Speaking to Learn & Learning to Speak: Service-Learning Involving Communication in the Chemistry Curriculum

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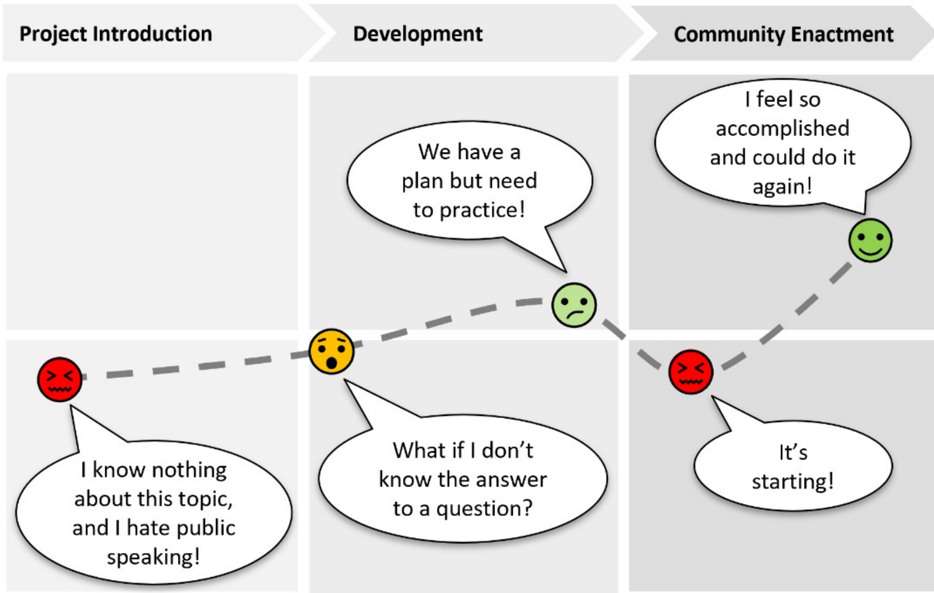
ABSTRACT

Community-based learning (CBL), also known as service learning (SL), provides students with an active and meaningful learning environment and has been studied in STEM courses for several decades. Chemistry for the Community is a novel chemistry curriculum that weaves service-learning projects throughout multiple courses, including gateway courses, and allows students to build self-efficacy and transferable skills. Over a three-year period, students experienced multiple projects while enrolled in two-semester general and organic chemistry courses, and one-semester organic survey, environmental, and analytical chemistry courses. Student experiences, gathered by surveys, reflections, and interviews were compared to those of students conducting equivalent non-SL projects, as well as projects conducted virtually due to the COVID-19 pandemic. Public communication and community partner interaction emerged as major themes from the data and were explored through the lens of self-determination theory. Results indicate that students were anxious about their role, but were motivated by community partner interaction. Project completion corresponded to an increase in self-efficacy regarding similar future tasks, with students perceiving benefits of multiple experiences.

GRAPHICAL ABSTRACT



KEYWORDS
First-Year Undergraduate, Second-Year Undergraduate, Chemical Education Research, Communication, Professional Development

INTRODUCTION

Employers expect[1,2] a combination of hard and soft skills in new graduates in science, technology, engineering, and math (STEM) fields; however, few students are given authentic opportunities to build a transferable skillset in STEM courses,[3] particularly skills such as teamwork,[4] project management,[5] and public speaking.[6,7] While these skills may be utilized and built up in humanities courses, their application in STEM courses at the college level is rare[3] despite evidence[8,9] that developing such skills also supports developing competence in science.

Service learning (SL), in which students complete community service-type activities as part of their regular coursework, followed by reflection[10] on the experience, is one type of naturally authentic and meaningful learning experience that provides students with the opportunity to build up both hard and soft skills. Active and meaningful learning benefits students by helping them interconnect and retain information learned in their courses.[11–15] SL follows Kolb's[16] learning cycle of experiential learning. Experiential learning is inherently active as students must go through a learning experience, followed by internal reflection of their learning, followed by insight about their learning, which then allows for action to be taken to go through another learning experience.[16] As experiential learning activities that connect students with their communities, SL activities have been shown to support student engagement[17,18] in their courses while increasing their competence and confidence as scientists through meaningful experiences. Reviews of SL[19] have reported that the activities can increase student self-efficacy,[19] sense of belonging in science,[20,21] civic engagement and sense of social responsibility,[22] and build essential transferable skills such as teamwork, project management skills,[23] and public speaking.[8,9]

However, SL is not common in science, particularly in chemistry courses. Most reports[20,24,25] are a description of the activity performed by students with little to no assessment of the activities provided. The activities are frequently structured around single events or courses. Assessments have primarily focused on civic orientation for the students taking part in service learning,[22,26] or on the benefits to the groups (particularly children) who are participating as community partners (CP) in the activity.[21] Additionally, little research has been done on the importance of the interactions between students and the community partners,[27,28] who indirectly facilitate the development of students' skills. The few studies have focused on college students' sense of social responsibility and civic orientation,[22] and the personal feelings of students after interacting with community members.[29] There is a need for qualitative reports[30] on how SL supports student competence-building in transferable skills and how participation in multiple opportunities may affect this.

