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Board 218: Assessing Scientific Literacy across the Undergraduate Curriculum: Preliminary Results from the Collaboration Across Boundaries (CAB) Pedagogical Study

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Assessing Scientific Literacy across the Undergraduate Curriculum: Preliminary Results from the Collaboration Across Boundaries (CAB) Pedagogical Study

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1. INTRODUCTION

Despite the growing need for scientific literacy, colleges and universities offer most scientific content in courses offered in STEM (Science, Technology, Engineering, and Mathematics). This paper reports on the evaluation of the Collaboration Across Boundaries (CAB) pedagogy, which incorporates project-based, community-engaged learning in undergraduate courses that pair STEM or social science students registered in one course with students in another course, including humanities and pre-professional disciplines. The project aims to serve the national interest by studying how interdisciplinary collaborations in the classroom can improve STEM learning for all undergraduates. The increasingly interdisciplinary and complex issues facing our society require diverse, STEM-literate experts from a range of fields who can work and solve problems in collaboration. Addressing this national need requires innovative, research-based teaching practices that retain students and improve STEM learning.

CAB is an innovative curricular model in which two undergraduate courses from different disciplines are taught in coordination. The instructors, goals, and outcomes of each course are distinct, but the courses are connected by a science-focused project that is developed through an active collaboration with a community partner. Over the past three years, we have conducted pre- and post-testing of 571 students at a primarily undergraduate institution in 30 courses to determine whether students who completed a course-based CAB project experienced growth in science literacy.

Among the participating courses are: Database Systems (6 sections), Software Engineering (6 sections), Electronics (1 section), Environmental & Biotechnology Systems (1 section), and Fundamentals of (Civil) Engineering Design (1 section). Paired sample t-tests determined that students report their own scientific literacy (skills and thinking) improve from pre- to post-test, regardless of the discipline of the course and across teaching modalities (emergency switch to remote, remote, hybrid, and in-person teaching). Preliminary analysis found some significant differences at initial levels at which students report their own scientific literacy, but analysis of variance (ANOVA) indicates that the mean change from pre- to post-test did not differ significantly between students enrolled in STEM, social science, or other courses. We found no consistent differences between students in different STEM disciplines, nor between STEM and non-STEM students overall. Standardized objective pre- to post-testing, including both the Test of Scientific Literacy (ToSLS) and a pilot measure created specifically for this project, failed to produce consistent improvements, and generally indicated a decline from pre- to post-test.

We suggest that an ungraded, online post-test given at the end of the semester is an unreliable instrument for objectively measuring student learning, particularly when student fatigue has been intensified by the COVID-19 pandemic. While our subjective results are promising, future research should investigate whether a graded, course-specific assessment would be a better tool for evaluating whether students increased their scientific literacy through completing a CAB project.

2. BACKGROUND

The CAB model draws from project-based, collaborative, and community-engaged learning to design STEM classroom experiences that improve learning outcomes and retention for all undergraduates, funded through NSF Award #1914869, for which Pulimood, Bates and Pearson are principal investigators. In the CAB model, students in two courses, from two disciplines, collaborate with each other and a community partner, on a STEM-focused project to address a community-identified issue. The intent of this curricular model is that students from both courses, with diverse perspectives and disciplinary backgrounds, will not only learn the STEM (Science, Technology, Engineering and Mathematics) concepts more deeply but will also learn how to collaborate and integrate concepts from their respective fields to develop scientific solutions for complex real-world problems. See tardis.hpc.tcnj.edu/cabportal/ for more details on the CAB project. An experiential report details the specific course collaboration between Pulimood and Leigey in Fall 2020, which is part of a larger Collaborating Across Boundaries (CAB) project [1].

The CAB model draws from three areas – interdisciplinary collaboration, project-based learning, and community-engaged learning – that have each been shown to improve student learning outcomes and improve retention, particularly among students from marginalized groups. Interdisciplinary collaboration emphasizes problem-solving in a gender-neutral, culturally and ethnically diverse community, and provides an engaging learning environment in which students solve real problems in collaboration with their peers from other disciplines. It has been shown to improve content knowledge and communication skills among undergraduate learners [2]. A balanced collaboration is an effective approach to engage participants more deeply since students can learn how concepts are applied in other contexts rather than being presented a traditional perspective on those concepts [3]. Such learning communities have been shown to be successful in helping students develop scholar identities as scientists and collaborators in the scientific process. [4, 5].

