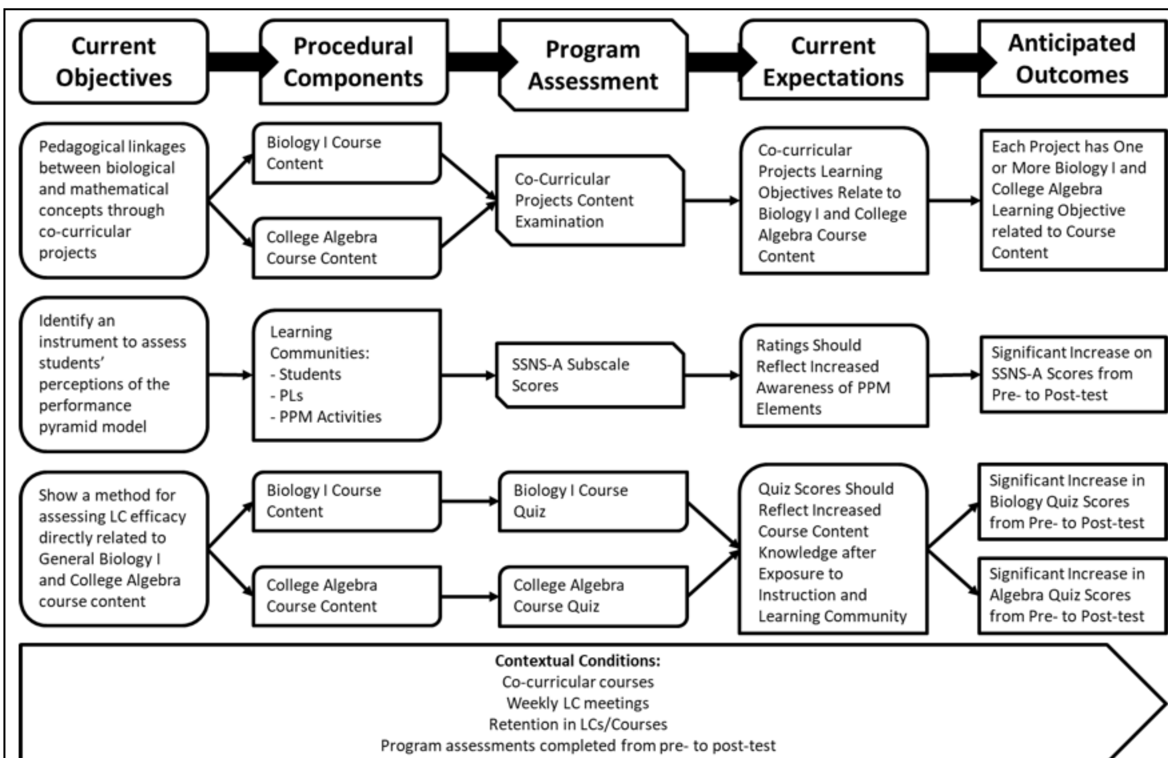

Figure 1. Mapping of Current Program Investigation Objectives to Anticipated Outcomes

Results

Co-curricular projects

All LC participants completed the co-curricular projects with all items correct because they were completed as a group, where each step was modeled by the PL and practiced by the LC participants until correctly completed. The projects did vary on the number and types of items, as well as the number of respective biology and mathematics learning objectives and learning outcomes. All projects had at least one biology and mathematics learning objective and at least one biology and mathematics learning outcome. There was a range of two to six biology and learning objective, and arrange of one to five biology learning outcomes. There was a range of one to three mathematics and learning objective, and arrange of one to three mathematics learning outcomes.

SSNS-A

See Table 2 pre- and post-test raw means using all participants and adjusted means for paired sample t-tests, as well as Cronbach's alpha. Twenty-nine LC participants completed the SSNS-A at both pre- and post-test. For the LC participants, reliability coefficients were mostly adequate, except for Performance at post-test. Generally, the scores had a slight decrease from pre- to post-test with the exception of Knowledge. However, paired-sample (n = 29) t-tests with bootstrapped confidence intervals (5000 samples) indicated that there was only a significant decrease in Performance, $t(28) = -2.93$, $p = .009$, Mean difference = -0.44, 95% CI [-0.73, -0.14], Cohen's d = -0.55.