To fill this gap, the Chemistry for the Community (CFTC) model aims to create a transferable SL-focused curriculum that weaves throughout a typical four-year chemistry trajectory, impacting students in gateway courses as well as younger students in the local community who represent the STEM pipeline. CFTC was designed based on the premise that for science students to reap the strongest benefits of becoming community-engaged scientists, they require multiple authentic experiences. This would build competence in necessary skills and develop their sense of belonging and identity within the scientific community. Skinner et al.[31] have proposed a model identifying the elements essential to motivation in undergraduate STEM courses, including prior experiences; the nature of the academic work; supportive relationships; and science motivation, including engagement and science identity. Their model is grounded in self-determination theory (SDT),[32] which assumes that all individuals have fundamental psychological needs "...whose fulfilment provides the motivational 'fire' that fuels engagement in learning" (p. 2435).[31] These needs include students' sense of competence, relatedness, and autonomy.[31–35] Previous studies on SL have been guided by SDT in order to study civic orientation,[30] as well as changes in student competence, relatedness, and autonomy.[36]

This report investigates how the features of the CFTC model (development of public communication skills; role of the community partner; and multiple, progressively more complex, experiences) align with these components of SDT. Specifically, the following research questions (RQs) are addressed:

1. How were students' sense of competence and self-efficacy supported by single and multiple SL experiences?
2. How do CP interactions during SL activities develop students' sense of relatedness?
3. To what extent do the SL projects support students' sense of autonomy?

We summarize findings from three years of data collected from students enrolled in two-semester general and organic chemistry courses, and one-semester survey of organic, environmental, and analytical chemistry courses.

METHODS

Context

The CFTC curriculum was developed and implemented at a small New England institution serving primarily undergraduate students. It includes SL opportunities in both semesters of general chemistry and organic chemistry; a one-semester survey of organic chemistry course (for STEM majors in non-medical and non-chemistry tracks); and one-semester upper-level analytical and environmental chemistry courses. The curriculum moves students through a series of SL projects requiring them to adopt different roles, handle progressively more difficult chemistry content, and interact with more sophisticated audiences (see Figure 1).

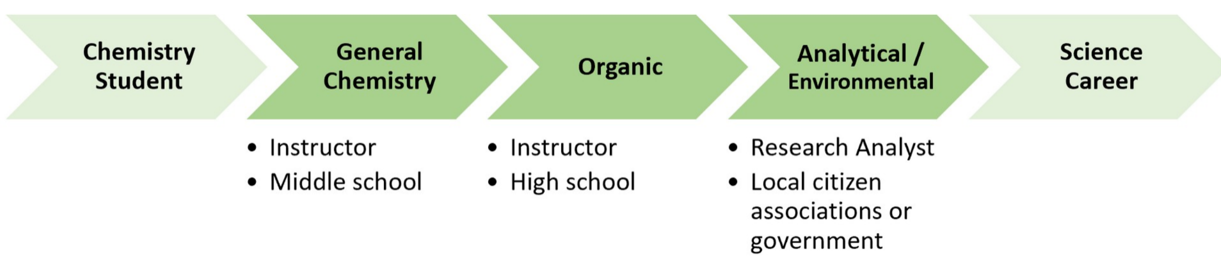


Figure 1. Simplified representation of curriculum progression, including student roles and community partner audiences.

Each project had three phases: introduction, development, and enactment. In teams of 3 to 4, students were introduced during lab periods to the community partner and project scope. In the Development phase, students outlined work to be done, determined necessary materials, conducted experiments, practiced presentations, and modified plans based on instructor feedback. In general and organic courses, students spent 3-4 weeks in development before completing a practice session with their instructor approximately a week prior to public engagement. Projects in analytical and environmental courses were slightly longer (4-5 weeks) as they involved sample collection, analysis, and method refinement. The projects culminated with some form of presentation for the community partner (Enactment). Additional information about project requirements, including examples of project outlines, project templates, and project rubrics given to students, are available in Supporting Information (Sections S1-S4).

This report focuses on student experiences with the CFTC curriculum over a three-year period (Fall 2019-Spring 2022). A summary of these differences is presented in Figure 2 and elaborated in the following paragraphs.

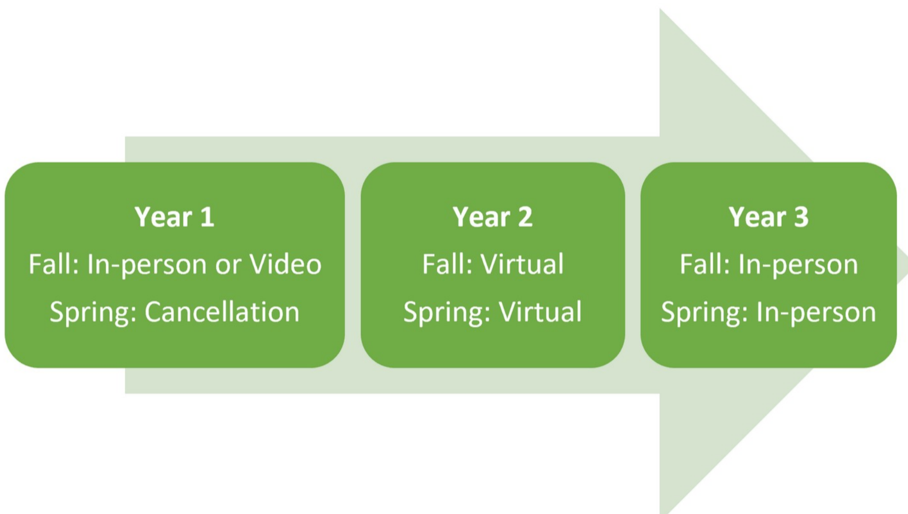


Figure 2. Overall student experiences with the CFTC curriculum over the three-year data collection period.