Inquiry- or project-based learning (PBL) involving peer-led teams has been shown to enhance process-oriented learning [6] – [10]. Research shows that the active teaching methods of PBL are more effective in helping students absorb and retain course content [11]. PBL is based on a constructivist learning theory that assumes that “learners form or construct their own understandings of knowledge and skill” [8], and that this is strengthened through requiring student teams to devise solutions to problems.

Community-engaged learning (CEL) is a high-impact practice that has been empirically linked to greater student engagement, efficacy and learning [12] – [19]. Unlike traditional service learning (sometimes referred to as community-based learning), CEL requires students and faculty to treat their community partner as an intellectual equal who helps to define problems and refine solutions in a real-world context [20] – [22]. It is designed to reduce the tendency for students to view community work as charity, but rather as a mutually beneficial collaboration [23], [24].

CEL has been linked to higher rates of retention [25], [26], particularly among women and members of marginalized groups [17], [27]. Qualitative studies of low-income, first-generation students found that CEL enhanced their skills, and helped them develop resilience and a sense of efficacy in academic settings [28, 29]. CEL's impact varies dramatically by the quality of the experience; direct service [30], [31], sustained community partnerships [23], and effective integration of service with the course material [32], [15] produce better learning outcomes. Students are more motivated by activities they perceive to be useful and socially relevant [8], [33] – [35].

In our prior research [36], [37], we developed, piloted, and tested a curricular model that enables students with diverse perspectives and disciplinary backgrounds to learn how to collaborate and integrate concepts from their respective fields to develop computational solutions for complex real-world problems. This model, Collaborating Across Boundaries to Engage undergraduates in Computational Thinking (CABECT), includes the following three main components: (a) implementing the curricular collaboration through coordinated, but separately taught courses with different instructors, goals, outcomes, and deliverables; (b) collaboration with a community partner on identified social needs; and (c) the design and deployment of discipline-specific instruments for assessing the impact of the course-based collaborations on computational thinking, collaborative skills, and community engagement. The study consisted of a multi-semester collaboration between students in existing computer science, journalism and interactive multimedia classes who endeavored, in collaboration with the community partner Habitat for Humanity, to design and develop a software application to identify pollutants in properties being considered for redevelopment. The courses were taught by faculty members in the departments of computer science and journalism respectively, at The College of New Jersey (TCNJ). We demonstrated that the model can be implemented using existing courses, without losing instructional time to meet the learning outcomes associated with these pre-existing courses. We found that STEM majors generally benefited most from this pedagogy, but that students from other majors also indicated better understanding of the focal STEM learning outcome (computational thinking), and in fact showed more improvement in their self-assessment of computational learning in comparison with computer science students [37].

As noted above, CABECT derived its student self-assessment of computational thinking from ABET's learning goals for baccalaureate students in all applied and natural science, engineering, and computer science programs that emphasize the scientific process and application, as well as teamwork, communication skills, and an understanding of social context. These skills are echoed in educational materials promoted by disciplinary professional associations in journalism [38] and in the local disciplinary learning goals for science and engineering major programs at TCNJ, as well as in the learning goals associated with the College's general education requirement in science. While faculty often incorporate these types of learning goals into their courses, they are rarely assessed independently of the content knowledge unique to each course, with an assumption that students will internalize the scientific processes as a side effect of learning the course content. The efforts to assess standards has focused more on K-12 science education [39] – [41], while there has been relatively less focus on higher education. One exception is the Test of Scientific Literacy Skills (ToSLS), which was developed and validated after administration to more than 1200 introductory biology students at multiple types of higher education institutions [42].

3. METHODS

This study used a before-and-after design to assess whether participation in CAB projects, which are interdisciplinary, community-engaged team projects designed around some sort of scientific learning, has a positive effect on undergraduate science literacy. Our hypothesis is that immersing students in interdisciplinary collaborative courses, where STEM and non-STEM majors work together and with community partners to address social issues, will result in deeper scientific learning for all the students involved.

CAB collaborations were designed to span across not just disciplines, but disciplinary groups. This research compares students in two disciplinary groups: (1) STEM: All courses offered in departments housed in the Schools of Science and Engineering (specifically, Computer Science, Mathematics & Statistics, Civil Engineering, Mechanical Engineering, and Engineering Education); and (2) All others, including social science, humanities, pre-professional, and interdisciplinary majors, such as those that include some STEM and social science curriculum (such as Nursing).

