New Community Creation Through a Shared Biology-Chemistry-Communication Laboratory Model for First-Year STEM Majors

By Margery Gardner, Neal Abrams, Gregory McGee, and Elizabeth Hogan

This article explores results from a 3-year model of laboratory instruction, Project Synapse, that synthesized biology, chemistry, and communication curricula for first-year science majors at a STEM-focused university. Laboratory biology-chemistry integration was featured at natural intersections where disciplines used similar tools, such as microscopy, or areas where content naturally overlapped, such as the biochemistry of photosynthesis. Communication-related proficiencies, such as lab report writing, were featured across disciplines and in stand-alone writing courses. Faculty perspectives are also part of model analysis using an autoethnographic approach. Primarily qualitative methods were implemented to better understand the participant experience, using Cultural-Historical Activity Theory (CHAT) as a guiding framework. The most prominent themes that emerged from the data and aligned with statistical findings included the following: (i) The instructors were positioned as collegial teaching and learning partners; (ii) formative lab experiences are pivotal for understanding interdisciplinary nature of science content; and (iii) students viewed communication skills as embedded within science learning.

Reforms to STEM (science, technology, engineering, and mathematics) education at the undergraduate level tend to focus on pedagogical improvements for the lecture hall rather than the laboratory (Weaver et al., 2008). The reason for this unbalanced focus is based on a variety of factors, including lack of sweeping consensus surrounding the purpose of laboratory coursework, as well as largely idiosyncratic development of laboratory materials that are based on university faculty background, context-specific resource constraints, and local assets (Weaver et al., 2008).

The first two years of postsecondary education are cited as the most critical to student retention, so targeted interventions may offer the greatest impact on undergraduate outlook and performance at this early stage of a science, technology, engineering, and mathematics (STEM) major’s career (President’s Council of Advisors on Science and Technology [PCAST], 2012). In 2018, the National Science and Technology Council issued a strategic plan for improving STEM education that advocated for the creation of STEM ecosystems to unite scholarly communities as well as greater transdisciplinary learning opportunities. PCAST (2012) also recommended replacing standard laboratory courses with discovery-based research approaches.

In alignment with these recommendations, Cresswell and Loughlin (2015) developed a guided inquiry laboratory model that centered on interdisciplinary forensic science for first-year undergraduates. The model engaged students in a one-semester mock case investigation that included chemical testing of pharmaceuticals and DNA analysis. Student participants provided overwhelmingly positive end-of-term feedback. Gray et al. (2015) examined a laboratory model for upper-division undergraduate biochemistry students that included an interdisciplinary inquiry in the fall semester followed by an independent research project in the spring. Students achieved at appropriate levels based on four key learning gains identified by the laboratory instructors, including concepts, experimental design, data processing, and broader context.

Also noteworthy are shifts in students’ affective responses to laboratory participation when exposed to integrated and collaborative models. Gray et al. (2015) found that a combination of group meetings, manuscript preparation, and poster presentation tasks with a collaborative focus yielded a 72% overall increase.
in student confidence. In a similar study by Lord and Orkwiszewski (2006), the team divided introductory laboratory students into two groups, one traditional and one inquiry-based, to better understand undergraduate responses to inquiry-based lab designs. They reported that students in the inquiry-based group expressed more positive attitudes toward science learning and performed better than their counterparts on weekly assessments on content. Toven-Lindsey et al. (2015) reported increased STEM persistence rates through the development of a Program for Excellence in Education and Research in the Sciences (PEERS) that supported underrepresented students early in their undergraduate career with academic interventions, collaborative learning workshops, counseling, and research opportunities.

Collectively, these prior studies of laboratory instructional models suggest that undergraduates who are exposed to scientific inquiry through opportunities to pursue authentic questions, collaborate with their peers and instructors, and interrogate and explore their own scientific ideas may be better equipped to transition into the STEM workforce. This article investigates how one group of faculty members sought to carry out an undergraduate laboratory model that threaded both integrated content and community to inspire first-year students to pursue STEM and persist in achievement of a science major and eventual career.