Subject Quizzes

The biology quiz had a Cronbach's alpha of .63 at pre-test and .76 at post-test for the LC participants. The mean score was 15.53 (SD = 12.43; n = 47) at pretest and 58.75 (SD = 19.14; n = 40) at post-test. However, 39 participants completed the pre- and post-test biology quiz. The mathematics quiz had a Cronbach's alpha of .68 at pre-test and .78 at post-test for the LC participants. The mean score was 18.14 (SD = 14.31; n = 43) at pretest and 72.5 (SD = 19.14; n = 36) at post-test. Thirty-two LC participants completed the mathematics pre-test and post-test. The biology and mathematics quiz scores at pre- and posttest were non-significantly correlated, as were respective pre- and posttest scores (Table 3 for correlations and paired-samples means). Paired-samples t-tests with bootstrapped confidence intervals (5000 samples) indicated that significant and large growth on biology quiz scores, $t(38) = 11.74$, $p < .001$, Mean difference = 41.79, 95% CI [34.90, 48.57], Cohen's d = 1.88. Paired-samples t-tests with bootstrapped confidence intervals indicated that significant and large growth on mathematics quiz scores, $t(31) = 14.81$, $p < .001$, Mean difference = 52.66, 95% CI [45.63, 59.26], Cohen's d = 2.62.

	Pretest (N = 46)				Post-test (N = 37)			
SSNS-A Scale	N	M	SD	Adj. M	N	M	SD	Adj. M
Knowledge	46	4.66	0.70	4.71	37	4.76	0.68	4.74
Performance	46	4.95	0.90	4.91	36	4.52	0.72	4.47
Motivation	46	5.52	0.71	5.51	37	5.21	0.72	5.21
Tools/Environment	45	5.32	0.73	5.23	37	5.08	0.72	5.04
Feedback Procedures	43	4.89	0.84	4.86	37	4.89	0.95	4.81
Feedback Rewards	42	4.80	0.87	4.74	37	4.56	1.07	4.54
Self-Efficacy	44	5.03	0.93	5.02	37	4.73	0.88	4.70

Notes. Cronbach's alpha (pre- and post-test, respectively): Knowledge (.69 and .80), Performance (.77 and .52), Motivation (.83 and .83), Tools/Environment (.78 and .78), Feedback-PE (.91 and .91), Feedback-RRI (.87 and .87), and Self-efficacy (.95 and .95). Adj. M = adjusted mean for t-tests with n = 29.

Table 3. Mean Scores for the Augmented Student Support Needs Scale (SSNS-A) at Pre- and Post-test for Students in the Learning Communities.

Discussion

Each co-curricular project had identified biology and mathematics learning objectives and outcomes. This indicated that the projects provide opportunities to concurrently practice biology and mathematics concepts and procedures through the projects. The SSNS-A was generally a reliable instrument, with the exception of the Performance subscale at post-test. This is in contrast to the pilot study (Author, 2019b) and the scale's pre-test results for Cronbach's alpha. Additionally, there was a significant decrease in the mean score for Performance. This could indicate that the SSNS-A scales are either insensitive to perceived changes or failed to measure performance pyramid program elements. The LC students had increased scores on the biology and mathematics quizzes from pre- to post-test. This could reflect that the quizzes are reflective of the content taught in the courses and the LCs.

	1	2	3	4
1. Biology Pretest	-	.03	.29	.15
2. Biology Post-test		-	.16	.29
3. Mathematics Pretest			-	.31
4. Mathematics Post-test				-
^{a}M	16.67	58.46	18.44	71.09
(SD)	(11.66)	(19.30)	(13.29)	(19.83)

Note. aThe means and standard deviations used are from the paired-samples t-tests for respective biology and mathematics pre-post comparisons.

Table 4. Zero-order Pearson's Correlations between Biology and Mathematics Quizzes with Paired-samples Comparison Means.

Linkage between Biology and Mathematics Courses

The first of the three objectives was to provide pedagogical linkages between biological and mathematical concepts. The current LC model addresses this objective by creating co-curricular projects between a biology (General Biology I) and a mathematics (College Algebra) course. The course instructors work collaboratively to develop projects specifically for the LCs. These actions are consistent with other cross-course LCs (e.g., Dagley et al., 2016; Lee et al., 2019; Salomon et al., 2015). A noteworthy of the LCs that we developed is that we aligned learning objectives in the biology course with a math course that provides foundational knowledge and skills. That is, students had the opportunity to apply and generalize discipline specific math skills as they were acquired.