The first measure of science learning was indirect, with students rating their own learning, modified from two indexes that had been used to measure student learning in the CABECT study, and that seemed able to capture different aspects of scientific knowledge and skills—both of which are part of scientific knowledge [1], [37]. *Scientific Skills* self-assessment addressed how students rated their own scientific skill set within their own majors. It was measured with six-item index using a 4-point scale of agreement for the following items: (1) I can apply knowledge of science appropriate to my major; (2) I can analyze a problem, and then identify and define the scientific requirements appropriate to its solution; (3) I understand the impact of science on society; (4) I can use current scientific techniques, skills, and tools necessary in careers for which my major prepares me; (5) I can collaborate with others to design and develop science-based tools and technologies appropriate to careers for which my major prepares me; (6) I can conduct research and evaluate information by methods appropriate to my major. *Computational Thinking (CT)* self-assessment asks students to evaluate their performance on four items related to computational thinking, a specific type of scientific literacy. This is measured with a four-item index using a 4-point scale of agreement: When solving problems, designing systems, and understanding human behaviors, I am able to… (1) use abstractions; (2) use logical thinking; (3) use algorithms; (4) use revision.

The second measure of science literacy was directly assessed using items from the publicly available Test of Scientific Literacy Skills (ToSLS) [42]. This measure was validated for use among introductory biology students in a variety of higher education contexts, and powerfully captured change among non-science majors. We used all of the items designed to measure four concepts from the ToSLS section on "Understanding Methods of Inquiry that Lead to Scientific Knowledge": (1) identify a valid scientific argument; (2) evaluate the validity of sources; (3) evaluate the use and misuse of scientific information; and (4) understand the elements of research design and how they impact scientific findings/conclusions. These four concepts are measured using a total of 15 multiple-choice questions, with 3-5 individual questions measuring each concept, all of which demonstrated high internal (construct) validity among the more than 1200 introductory biology students who completed the initial test [42]. An electronic version of the ToSLS instrument was piloted for TCNJ students in Fall 2018, distributed in three introductory, general education social science classes (n = 77). Students scored an average of 60.11% correctly, with responses distributed normally; average scores varied between students in STEM majors (76.37% correct), SBE majors (54.50%), and other majors (58.49%). This pilot suggested that the ToSLS would be an appropriate assessment tool for scientific literacy among TCNJ students.

3.1 Sample of Classes

The data for this study rely on a self-selected sample of courses that were designed by collaborating faculty to incorporate the CAB model; this is thus not a representative sample of students or courses at our institution, although we have actively sought out professors from departments with higher levels of student diversity in terms of gender, race, and ethnicity (as officially reported to the institution). In Spring 2020, 6 classes participated: two sections of a cross-listed Business/Management course, four sections of two different Computer Science courses, one cross-listed Journalism/African American Studies course, one Sociology course, and one Women's Gender and Sexuality studies course. All courses were upper division courses (300- or 400-level). Most courses, except the Computer Science courses, were electives within their majors. In Fall 2020, 2 classes participated: two sections of a 200-level required course in Criminology, and 2 sections of a 400-level Computer Science class. In Spring 2021, 12 classes participated: upper division electives in Anthropology, Business/Management, Electrical Engineering, Linguistics (cross-listed as a 200-level Honors course), Journalism/African American Studies, Sociology, and Women's Gender and Sexuality Studies, one 200-level elective in Engineering and Technology Education, four sections of two different upper division requirements in Computer Science, and two capstone courses—one in English and one in Statistics. In Spring 2022, 10 classes participated: 300-level electives in Anthropology, Sociology, and Women's and Gender Studies, 100- and 200-level requirements in Business, Civil Engineering, and Criminology, 300-level required courses in Accounting (2 sections), Computer Science (2 sections), and Nursing (2 sections), and one 400-level required course in Computer Science (2 sections). In total, 30 courses (39 sections) have participated in CAB research, involving 13 collaborating faculty members.

The disciplines categorized as STEM that participated in this study are: Computer Science (CSC), Electrical Engineering (ELE), Engineering and Technology Education (ETE), and Statistics (STA). Following the division of the National Science Foundation that funds basic social science research, the disciplines categorized as social and behavioral sciences were: Anthropology (ANT) and Sociology (SOC). The disciplines categorized as other were: African American Studies (AAS), Business (BUS), Criminology (CRI), English (LIT), Honors (270), Journalism and Professional Writing (JPW), Linguistics (LNG), Management (MGT), and Women, Gender, and Sexuality Studies (WGS).