**Theoretical framework**

While much research has focused on the effectiveness of various pedagogies on student learning, less attention has been paid to preparing students to participate in professional communities of science. Authentic experiences in scientific exploration would include not only learning content and the use of equipment but also the incorporation of social interactions between investigators in order to develop transferable professional skills. Cultural-Historical Activity Theory (CHAT), which has roots in Vygotsky’s (1982) notions of teaching and learning as a social endeavor, involves three inextricable components: (i) engagement with one another in social spaces using both language and semiotics to express learning; (ii) creation of tools to communicate and demonstrate learning; and (iii) the existence of a community that dictates the norms associated with learning, communication of learning, and ways of acting within educational spaces. “In CHAT, knowledge is always in context,” with people, places, and environment bounded by their unique contexts (Plakitsi, 2013). Boundaries are areas artificially generated through a siloing of disciplines that is the historical norm in academia. Crossing of boundaries is simultaneously concrete and abstract, involving social exchanges as well as transfer of equipment and tools (Akkerman & Bakker, 2011). Plakitsi (2013) asserts that new science methodologies are needed to advance working relationships such as communities of practice, collaborative planning, and learning communities. This inquiry seeks to leverage CHAT as a theoretical lens to understand complex learning systems more fully.

**Synapse model description**

The Synapse project was funded by the National Science Foundation and carried out at a doctoral-accrediting state institution in the Northeast. The project featured three primary goals for first-year STEM students:

1. Improve understanding of the interconnectedness of biology and chemistry at the introductory level.
2. Elevate interest and attitudes toward both science disciplines.
3. Equip students with necessary laboratory and writing skills that are required for advanced coursework.

The three instructors involved in the model development and enactment taught the introductory chemistry laboratory, biology laboratory, and communications courses. All were fully invested in maintaining a learning stance through an active presence and contributions in one another’s classrooms and co-planned activities. A total of 17 Synapse students were enrolled for the entire academic year in a two-credit integrated chemistry-biology laboratory and a common section of a three-credit communications course. The model exposed students to 9 hours of collective in-class contact time per week, or 31% of their total course load.

This study investigates how participants interacted within an interdisciplinary laboratory environment that promoted science learning as a collaborative effort nested within a single social environment. The research question involved in the study is as follows: How did the engagement with the Synapse model shape participants’ STEM teaching and learning perspectives? We cited the laboratory as an ideal location to observe interactions among people, objects, and tools.

**Study participants**

The age of the Synapse participants averaged 17.9 years of age ± 0.3 (standard deviation [SD] = ±1) at the start of the fall semester, with all students registered as first-year under-
graduates at the college. There were 12 students with declared majors in biology and 5 declared in environmental science. This distribution was proportional to student enrollments among the institution’s academic units. Nine participants identified as female and eight as male. At the beginning of the project, participants self-reported high school activity in science-related activities as 2.4 ±1.1 on a 4-point scale. At least six students reported taking either an International Baccalaureate or Advanced Placement course in science while in high school. There were two science faculty members who actively participated in the study, as well as an instructor in the writing program. The chemistry laboratory instructor, Nick, holds a doctoral degree in chemistry and also completed a teacher preparation program as an undergraduate. Jim, the biology laboratory instructor, earned an undergraduate degree in environmental science and a doctoral degree in ecology. Both faculty members offer an autoethnographic perspective, as they presumed multiple roles as both research participants and data analysts.

**Research methods**

We designed a mixed methods approach to capture model effectiveness from multiple analytic angles (Creswell, 2014). Both the qualitative and quantitative components were completed simultaneously at several points throughout the academic year. To answer the research question grounding the inquiry, we focused a greater proportion of analytic efforts on qualitative data due to how the data can give voice to the participant experience.

Synapse was implemented for 3 years and included participants in three sequential first-year student cohorts in 2012–13, 2013–14, and 2014–15. The data reported in this study draw on student experiences from the third year of implementation. We conducted focus groups and individual interviews with a sample of students from both the Synapse and comparison groups (students from same set of majors who have the same first-year course requirements as the Synapse group but differ only in having the traditional separate chemistry and biology laboratories). We interviewed both the biology and chemistry instructors. The Synapse cohort was surveyed again in 2019, a year after their graduation.