Prior to the formal project, the upper-level chemical analysis courses had routinely incorporated SL components but the general and organic chemistry courses had not. The research team saw an opportunity to conduct a pseudo-random controlled experiment in which some sections of the general and organic courses would implement SL but other sections would not. This was possible because lab sections did not indicate during enrollment if SL activity would be required. Planned SL activities would involve the design and implementation of interactive in-person lessons in local middle and high schools. However, comparing an SL experience with the non-experience of another group would likely not generate informative data for comparison. The research team decided to focus on the more interesting and unique feature of SL: the involvement of a community partner. In order to make a reasonable comparison between chemistry understanding, transferable skills, and experiences of the “treatment” SL group versus the “control” group, the control condition designed was a short video lesson of the same content but with no direct engagement of a community partner. This was to be compared with the direct engagement inherent in in-person lessons. A similar comparison was intended for the spring semester in the first year, but the pandemic caused cancellation.

During the second year, general and organic students participated in SL projects, but all were conducted virtually with the local middle and high schools via online meeting software (Figure 3). In this modality, students created media such as videos or podcasts to share with the community partner ahead of a planned synchronous meeting, and then developed virtual presentations and discussion materials for the synchronous meeting. Additional detail about each project modality is available in Supporting Information Section S5.

In the third year of collection, general and organic chemistry students returned to designing and executing in-person lessons at local schools. Analytical students analyzed water samples collected from the local lake for phosphate levels and presented results to various community groups (local lake association; two city councils with jurisdiction over the lake; university poster session). Although the pandemic interrupted the planned pseudo-random experiment, it created the opportunity to qualitatively compare three activity modalities: video (“control”), in-person SL (“treatment”), and virtual.

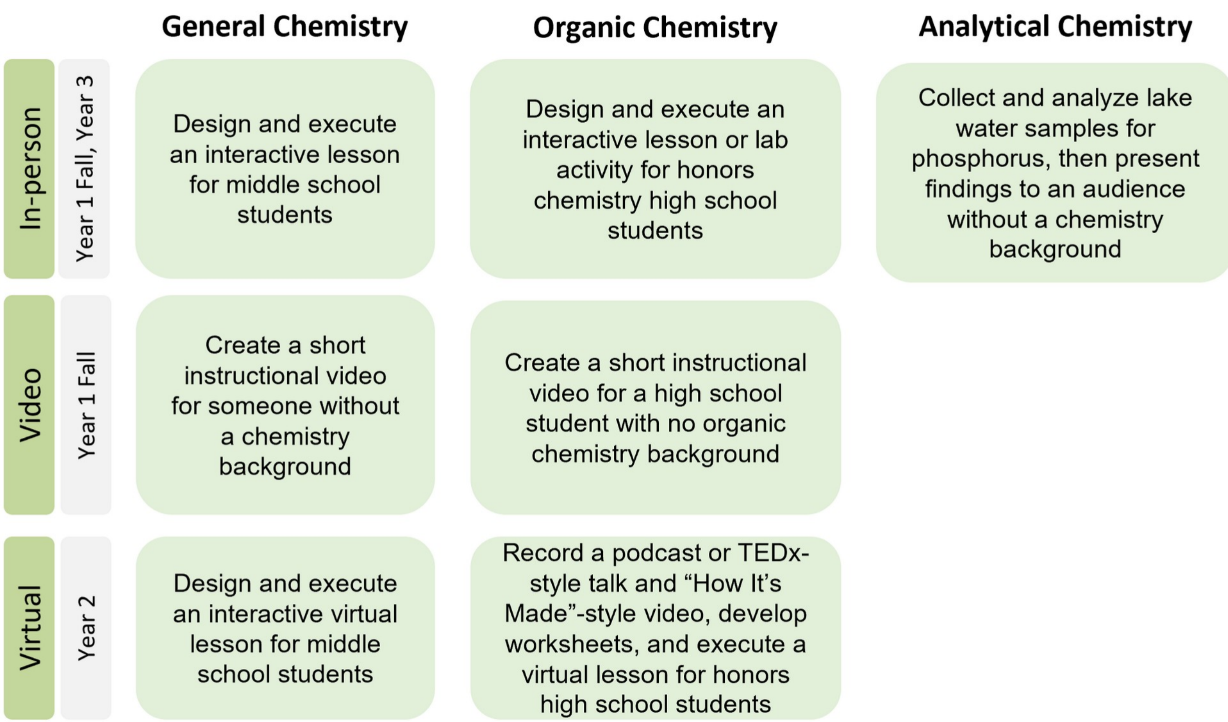


Figure 3. Short descriptions of projects, organized by course and mode across the three-year study. The in-person modality was available in the fall of Year 1 and fall and spring of Year 3. Video occurred only in fall of Year 1. The virtual modality took place in fall and spring of Year 2.

Participants

One hundred forty five undergraduate students participated in one or more projects over the three-year data collection period. Students were first to third year and primarily STEM majors. A summary of the number of participants in each course and treatment group is provided in Table 1.

Table 1. Number of students in each course, each semester, and each treatment group

	Number of Students								
	Year 1 Fall		*Year 1 Spring*[a]		*Year 2 Fall*	*Year 2 Spring*		*Year 3 Fall*	*Year 3 Spring*
Course	*SL*	*Video*	*SL*	*Video*	*SL*	*SL*	*Non*	*SL*	*SL*
General	22	12	16	13	31	4	16	26	20
Organic	15	8	12	11	15	13	N/A[c]	9	11
Organic Survey	N/A[b]		8	N/A	N/A	N/A		N/A	6
Analytical	5		N/A		N/A	N/A		10	N/A

[a] Due to the onset of the COVID-19 pandemic, the Spring 2020 projects were canceled during the development phase and were never completed by the students.