3.2 Administration of Pre- and Post-Tests

In Spring 2020, pre-tests were administered in paper format during class time by CAB staff within a week following the end of the add/drop period. However, the COVID-19 pandemic required that we switch the post-test to online. The post-test was administered as an electronic

Qualtrics survey, which was made available to students via an email invitation during the last week of classes. It remained available during the final exam period. In all other semesters, pre- and post-tests were administered electronically using a modified version of the Qualtrics survey that had been designed for the post-test in the Spring 2020. Students were invited to complete the pre-test via email or through the course Learning Management System (LMS); it was available to students for two weeks after the add/drop period. Students were also invited to complete the post-test via email or through their class LMS; it was available from the last week of classes through the final exam period. In Fall 2020, CAB staff electronically visited participating classes to introduce the project and explain the research component in real time. In Spring 2021, a CAB staff member created a short video with the same content which was available to all participating classes through the course LMS but was not necessarily shown during class time. In Fall 2021 and Spring 2021, faculty continued to have access to the video, but staff were able to also personally visit four classes to introduce the project and explain the pre- and post-testing.

3.3 Sample of Students

We collected student pre- and post-test data over six semesters, beginning in Spring 2020. The Spring 2020 semester, which saw the emergency shift from in-person instruction to a hodgepodge of synchronous and asynchronous remote instruction, we received complete responses from 76 students, but this semester had by far the lowest response rats of all semesters, with an overall response rate of just 48.41% (course-by-course responses rates ranged from 11.11% to 75.00%).

In Fall 2020, response rates were much better, despite instruction being done only in a remote, synchronous manner. We have data from 77 students, representing 76.24% of all students enrolled in CAB classes, including 64 (87.67%) who completed CAB projects. Response rate for a control group was much lower (61.90%).

In the Spring 2021 semester, some classes met in a hybrid fashion (some in-person meetings, but mostly remote learning-- and because of restrictions on in-person experiences, all CAB experiences were remote-only). We collected complete data from 157 students, representing 69.13% of all students who completed the courses. Response rates were notably lower outside the computational sciences (92.13%): Humanities classes produced a response rate of 37.5%; Engineering classes 60.71%; Business classes: 62.96%; and Social Science 65.79%.

In AY 2021-22, classes returned to in-person instruction. During this year, we have complete pre- and post-tests from 213 students who participated in a CAB project and an additional 43 students who did not (as a control group). Our overall response rate for students who participated in CAB courses was 77.42%, although course-by-course, response rates vary from 0% to 93.75%. Response rates for classes participating as control groups were highly variable, with three classes producing very low responses (5%, 14%, and 38% respectively); only one recorded a representative response rate (93.55%).

Students in the control group (who did not participate in classes that incorporated the CAB model) are included to contextualize response rates, but they are excluded from analysis below.

Table 1: Response Rates

Semester	Pre & Post Test Completed / Students Enrolled	Response Rate
Spring 2020 (6 classes, all emergency shift to remote)	76/157	48.41%
Fall 2020 (2 CAB classes, 1 control, all remote)	77/94	76.24
Spring 2021 (12 classes, all hybrid)	159/230	69.13
Spring 2022 (9 CAB and 5 control classes, in person)	259/369	70.19
Total (CAB students only, 29 classes)	507/734	69.07
Total (CAB + Controls, 35 classes total)	571/850	67.18

3.4 Findings

Spring 2020 (Table 2) saw the emergency switch after spring break to remote instruction, which was offered in various synchronous and asynchronous formats. STEM and non-STEM students were not different in initial pre-test, nor in post-tests in any measure. However, STEM students accounted for all of the increase in self-reported skills from pre- to post-test, and a greater portion of change in self-reported knowledge from pre- to post-test. All students declined in ToSLS from pre- to post-test.

Table 2: Spring 2020, Emergency Switch to Remote

	STEM			Non-STEM			All		
	Mean	N	P (pre to post)	Mean	N	P (pre to post)	Mean	N	P (pre to post)
Skills Pre	20.12	43		19.44	27		19.86	70	
Skills Post	22.07	43	.000	19.85	27	.346	21.21	70	.000
Knowledge Pre	12.98	42		11.92	27		12.57	69	
Knowledge Post	14.24	42	.000	12.78	27	.022	13.67	69	.000
ToSLS Pre	11.00	36		10.61	28		10.83	64	
ToSLS Post	10.58	36	.324	10.25	28	.543	10.44	64	.324

Fall 2020 (Table 3) had classes that were offered in a synchronous, remote format. This semester also found no significant difference between STEM and non-STEM in any measure, pre or post. STEM students were no different from pre-to-post in the skills self- assessment, as they were not significantly different from pre- to post-test, although the non-STEM students did increase. STEM students did increase in self-assessed knowledge pre- to post- test, but so did non-STEM students. Unlike any other semester, STEM students significantly increased ToSLS score from pre-to-post, but non-STEM did not.