The research team developed semistructured protocols based on the work of Patton (1990), which focused on social interactions and firsthand encounters in science learning in alignment with CHAT’s two core elements of “the cultural-historical” and “the material” (Plakitsi, 2013). Protocols for the interviews included questions such as the following: “In what ways did you collaborate with your peers?” “What laboratory practices did you find most useful?” Faculty interview questions also centered on experiences of interdepartmental collaborations and student responses to the curricular modifications included as part of the model. We assigned pseudonyms to students and faculty to protect participant identities. Transcriptions of audio recordings included verbatim accounts with major themes extracted from the data set. These data sets were compiled, open coded, and then axially coded to generate themes from a grounded theoretical lens (Creswell, 2007; Strauss & Corbin, 1990). We verified qualitative data through reflective memos and peer review.

During the fall 2014 and spring 2015 semesters, we issued two separate Likert-scale student surveys called “Science and You” (see Appendix A online). The fall semester survey focused on demographic questions in order to validate the comparison between the Synapse and comparison groups. Results from one-way ANOVA tests showed no significant demographic difference between the Synapse and comparison groups. The spring semester survey isolated differences in affective outcomes and was modeled after Stratford and Finkel (1996), who explored high school students’ attitudes toward science and science classes. The survey asked students questions in an effort to rate their attitudes toward science (e.g., “Science improves my ability to think and solve problems”), their confidence in academic performance for all core coursework (“How easy or hard did you find each class?”), grade satisfaction in the fall term as well as grade predictions for the spring, study habits (“How often do you study with your lab partner?”), and extracurricular activities.

To verify results, an external evaluator coordinated all analyses of raw data. Survey data served as the primary quantitative data source and relied on student self-reports. We conducted an analysis of internal consistency of reliability using Cronbach’s coefficient alpha for the surveys developed as part of this study (Leech et al., 2011). We considered the surveys to possess good internal consistency (α > 0.7).

**Findings**

Qualitative data were compiled and themes extracted that appeared across data sets, participants, and time. The most prominent themes that emerged from the data and aligned with statistical findings included the following:
The model positioned instructors as both mentors and peers, (ii) early “gateway” labs set an interdisciplinary tone, and (iii) students acquired a more expansive conception of learning skills that included communication.

**Professors positioned as active boundary crossers**

Early on in their careers at the institution, Jim and Nick sought to understand each other’s work:

> I was interested in what he does in chemistry and you know vice versa ... and at that moment we realized that there were opportunities to integrate some activities to give students some enriching experiences and try to build some interest and context to understand why they are learning skills. (Jim, faculty interview, October 20, 2014)

Over a span of months and years, the team identified common subject areas, tools of inquiry, and objects required as part of laboratory objectives for both biology and chemistry (see Table 1).

Jim and Nick assumed a boundary-crossing stance that involved the entrance “onto territory in which we are unfamiliar and, to some significant extent therefore unqualified” (Suchman, 1994, p. 25). This position allowed for the advancement of interdisciplinary instruction that evoked at times biological, chemical, or biochemical focus. Jim explained, “My role in general biology is trying to learn general chemistry along with the students and reinforce those things that Nick does in the chemistry lab” (Jim, faculty interview, October 20, 2014).

Close and ongoing instructor collaborations were modeled for students through the entire year. Instructors were present during each other’s laboratory practices and contributed their disciplinary expertise as needed. Jim describes how this interaction played out in the lab setting:

> I’m always learning something or re-learning those things I forgot 25 years ago. I think of this as a model of scholarship and inquiry for the students to see that their instructors are truly interested in what the other is doing. We do the same with writing. (Jim, faculty interview, October 20, 2014)

Students developed personal interactions with instructors who supported them in other academic venues.

> The Synapse program gave the confidence to develop relationships with faculty and develop connections with different professors. Having that first experience with faculty was truly amazing because it gave me a support network of people who care about my academics and gave me approachable faculty who I could go to if I needed help. Having this first experience made it easier to further develop connections with other professors later on. (Mary, alumni survey, July 22, 2019)

The informal mentorship that occurred as part of the model seemed to also motivate students to pursue advanced degrees in the sciences.