[b] The Survey of Organic and Analytical Chemistry courses are offered every other semester, so students were not participating during these periods of time. Single semester courses only offered a single lab section, so there was no Non-SL project option.

[c] During the Spring 2021 semester, the projects were mandatory for the Organic Students and the General Chemistry students were allowed to opt-in to the projects. The Non-SL project that semester consisted of regular lab activities.

Data Collection and Analysis

A mixed-methods approach was used to collect data, including a survey; open-ended reflections before, during, and after project completion; and semi-structured student interviews. IRB approval was obtained at the University of New Hampshire.

Survey. The survey was administered online at the beginning (pre-survey) and end (post-survey) of each course each semester. Students were given several reminders to complete each survey within an approximately three-week period. Students received a small amount of course credit (~1% of overall course grade) for completing all surveys. Responses were not available to course instructors, except as aggregate, de-identified data. The survey (Supporting Information Section S6) was developed through a literature review[1,2,37–40] of skills required in STEM professions by employers and universities. The survey contained a mix of open-response and ranking style questions to explore student perceptions of skills required to work as a scientist, as well as their confidence in performing various community-oriented tasks (e.g. conducting a phone poll, etc.). Tasks were chosen based on prior and probable SL activities in consultation with the designers of the CFTC curriculum.

Survey responses were included in analysis only if a student completed both pre- and post-surveys. Quantitative survey data was analyzed via one-way analysis of variance (ANOVA) using JMP® Pro 16 statistical software, comparing responses over time and between courses. Responses to open-ended questions were analyzed inductively by one author (AG), and patterns triangulated with quantitative data, written reflections, and interviews.

Written Reflections. Students were assigned three open-ended reflections during each project as part of their normal coursework (example in Supporting Information Section S2). Each reflection asked students to write about their expectations, perceptions, and experiences relative to the projects; how those changed during a project and after multiple projects. The first reflection was completed after project introduction; the second, after students had begun groupwork; and the final within approximately one week of finishing. Reflections were available to instructors. Minor changes to the questions were made over the course of the study as appropriate (e.g. clarity, comparison to previous experiences, project cancellation due to COVID-19).

All reflection responses were included in analysis, regardless of whether students completed all three in a semester. Thematic analysis, using a constant comparison approach[41,42] with open coding followed by axial coding, was used to explore reflections by one author (KAB). Year 1 Fall data was used to create initial codes, which were refined and organized into initial categories. Codes and categories were further refined as new data from each semester was added. The dataset was reviewed to ensure that the entire range of student voices (positive and negative) were captured. After the first year, no new categories or themes emerged in subsequent semesters, suggesting sufficient saturation was achieved,[43] except in the case of one-time questions (e.g. questions about project cancellation where repeat circumstances are impossible).

Student Interviews. Volunteers from each course were recruited at the end of each semester to participate in individual semi-structured interviews. Interviews lasted 30-60 minutes and were audio-video recorded. Students received compensation for their time. Students were asked to reflect on their course and project (either video or SL), and comment on any similar prior experiences. Again, minor changes were made over time (e.g. question comparing in-person and virtual SL experiences). This paper includes excerpts from interviews with two students who each completed three interviews over the course of two years. Each interview represents a case study of the student longitudinal experience. Student comments in the interviews echoed those in student written reflections, corroborating previously developed codes and categories. Interviews were not accessible to the course instructors.

RESULTS

Student comments provided insight into many facets of the project experience. In this report we explore the relationship between factors that influence motivation (i.e. competence, autonomy, relatedness) and two themes that emerged during inductive analysis: public communication and community partner interactions. To address each research question, we present written reflection data, triangulated with survey responses and interview excerpts. To let the students ‘speak’, we integrate quotations in-line, in the form of block quotes, and in tables and figures throughout the Results section.

Each quotation is followed by a student code to demonstrate the variety of student voices: codes take the form of c#_##, with the first portion (c#) indicating in which semester or cohort a student entered the research database, and the second designating a specific student (##). Semester (FS-Fall, SS-Spring) and year (1-3) are also provided.

RQ1: How was students' sense of competence and self-efficacy supported by single and multiple SL experiences?

Competence is defined as the need to feel capable when completing a task. When students' need for competence has been met, they feel capable of completing demanding activities and report high levels of self-efficacy;[44] that is, they believe in their ability to complete a task and produce a particular outcome. Prior experiences are the most influential source of self-efficacy "because they provide the most authentic evidence of whether one can muster whatever it takes to succeed" (Bandura, 1977).[44]

Feelings about communicating with an audience was prominent in student reflections. Particularly, students expressed concern, anxiety, or fear about speaking in front of an audience or a camera. Several factors fed this anxiety. Some students felt shy while others disliked public communication due to previous experiences or lack thereof. Students commonly expressed worry about "getting [their] ideas out" (c1_46, FS1) and "not explaining the information well enough" (c1_25, FS1). Student anxiety was heightened by how little students felt they knew about the topic and the desire to "[know] the material well enough to teach it" (c3_33, FS3). It was apparent that SL students felt a specific kind of pressure associated with being the 'bearer of knowledge' to an audience. Students worried about being "unprepared" (c1_50, FS1) or "not knowing an answer" (c2_9, SS1) to a question asked by the CP. This pressure was, for some, driven by a desire to appear competent to the CP: "I wanted them to know that I understood what I was talking about" (c1_9, FS2).

