The Integration of a Community Service Learning Water Project in a Post-secondary Chemistry Lab

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Community Service Learning (CSL) is an experiential learning approach that integrates community service into student projects and provides diverse learning opportunities to reduce interdisciplinary barriers. A semester-long chemistry curriculum with an integrated CSL intervention was implemented in a Canadian university to analyze the potential for engagement and positive attitudes toward chemistry as a meaningful undertaking for 14 post-secondary students in the laboratory as well as for their 400 K-12 student partners in the community. Traditionally, introductory science experiments typically involve repeating a cookbook recipe from a lab book, but this CSL project allowed the post-secondary and K-12 students to work collaboratively to determine the physical and chemical properties and total dissolved solids in the water fountains from the K-12 students' schools. Post-instructional surveys were completed by all learners and were analyzed using a mixed methodological approach with both quantitative and qualitative analyses. The expected audience that may be interested in this study are those involved in teaching chemistry in higher education and at the K-12 level as well as those interested in service learning, community and civic engagement, experiential learning, and development of transferable skills in chemistry. The results demonstrate that both groups of students report favorable engagement and attitudes towards learning chemistry and higher self-confidence levels on performing lab skills after the activity. Furthermore, both groups of students expressed interest in exploring future projects, which is indicative of the positive impact of CSL and the mutual benefits of the partnership.

Introduction and Framing

Community service learning (CSL) is an experiential learning method that integrates community service into student projects and provides diverse learning opportunities to reduce interdisciplinary barriers (Smith, 2012). Another synonymous term that is commonly used is community based learning (O'Connor *et al.*, 2011). A common metaphor used by service learning practitioners frames their thinking about the service learning experience as "boundary crossing" (Sandy and Holland, 2006; Hayes and Cuban, 1997; Keith, 1998; McMillan, 2002; Skilton-Sylvester and Ervin, 2000; Taylor, 2002). Metaphorically, CSL is a bridge to connect what is possible between students and their community partners. Robert Sigmon first defined service learning in 1979 with the intent of creating equal partnerships between students and their community partners in order to promote mutual teaching and learning experiences (Smith, 2012; Sigmon, 1979). CSL programs change the framing of education opportunities from *within* to *access to*, where "frames invoked outside classrooms produce, reproduce, or transform access to learning opportunities inside the classroom" (Hand, Penuel and Gutiérrez, 2012, p. 252). As part of the CSL process, students have an opportunity to reflect on their experiences with this partnership. This is an important process as it helps students to focus their thinking on certain aspects of the activity. Previous studies indicate that learners in K-12 environments that have integrated CSL programs show improved leadership skills and are able to make connections with other subjects and in the community (Flinders, 2013). This finding builds on perspectives from Papert and Harel (1991) that (a) learning is an active process of constructing knowledge and (b) learning involves relating new concepts to what one already knows. Furthermore, students describe an increase of interpersonal skills and self-confidence levels because they are taking greater responsibility in their own learning (Lee, 2012; Flinders, 2013).

Benefits of CSL for students

Researchers have shown in their studies that courses with integrated CSL help students connect to the subject matter in greater depth, be more engaged, as well as improve their academic performances (Dumalo, 2018; Hubert and Hauf, 2015). Academic performance includes not only grade point average but also writing and critical thinking skills. At the same time, students benefit from the opportunity to connect to the wider community, contributing and gaining service experience (Vogelgesang and Astin, 2000). In addition, increased heightened political awareness and civic engagement among students help create active citizens in the communities where they live (Warren, 2012). The structure of the CSL programs creates a supportive environment where students are empowered to move from being participants to being proactive collaborators. Students have the opportunity to identify research questions, share experiences, seek support from peers, and review their progress.

Benefits of CSL for community partners

From the community partner's perspective, the benefits can be divided into three categories: direct impact, enrichment, and social justice. The definition of direction impact, enrichment, and social justice in Table 1 is based on the work of Sandy and Holland (2006).

Table 1 Benefits of CSL for community partners

Direct Impact	Directly measurable client outcomes and enhanced organizational capacity.
Enrichment	Result from the introduction of new innovations in technology and an increase in community capacity by having student volunteers.
Social justice	The motivation to benefit students and community partners through strengthening common values to build and influence the community.

Challenges encountered by community partners

The concerns of community partners in CSL programs are less well documented. Cruz and Giles (2000) indicate that there are complicated political and intellectual reasons why the perspectives of community partners are underrepresented in the field. In 1998, Eby was the first to explore these issues, showing the emotional impact on K-12 children along with the disruption of the classroom as a whole when short term post-secondary CSL students suddenly leave at the end of a semester. When post-secondary students come and go, the relationship between post-secondary students and K-12 students is short term and might feel fragmented to the K-12 students. Furthermore, Daynes and Longo (2004) identify a problem with time constraints when the CSL project is based on the academic calendar of the post-secondary institution. As a result, K-12 students are often left without the full benefits of in-depth research experience. Additionally, K-12 teachers indicate concerns that time required for training and orientation for their students is sometimes longer than the duration of the service-learning commitment (Sandy and Holland, 2006).