> It’s really beneficial getting to know your professors. Especially

### TABLE 1

**Shared activity system of biology and chemistry laboratory.**

<table>
<thead>
<tr>
<th>Interrelated topics of study</th>
<th>Subjects</th>
<th>Tools</th>
<th>Objects</th>
<th>Division of labor</th>
<th>Community</th>
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<tbody>
<tr>
<td>Growth and culturing of bacteria</td>
<td>First-year science majors in biology, chemistry, or environmental science</td>
<td>Authentic inquiry</td>
<td>Laboratory reports</td>
<td>Biology, chemistry, and communications instructors</td>
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<td>Serial dilutions/molar concentrations</td>
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<td>Peer review</td>
<td>Research papers</td>
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<td>Chemical structure and biological function of biomolecules</td>
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<td>Visiting lectures/panel discussion from other faculty</td>
<td>Hands-on lab skills proficiency exams</td>
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<td>Soil chemistry analysis, herbaceous niche differentiation, and physiological effects of soil acidification on plants</td>
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<td>Laboratory equipment</td>
<td>Final exams</td>
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<td>Pigment extraction and chromatography</td>
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<td>Children’s books</td>
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<td>Photosynthesis and photovoltaic cells</td>
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<td>Social media posts</td>
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<td>Bioenergy and fuel production</td>
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<td>Poster presentations</td>
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<td>Laboratory reports</td>
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<td>Faculty across departments</td>
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<td>Research papers</td>
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<td>Second-, third-, and fourth-year students who also participated in the project as mentors</td>
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<tr>
<td>Hands-on lab skills proficiency exams</td>
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<td>Alumni networks</td>
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<td>Final exams</td>
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Early “gateway” labs set an interdisciplinary tone

The first lab as part of the Synapse model included a field investigation of understory wildflower colonization in post-agricultural forests that involved observations and sampling as well as soil analyses using an open inquiry approach (see Appendix B online). Five years after participation, Alana identified the first lab as a very memorable experience because “it was the most exciting and different” (Alana, survey response, August 15, 2019).

Another student, Alison, coined the term gateway laboratory in the following passage:

Unlike other sections, we actually did stuff with the data. The other sections did like pH and maybe one other thing in the bio lab; we took it [the soil] to the chemistry lab and tested all these variables. I think it was interesting all the things you could test, I think it was a good gateway laboratory. (Alison, focus group, April 28, 2015)

Alana’s statement suggests that this laboratory investigation opened her eyes to the world of scientific inquiry at the undergraduate level, allowing her to see experimental possibilities that were previously not afforded to her as part of her high school education.

The team acknowledged that other subjects not directly covered in the model also have the potential to generate shared instruction opportunities, such as macromolecules and intermolecular forces, kinetics, thermodynam-ics, and diffusion. However, due to demands on faculty time, the topics were restricted to those listed in Table 1. The early engagement in shared subjects, tools, objects, division of labor, and community as part of the forest soil chemistry and herbaceous niche lab set the norms of practice for the entire academic year. Instructors openly discussed the relationship between subjects, tools, and objects, and students thus anticipated shared connections as the year progressed. “We are explicitly showing students, ‘Here are the connections, here’s how we can use chemistry to apply to biological problems’” (Jim, faculty interview, October 20, 2014).

An extension of skills beyond “pure” science content

A prioritization of communication skills was also embedded as part of the model. “You know the English instructor is sitting on my shoulder saying communication is paramount, and without being able to state what you have observed, science doesn’t move forward” (Nick, faculty interview, October 22, 2014).

Alison recognized the importance of science communication for the advancement of the field:

Let’s face it. Scientists are not good at communicating themselves, not in many cases. You have scientists that are good at interpretation like Neil deGrasse Tyson. It’s just they are so well known because there are so few of them. … It’s just hard to step back from all the information and large words and everything and say it plainly. (Alison, interview, January 30, 2015)

To help first-year science majors develop technical communication skills, the lab instructors evaluated the commonalities of learning objects nested within writing assignments. “The same formula applies whether it is in a writing course or a science course; the data source will differ, but we are trying to get the same points. I have learned a lot about parallel strategies” (Nick, faculty interview, October 22, 2014).