Comparison of in-person SL (treatment) and video (control) experiences similarly suggested that the need to appear competent motivated students participating in SL activities. While students in both conditions faced anxiety about public speaking, the 'pressure' of recording a video was typically seen as less by both groups compared to presenting to a live audience. Students reasoned that with SL there is only one opportunity to 'get it right' whereas when producing a video, one could always edit or re-record so the audience never sees a mistake. While this lowers the overall stress level, students pointed out that a live audience was an incentive "to be more sure of the topic" (c1_50, FS1), intensifying preparation efforts (Table 2). SL students tended to view community partner interaction as beneficial to their understanding because they had to have "actual meaningful conversations," (c1_17, FS1) that "challenge you… to answer questions that you maybe hadn't thought of," (c1_20, FS1) and "…make [you] think more about the subject and thus… learn more" (c1_18, FS1).

Table 2. Example student quotes comparing in-person SL activities (year 1, treatment) and video (year 1, control) projects.

Condition	Student Quote
Video	I would chose to create a video because I think I would be too scared of getting up in front of a classroom full of people and would much rather make a video for people to watch instead of having to perform it live, because you can cut things out in a video if you mess up, but you can't cut out your mistakes in real life. (c1_6, FS1)
In-person	If I had created a video about the topic I don't feel as though I would have learned as much. I say that because I could have had more chances to get the presentation right. Additionally, I would not have had to prepare for possible questions which honestly would have led me to just memorizing what I was saying instead of actually comprehending it. (c1_54, FS1)
Video (Fall) to In-person (Spring)	I feel like the in-person version with the high schoolers was going to be better. Because in my head for the video one I was like, 'Oh, well, we could just do like retakes or we can just like re-do,' you know? So for like the in-person one, I was like, 'I don't want to look like a fool.' So then, really practice. I can get it all straight and get to know everything. ...at first I was like, 'Why do we have to do this? No!' ...I know other people in the class were like not excited for it. But I also wasn't until I like really like thought 'Okay, like being forced to do this, like it's gonna make me better.' (c1_64, SS1, interview)

Reflection data from virtual SL activities during the COVID-19 pandemic underscored students' anxiety over presenting and the need to appear competent in front of their audience. For example, some students indicated a preference for a virtual experience over an in-person one, making statements like "messing up in person is... more embarrassing than doing over a screen," (c1_32, SS2) "it's less stressful looking at a camera vs a room full of high schoolers" (c1_12, SS2), and "it is not as intimidating" (c2_1, SS2). Even so, students "wish[ed] [they] got the chance to do something in person to become a better public speaker" (c1_6, FS2).

Students' mixed feelings suggest that lack of competence in public communication was initially demotivating, but the need to appear competent in their role as a presenter incentivized learning. At the end of a project, students commented that the presentation experience often went better than expected and had its benefits. Students reflected "...leading up to the presentation I dreaded the thought of presenting... but once it got started all of that went away," (c1_35, FS1). Successfully completing such an experience fostered confidence in their future ability to do so; that is, it increased their self-efficacy. This typical emotional journey is mapped in Figure 4.

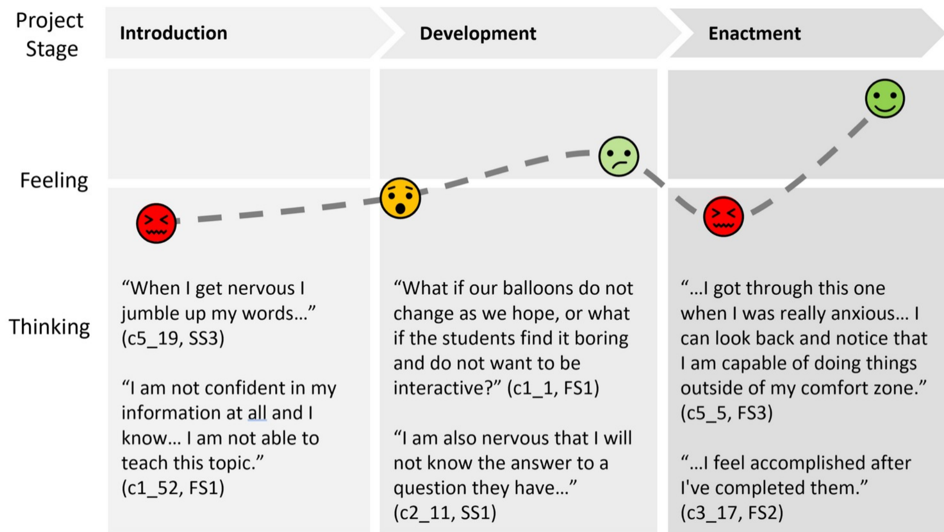


Figure 4. Journey map presenting examples of thoughts and feelings from students over the course of an SL project.

To evaluate student progression through multiple SL experiences, students were asked to reflect backwards to prior experiences as well as to project forwards to future experiences. Students were asked whether they had previously engaged in similar projects and asked to rank potential SL activities by how confident they were in performing them (Supporting Information Section S7). They were also asked to pick one activity and explain why they felt prepared for it. Additionally, students were asked in post-reflections to compare the current semester’s project to those previously completed.