Performance Pyramid Assessment

The next objective was to identify an instrument to assessment students' perceptions related to the performance pyramid model. We adopted the SSNS-A. The SSNS-A was initially piloted at the same university with approximately 10% of the student population (Author, 2019b). The only scale that did not have adequate internal consistency was the Performance scale at post-test ($\alpha = .52$). The pre-test internal consistency was consistent with previously reported coefficients ($\alpha = .71$; $\omega = .67$); however, the change in the internal consistency coefficient could reflect factor inconsistency that was previously found (ω BC 95% CI [.50, .75]; Author, 2019b). Additionally, there was a general downward trend in the subscales with a significant reduction in the Performance score. Possible explanations include the measurement instability of the Performance subscale, students becoming more critical of their own performance as they learn more, or performance pyramid elements need to be made more salient. That is, many of the items ask for students' perceptions of their performance or elements within their course; whereas, modifying the SSNS-A to ask about the LC specifically could better relate to the participants' experience of performance pyramid elements. However, the SSNS-A and the intervention used were recently developed, therefore more information might be needed.

Assessments of Biology and Mathematics Concepts

The development of the math and biology assessments could be helpful to understand student progress in their knowledge from the beginning to the end of the courses. Moreover, the connections in content between these and the co-curricular projects could help students more clearly connect course content to cumulative assessments. Correspondingly, taking time to collaboratively develop co-curricular projects and cumulative assessments could help faculty members better connect with and between course concepts when developing assessments of knowledge and skills.

The participants in the LCs had large gains from pre- to post-test on the biology and mathematics quizzes. This consistent with previous findings that LCs predict increased course grades and academic achievement (Xu et al., 2018). Moreover, it is likely that the quizzes are sensitive to students' gains in knowledge related to the corresponding courses. While LC participation might have impacted grades, it is also likely that developing course specific assessments before instruction starts could help instructors and PLs to target specific knowledge and skills from the courses that are present on the quizzes.

Limitations

While many of our findings and practices were promising, there are limitations. One limitation is the small size and convenience sample of LC participants, and an attrition rate of LC participants. These limit generalizability beyond the university, as well as limit confidence in inferences from statistical analyses. However, *X University* reported an attrition rate of 66% from biology majors, whereas, the LCs had a 19% attrition rate. This could be seen as promising for improving retention in the future. We also use bootstrapping to create robust standard errors, and more conservative estimates of confidence intervals around point estimates. An additional, consideration with the sample was that it consisted primarily of Black/African-American women ($n = 40$; 83%). Other gender and racial groups might respond differently to the current program practices, or might be successful with different program components.

Nonetheless, there are more nuanced limitations related to the LC key products and assessments. Our use of delivering corresponding biology and mathematics courses with linked projects might be useful for connecting foundational content. However, it is likely that how biology and mathematics courses are sequenced are specific to each university. Requiring biology programs to revise approved course sequences could create disruptions to degree plans or interfere with course delivery. In order to support faculty to create these co-curriculum projects, universities might need to provide relief from other responsibilities.

The SSNS-A does not measure all the elements of the performance pyramid and was developed at a relatively small HBCU. More items, refinement of items, or recombination of items might be useful to further refine the SSNS-A. The continued investigation of this instrument is needed to understand how it appraises student support, and its value for longitudinally assessing student needs related to the performance pyramid.

One caveat to the course assessments (biology and mathematics quizzes) is that we developed them for the courses at *X University*. This could limit their use across biology degree programs or universities. Some attention should be given to examining performance on these measures correspondence with other assessments of biology and mathematics. Further, it should be examine if developing pre-post course assessments, such as these quizzes, for other overlapping or independent biology and mathematics courses show changes in scores related to course and LC exposure. Moreover, we had examined these scores just within the LC participants, next steps should include comparisons to control group students.

Conclusion

Overall, we presented information regarding activities and assessments used in the evaluation of a theory-based LC to connect biology and mathematics course content. We acknowledge that there are limitations to our procedures. However, the activities and assessments used could serve as a model for other undergraduate biology programs to meet the learning needs of their students. The co-curricular projects could serve help others deliberate over how to connect objectives and outcomes across courses. The SSNS-A can provide information regarding student perceptions of themselves, but might be limited in appraising their perception of the performance pyramid's theoretical constructs. The biology and mathematical quizzes could demonstrate one way to give a brief assessment to determine if instructional practices resulted in increased course related knowledge.

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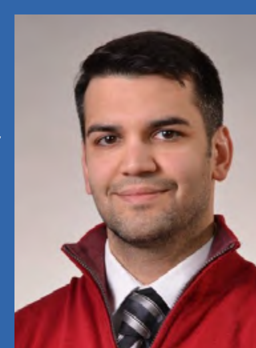

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