Student reflection on the Synapse experience tended to focus on the communications aspect of the model at both the close of the academic year and after graduation. For instance, one student said, “I feel that it was more science oriented because they know that Synapse has science majors. … We looked at rhetoric of lab reports instead of just rhetoric in the sciences” (focus group, April 28, 2015). Peer review emerged as a key focal skill that resonated with students and reinforced feelings of community.

Alana, who planned to attend veterinary school, reported a year after her undergraduate graduation that she found these communication skills to be helpful later on in her academic career, saying, “[I gained] writing skills and communication skills mostly, but it also helped me better understand how to design an experiment and write a report” (Alana, survey response, August 9, 2019). This communication skill transferred to more advanced coursework: “It helped me to write better lab reports for other classes” (Alana, survey response, August 9, 2019). George, now an operations forester, recounted multiple skills obtained as a result of Synapse participation: “The greatest skill I learned was how to better incorporate chemistry and biology instead of thinking of them separately. Report writing did carry through my college career though, as most classes included it” (George, survey response, July 22, 2019). George again mentioned the development of tools of communication from his freshman year experience: “Synapse taught me technical writ-
ing, which aided me greatly through school. It also taught me to critically analyze everything, which carried over well” (George, survey response, July 22, 2019). Alana’s and George’s responses indicate the ability to transfer lessons learned from their first-year Synapse experience to upper-division courses and into their current professions. This seems to be the case based on the accounts of a series of graduates.

Given the CHAT framework of interaction between people, objects, and tools, the Synapse model generated more robust curricular explorations while increasing the availability of tools of inquiry that expanded the learning community network more broadly. As a result, students tended to work more collaboratively with their peers than did their non-experimental counterparts. The Synapse cohort self-reported studying with their lab partners at a greater level ($p = 0.001$) than their peers enrolled in the traditional introductory biology and chemistry labs. Likewise, Synapse students indicated they preferred studying with a lab partner at an increased level than did students enrolled in the traditional lab classes ($p = 0.011$). “It makes you more comfortable, I guess, to like, talk,” stated Lori during an end-of-the-year focus group session. Synapse students also reported participation in extracurricular activities at a rate almost twice that of the control group in this cohort. These findings align with instructor observations in the laboratory, as Jim mentions:

*The outcome [of the Synapse model] I think is a cohort of students, who work very well together as peers, they are comfortable with one another, I think that they are more comfortable with us… I think that the teaching environment is more enjoyable and productive.* (Jim, faculty interview, October 20, 2014)

**Discussion**

Boundary crossing involves the multidirectional transfer of both people and objects across contexts. In the case of Synapse, both instructors and students actively transitioned between introductory biology and chemistry labs and developed ways to understand and communicate their newfound knowledge. Akkerman and Bakker (2011) support this assertion and advocate for boundary-crossing opportunities that provide students exposure to hybrid situations that reflect real-world challenges. Based on the results of this study, both students and instructors used boundary-crossing episodes to advance both their science knowledge base and communication skills while simultaneously generating strong community. This outcome resonated across both the quantitative and qualitative data sets.

Because the Synapse model crosses science and communication boundaries, there is a deep appreciation for diverse ways of thinking and approaches to problem-solving. This laboratory paradigm offers greater opportunity to establish a more culturally competent environment that may allow access for previously marginalized student groups (Tanner & Allen, 2007). The sociocultural science perspectives could potentially be broached more explicitly as part of an interdisciplinary model with diverse faculty voices.

**Conclusion**

Close and ongoing instructor collaborations resulted in instruction and curriculum that fulfilled the need for student skill acquisition, real-world relevance, and personal connection. The Synapse model created an atmosphere of support as well as academic challenge that allowed students to maneuver the cognitive demands presented in their first year as undergraduates. The Synapse approach to curriculum instruction warrants expansion into other contexts based on the results presented in this study.

We documented direct and compelling connections by participants as they engaged with each other, the scientific laboratory equipment, and the rest of the participants in this cohort collective. As outlined in CHAT, both instructors and students took part in dismantling siloed instruction, which offered greater opportunity for social interactions and enriched scientific inquiry. Communication became a visible and prolonged feature of the model that acted as an expressive outlet for students to demonstrate science knowledge in transferable ways. This study aligns with the latest interpretation of CHAT in the field because the focus of analysis involved the merging of two separate yet related systems.

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