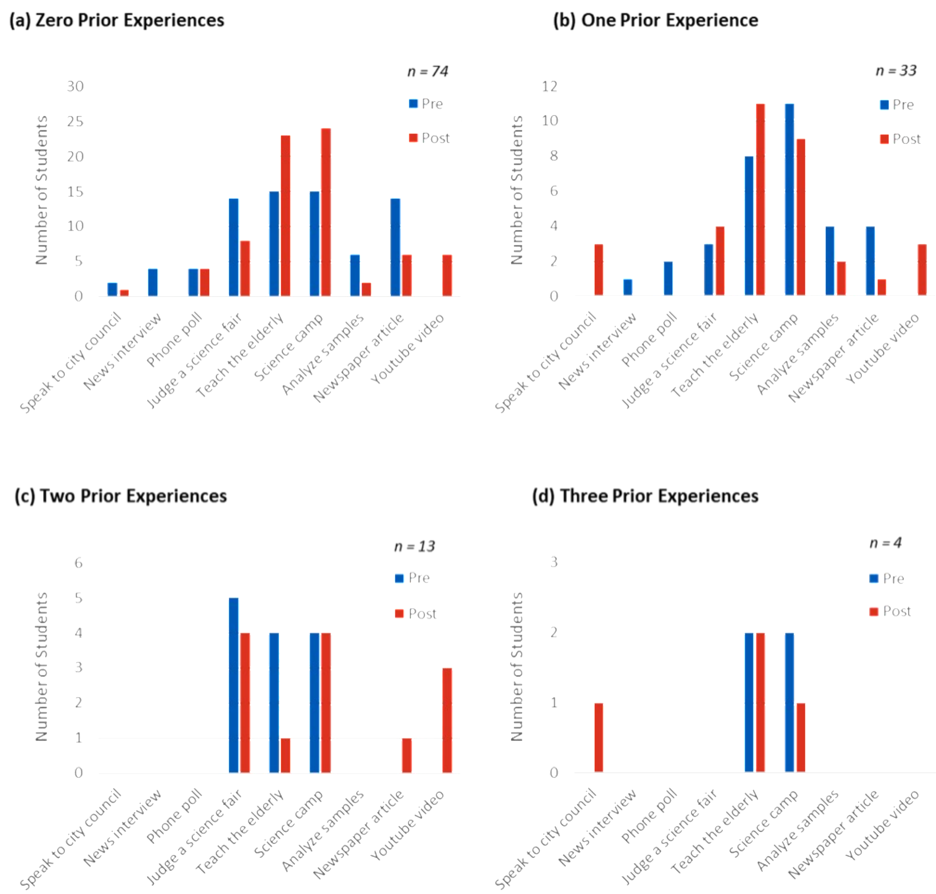


Figure 5. Graphs displaying the specific activities selected by students based on their confidence in being able to complete the activity, before and after engaging in an SL task. The graphs are organized by number of prior SL experiences, Zero (a), One (b), Two (c), and Three (d). Semester projects impacted by cancellations and video projects were not included in the given data, resulting in a subset of student participants being included. Data was only included if the participant responded to the pre- and post-surveys for the experience. Vertical scales are not the same.

Figure 5 shows the activities students ranked as being completely or moderately confident in performing. Students were asked to choose a single activity and elaborate on why they were confident in completing it. Responses are organized according to how many prior SL experiences in chemistry (0-3) each student had. Pre-survey data indicates students were less likely to choose public speaking-based activities (e.g. speaking to a city council, teaching the elderly) or activities where they lacked experience with the audience (e.g. speaking to a local news station). For example, among students with no prior SL experiences (Fig. 5a), some chose familiar activities like writing a scientific article because "...[their] writing skill sets and [their] enthusiasm for science" (c1_12, FS1) gave them confidence. However, others felt comfortable teaching the elderly because "[they] have worked with elderly in the past" (c3_28, FS2) and "understand how to communicate effectively to the elderly" (c1_41, FS1).

Post-survey results suggest that as students completed SL experiences, their activity confidence rankings shifted to reflect those experiences (Supporting Information Section S7). Figure 5a and 5b show that more students selected a teaching or experiment design-based activity after successfully completing an SL experience requiring similar skills. Similarly, in the case of analytical chemistry, the number of students that selected speaking to a city council went from zero to four (out of eight) after they effectively presented their results to that audience (Fig. 5b-d). Students shared that they felt they had gained an understanding of "...how to effectively communicate information to those who have little background in [chemistry]" (c1_54, FS1), and "to think of complex ideas in simple terms and how to portray the information" (c1_58, FS1).

Multiple projects provided multiple opportunities to speak, such that skills learned in previous activities were carried forward. As a result, students overall indicated greater self-efficacy in completing a future project after one or more SL experiences. Students felt prior experiences supported communication skills in subsequent projects by giving them a better understanding of "how to communicate on different levels and guide new ideas" (c1_19, SS1), "how to... put [themselves] in the shoes of the audience and... what they would want to learn" (c3_25, FS2), and "...how to troubleshoot problems and explain a concept on the spot" (c1_9, SS2). This also gave students confidence that they could do the same with other audiences "...that do not have the same knowledge [of chemistry]" (c2_13, SS1). Discovering the experience "was not as intimidating as [they were] expecting" (c3_12, FS2) and experiencing a success were often mentioned in support of student confidence. One student shared that "... each time I complete one I get more and more confident in my own abilities" (c3_4, FS3). Similarly, one interviewee described progressing through projects each semester as a "pathway". They saw a "sharpening" of their communication skills and evidence of their growth when reflecting on prior projects:

> So I would say that like with each project...I've gotten better at like interacting with other people. ...as every project progresses, I just get significantly better at how to talk to people and like how to present information without like talking too fast or stuff like that. Like compared to my first project, I noticed that I was talking super-fast to the point where I didn't understand what I was even saying. But now I've looked back at the recording of the podcast since, like I was the main voice for the podcast, and like everything was so clear and my voice was slow to the point where, like I could write notes down as I hear myself talk. (c1_32, FS2)

RQ2: How do community partner interactions during SL activities support students' need for relatedness?