Table 3: Fall 2020 All Remote

	STEM			Non-STEM			All		
	Mean	N	P (pre to post)	Mean	N	P (pre to post)	Mean	N	P (pre to post)
Skills Pre	20.62	34		17.52	23		19.25	69	
Skills Post	21.41	33	.067	20.04	23	.000	20.65	69	.000
Knowledge Pre	13.55	33		11.22	23		12.56	68	
Knowledge Post	14.12	33	.026	13.00	23	.000	13.60	68	.000
ToSLS Pre	10.48	33		8.67	21		9.75	65	
ToSLS Post	11.42	33	.021	8.95	21	.540	10.34	65	.049

Spring 2021 (Table 4) offered classes in either a hybrid or remote, synchronous format. This semester all recorded no significant difference between STEM and non-STEM in any measure, pre or post, except STEM classes had significantly higher ToSLS post-test. STEM and non-STEM students both significantly increased from pre- to post-test for self-assessed skills and knowledge. STEM students had no significant change in ToSLS scores, while non-STEM students significantly declined.

Table 4: Spring 2021 All Hybrid or Remote

	STEM			Non-STEM			All		
	Mean	N	P (pre to post)	Mean	N	P (pre to post)	Mean	N	P (pre to post)
Skills Pre	20.60	96		18.62	60		19.84	156	
Skills Post	21.95	96	.000	20.77	60	.000	21.49	156	.000
Knowledge Pre	13.09	96		12.17	60		12.74	156	
Knowledge Post	14.30	96	.020	13.25	60	.001	13.90	156	.000
ToSLS Pre	11.00	94		10.11	54		10.68	148	
ToSLS Post	10.85	94	.568	9.09	54	.004	10.21	148	.026

Spring 2022 (Table 5) classes were held in-person, much like a "normal" semester pre-pandemic. This semester also recorded no significant difference between STEM and non-STEM in any measure, pre or post. STEM and non-STEM students both significantly increased from pre- to post-test for self-assessed skills and knowledge. STEM students had no significant change in ToSLS or ALT SL scores while non-STEM students significantly declined in both.

Table 5: Spring 2022 All in person

	STEM			Non-STEM			All		
	Mean	N	P (pre to post)	Mean	N	P (pre to post)	Mean	N	P (pre to post)
Skills Pre	19.99	79		18.66	128		19.15	248	
Skills Post	21.46	79	.001	20.16	128	.000	20.83	248	.000
Knowledge Pre	13.10	79		11.97	133		12.37	252	
Knowledge Post	13.96	79	.000	12.82	133	.001	13.35	252	.000
ToSLS Pre	11.60	80		12.37	134		12.25	256	
ToSLS Post	9.70	80	.098	9.25	134	.047	9.62	256	.009
Alt SL Pre	15.08	75		14.91	119		15.09	230	
Alt SL Post	14.77	75	.346	14.32	119	.031	14.65	230	.017

4. DISCUSSION AND ANALYSIS

Although STEM students typically have higher initial (pre-test) mean scores for skills and knowledge self-assessment, we found that these scores were not significantly different from non-STEM students in the same semester. Remarkably, mean pre-test scores for the ToSLS and our alternative measure of scientific literacy did not generally differ between these groups, although STEM students had consistently—if not statistically significantly—higher pre-test means for these more objective measures of scientific literacy.

With the exception of the emergency switch to remote (Fall 2020), STEM and non-STEM students generally reported their own self-assessed skills and knowledge higher in the pre-test than in the post-test. In contrast, in 3 of the 4 semesters, all students' ToSLS scores declined from pre- to post-tests, although this seems to be more likely to be a significant decline among non-STEM students. The pattern for the Alternative Scientific Literacy Measure produced a similar pattern to the ToSLS, so there is no reason to suggest that the decline is due to the ToSLS itself. In addition, grades for students in these classes serve as an objective measure that most students are learning this material, they are just not translating this learning to their performance on post-tests.

5. CONCLUSION

We conclude that students, both STEM and non-STEM, indicate that their scientific skills and knowledge increase over the course of a semester in which they participate in a CAB project. This is reflected in the high pass rates of students enrolled in all of these classes, which objectively assess (through a variety of means) that students have learned the assigned material. The anomalous findings from the ToSLS and the Alternative SL measures we thus attribute to a problem of measuring scientific learning in a low-stakes, ungraded assessment administered at a time in the semester when students already have competing demands for other classes. Essentially, we suggest instrument decay as the explanation for lower ToSLS and Alternative SL scores; the instruments themselves are the same, but they fail to fully capture student learning due to students (rationally) spending less effort on determining the correct answers.

We suggest, therefore, that any post-test assessment of student learning must carry more direct weight towards the student's grade for students to take the assessment seriously.

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