Relatedness can be described as the need to deeply connect with others or to feel belonging. As described by Skinner et al.,[31] relatedness is pertinent to a student developing motivation to persist in STEM: if students can see themselves as building connections to a community of scientists, they will be more motivated to stay connected. This has the sense of the student reaching inward to the community to build that connection. In the current study, student development of relatedness seems outwardly directed: by performing an external service on behalf of science, they establish themselves as belonging to the scientific community. The data suggests the need to interact with a CP prompted students to think of themselves as ambassadors of science.

First, reflections showed that students hoped the community partner would develop an interest in science or chemistry and wanted to be a part of that process (Table 3). Students hoped the CP would have a positive experience from "seeing [older students] excited and engaged about the material" (c1_1, FS1). Some explained they wanted to share their passion for science and described how these experiences can be inspirational for younger students, possibly "...influenc[ing] them to continue in science related careers" (c1_9, FS1). This hope also appeared when students reflected on in-person SL cancellation. Students felt they lost the opportunity to "[create] connections with the younger people of the community" (c1_16, SS1) and were "stopped… from showing them that science is actually very useful, exciting, practical, and most importantly… fun" (c1_7, SS1). With this reasoning, students positioned themselves as individuals bringing younger students into a community of science-lovers.

Table 3. Example quotes reflecting students' desire to inspire the community partner through the SL activities.

"[I'm most excited about] Working with kids, I hope we can make an awesome presentation that'll impress them and they'll see science as cool." (c1_19, FS1)

"I am looking forward to explaining science to younger students. I think simple displays like this can inspire someones interest in science." (c1_14, SS1)

"[I'm most excited about] Talking with the students and seeing them get excited about science." (c3_3, FS2)

"I think its also really cool that we get to be the ones to get them engaged and interested in the topic and hopefully inspire them to consider continuing with organic chemistry class." (c3_33, FS3)

"I believe that working with the high schoolers... will create an experience that will inspire the future generation" (c3_2, SS3)

"I am excited to be able to take to take part in another CBL. This one is going to be a fun experience because the students are going to be able to come into the lab and work with the equipment we get to use all of the time. I want to share my love for science and this is a great way to do it." (c3_4, SS3)

RQ3: To what extent do SL activities support students' sense of autonomy?

Autonomy is defined as the need to experience one's true self as the source of motivation and action.[31,45] When students' needs for autonomy are met, they have a sense of ownership and commitment to their work. While the evidence for autonomy is not as prevalent in student responses compared to competence or relatedness, student reflections suggest that having to interact with a CP supported students' need for autonomy because they felt a sense of responsibility to control the outcomes.

First, students were concerned about how their project would be received and felt pressure to successfully fulfill their role for the benefit of the CP (Table 4). Some students were extrinsically motivated, wanting to avoid delivering incorrect information (first three quotes, Table 4), and others were intrinsically motivated to deliver a presentation that was interesting, educationally beneficial, and at the right level of complexity for their audience. There was additional pressure because students had only one opportunity to deliver their presentation accurately, including the success or failure of any demonstrations or experiments. Some students worried the partner would view them poorly or be inattentive, which would create a bad experience. One interviewee (c1_32, FS2) shared that they were "extremely nervous at first," were "afraid [the community partner] wouldn't care" and would "space out and just sit there in silence" during the virtual SL activities. Students also hoped that the partner would be "having fun and enjoying what [they] are talking about" (c3_7, FS2), and worried that the partner would "find it boring and... not want to be interactive" (c1_1, FS1). They wanted the community partner to be able to understand what they were teaching and worried about "talk[ing] too fast or us[ing] terms that the students don't have a grasp on yet" (c1_59, FS1). Related to this, they discussed figuring out "...how [they] can deliver the knowledge so [the community partner] retain[s] it best," (c1_10, FS1), and ensuring they "...have a good strategy to engage the kids so they can learn more" (c1_22, FS1). Student comments suggest they enjoyed and/or wrestled with balancing complexity with value to the CP:

> [The best part so far has been…] Trying to figure out how to efficiently and succinctly present concepts students are unlikely to be familiar with in a way that may entice engagement from them. (c5_28, SS3)

After the project concluded, students further reflected on how to enhance the CP's experience, including different experiments or demonstrations to increase the CP's interest, or improving lesson examples, explanations, and instructions to ensure the CP understood the science. Students' commitment during and after the project to deliver a good presentation is suggestive of ownership and commitment to the project.

Table 4. Example quotes reflecting students' need to succeed at SL activities for the sake of the community partner.

"I'm most nervous that the students will look at me like I'm crazy by the end of it because it is a really tough topic, but I hope they will be able to even understand a little bit of [it]." (c1_47, FS1)
"I am just fearful of messing up or giving the wrong information." (c1_30, FS1)
"I most anxious about... teaching them the wrong thing." (c2_11, SS1)
"Making sure everything runs smoothly on the day we present and hopefully the kids take away valu[a]ble information from the demonstrations while also having fun." (c1_27, SS1)
"I am most anxious about giving the presentation, I hope the 8th graders enjoy what we're doing, and also can understand and learn what we are trying to teach them." (c3_11, FS2)
"I am most anxious about the students being able to grasp the ideas we are trying to help them understand through the experiment." (c5_12, FS3)
"I am most anxious about executing the experiment well for all of the kids so that they can learn from it." (c5_16, FS3)

Additional evidence regarding autonomy was found in how students responded to project cancellation. Students revealed feelings of loss and their responses indicated that they had come to own their work and were emotionally engaged in carrying it through to completion. Students were disappointed because they "had put a lot of work into planning" (c1_7, SS1) a project which was essentially "washed away due to the circumstances" (c1_58, SS1). Students in both video and SL experiences also felt they lost “the satisfaction/gratification of finishing what [they] started” (c2_12, S1) and seeing if they would have been successful. Demonstrating commitment to their own learning and the community’s partner, some considered it a lost opportunity for both, as in the following quote:

> I was disappointed that the project was cancelled since I was excited that we had gotten our rockets to work well when testing them outside before the class came for the actual demonstration and I feel like the kids would have enjoyed doing this project. (c1_9, SS1)

Beyond their feelings about the cancellation, students cited other items they felt they lost, including losing a chance to “gain experience public speaking” (c2_6, SS1) or to become “more comfortable talking on video” (c1_60, SS1). One interviewee shared that was “the biggest loss” because she wanted “to work on [her] public speaking skills” and that “...normally [she’s] not excited to do like presenting projects, but this one [she] was like, ‘Oh, okay, like we’re really prepared. We got this!’” (c1_64, SS1). These sentiments indicate that students had developed a personal commitment to learning or improving their public communication skills, suggesting their needs for autonomy were met through the SL activities.

LIMITATIONS

Direct comparisons of quantitative data across the semesters cannot not be made due to the projects changing each year after the onset of the pandemic. Additionally, the reflection data may display self-censoring or social desirability bias from students due to the course instructors reading the reflections as part of the project grade. However, students provided both positive and negative perceptions in their reflections, and the same sentiments were echoed in student interviews and surveys, both of which were not available to instructors. This allowed students to honestly respond to the interviews and surveys without fear that the instructors would see their comments, thus providing less biased results.

DISCUSSION

The ‘Chemistry for the Community’ curriculum model aims to incorporate service learning across multiple courses to support learning chemistry while building transferable skills, a sense of belonging, and scientific identity through serving the local community. Following Skinner et al.’s[31] SDT-based model of elements essential to motivation in undergraduate STEM courses, this report examined students’ sense of competence, relatedness, and autonomy to explore aspects of the CFTC model. including the development of public communication skills, the role of the community partner, and the presence of multiple, progressively more complex, SL experiences. The data examined included survey, reflection, and interview data collected over a three-year period. The COVID-19 pandemic forced community activities to be canceled or altered to virtual mode for some of this time. This was both a problem and an opportunity.

A major theme that emerged during inductive analysis was how the project related to students' sense of competence regarding public communication. As captured in Figure 5, the typical journey of students over the course of a single project was from uncertainty and anxiety about their abilities to confidence that they could do it in the future. In-person (as opposed to recorded and more so than virtual) activities were perceived as more stressful due to the need to appear competent when speaking and answering questions. Nevertheless, these experiences were acknowledged as motivation for preparing more thoroughly. Students' early mixed feelings suggest that the initial lack of competence was demotivating, but subsequent completion of in-person SL projects, and virtual projects to a lesser extent, made them feel capable of communicating and interacting with an audience. With their need for competence having been met, students felt they were capable of successfully completing demanding activities and reported high levels of self-efficacy. This corroborates previous findings that SL projects can increase student self-efficacy.[8,9,30,46,47]

Student self-efficacy for performing similar activities increased with each additional experience. By participating in multiple semesters of SL, students were able to learn from what did or did not work in prior experiences, growing skills and increasing self-efficacy while lowering anxiety. Furthermore, with SL woven throughout the chemistry curriculum, students were able to interact with a variety of community partners and thus learned how to approach speaking to and interacting with audiences of differing levels of expertise (e.g. from middle school students to city council members). Thus, while a single SL project was beneficial, taking part in multiple projects was more so. The instructors reported that repeated exposure seemed to raise students' comfort level and willingness to engage in these experiences, with less effort required to garner student buy-in as they participated in additional SL activities.

Community partner interaction is a key component of SL and therefore the CFTC model. Accordingly, students frequently described expectations and perceptions of interacting with a CP. We explored how interacting with a CP during SL activities contributed to students' senses of relatedness and autonomy. When these needs have been met, students feel that they belong to a community and a sense of ownership of their work. Previous research suggests that the need to belong powerfully affects how people think and feel, prompting them think more thoroughly about interactions and interpret situations with regard to their implications for relationships.[48] When students build relationships in their science courses and majors, their sense of belonging in STEM is enhanced.[30,31,49] Students did report in their reflections that they appreciated the chance to work in groups with their classmates, and for some it resulted in longer-term friendships. In the data presented here, we wanted to explore how the CP may have mediated a sense of belonging. The data suggests that the role adopted by students prompted them to position themselves as ambassadors for the scientific community, aiming to demonstrate the value of science and inspire others. If this is the case, it may be valuable to consider how different roles during SL could support relatedness, and therefore persistence, in STEM.

The data suggest that interacting with a CP also supported students' need for autonomy. They wanted to make the experience valuable for themselves and the community partner and were committed to delivering interesting, educationally beneficial, and appropriately complex presentations. Project cancellation because of the pandemic produced feelings of loss, suggesting that students had taken ownership of the project and their learning process and wanted to carry it through to completion.

In summation, the data indicate that students were anxious about adopting a communication role where they were seen as the 'bearer of knowledge'. CP interaction motivated students because they prepared more thoroughly to understand the material and present it well (competence); designed their presentations with the hope of drawing the CP into the science community (relatedness); and endeavored to provide the CP with a fun and educationally beneficial experience (autonomy). With the three important components of SDT being active for students through engagement in repeat SL projects, these conditions would support continuing motivation for students to persist in STEM.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI:

10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.]

CFTC Curriculum & Research Materials (DOCX)

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