Traditional approaches to teaching and learning in the laboratory

Although most studies support the idea that CSL has a positive impact on students and their community partners, there are few chemistry courses in post-secondary institutions that implement CSL in practice. In traditional chemistry labs, experiments often lean toward instructionism by focusing on aggregations of isolated facts and on having students follow rote lists of steps in a "recipe" style (Schug, Tarver and Western, 2001). This type of learning tends to be standardized, with instruction directed toward the transfer of skills and knowledge from teacher to student, often in the form of practice and rote memorization (Kazdin, 2012). The laboratory lessons are teacher-controlled, prescriptive, and focused on observing student achievement outcomes based on written lab reports. Most institutions use this pedagogical approach because of limited time and equipment and the need for standardization among multiple laboratory instructors. Students also indicate that they do not wish to spend extra time outside of class for coordination between their group members (Altman, 1996). This learning approach typically does not focus on connections to students' lives. Thus, students often do not understand the relevance of chemistry learning in a big picture. In addition, traditional chemistry instruction focuses on high levels of specialization and content knowledge. As a result, students experience difficulties when tasked to communicate scientific information to the general public. Furthermore, the traditional dactic model of knowledge learning is fragile in the sense of longer-term learning (Barab et al., 2000).

Design Intention of the Water Project and Research Questions

This study is part one of a multi-year CSL project that was conducted in a mid-sized Canadian post-secondary institution. This manuscript focuses on the process of the project and student attitudes in a laboratory setting with the integration of the different instructional methods that were involved in the project. The study was conducted in the lab component of a second-year analytical chemistry course. Analytical Chemistry II (CHEM 2302) is the first of three required courses with an integrated CSL project in the Bachelor of Science Chemistry program. The K-12 students were grade 8 students around the ages of 13-14 years old from two local public schools. The two schools were selected based on proximity and willingness of the schools to participate. The researchers did not have a pre-existing relationship or connection to the schools. During the activity planning, the main researcher discussed with the K-12 science teachers the learning outcomes that the teachers would like their grade 8 students to achieve through this activity. An open-ended worksheet was generated for the grade 8 students and was reviewed with the science teachers prior to distributing. The goal of this sustainable project is to partner with two new middle schools each year. The reasons for having new schools involved each year with the project is twofold. First, we wish to introduce and organically expand CSL to other schools. Second, from a chemistry perspective, the location of our K-12 students might also involve a difference in the experimental values of the drinking water, which could indicate potential health-related issues, such as lead corrosion in pipes.

The design intention of this CSL project is long-term rather than being focused on a single study (Coburn and Penuel, 2016; King et al., 2010; Metzler et al., 2003). The CSL experience connects to course learning objectives as well as personal, professional, and civic goals (Simons and Cleary, 2006; Prentice, 2007). The epistemological framework employs constructivism in the sense that the instructional practices are student-centered, student-controlled, process-driven, and highly interactive (Ernest, 1995). Rather than learning information and ideas simply as a function of "absorbing" them as a blank slate, constructivism posits that students construct or create their own knowledge as they integrate new ideas into existing knowledge (Phillips, 1995). The project emphasizes learning processes as opposed to learning products. Students have the opportunity to experience real-world situations and the project allows them to apply the knowledge from textbooks to the experiential world (Smith and Elley, 1995). This design of the participatory learning setting allows students to have some degree of co-creation, student voice, and decision making. The participatory learning environments with K-12 students support a natural complexity of content, avoid oversimplification, and require students to work with others as they negotiate goals and learn (Barab et al., 2000). In this context, working collaboratively includes groups among post-secondary students, groups among K-12 students, and groups integrating the post-secondary students and K-12 students. The complexity of this active learner engagement project provides all of these groups of learners with the opportunity to create meaning, understanding, and knowledge. The complex group dynamics necessitate supporting positive interactions as a focal point (Barab et al., 2000).

Self-confidence or self-efficacy is importantly connected to learner motivation and can be fostered socially through interactions (Ferkany, 2008). High self-confidence is shown to have high behavioral benefits. These include independence, responsibility taking, toleration of frustration, resistance to peer pressure, willingness to attempt new tasks and challenges, the ability to handle positive and negative emotions, and willingness to offer assistance to others (Ferkany, 2008). According to Hofestein and Lunetta, laboratory work is the most effective instructional method for promoting and enhancing students' interest toward learning chemistry (1982).

There is very little literature to date that discusses both the benefits and challenges of the learning experiences that post-secondary students and K-12 students have within a CSL program, especially in the disciplinary field of chemistry. While the existing studies cover their own projects with regards to CSL in general, each project is unique. Therefore, it is difficult to draw conclusions when applied to different disciplines. Thus, it is important to further study CSL projects in new contexts for comparison purposes. Toward these goals, the current study was undertaken to explore the following questions:

1. On completion of the CSL project, do both post-secondary and K-12 students express favorable enjoyment, attitudes, and interests towards learning chemistry?
2. What aspect of participating in the project do post-secondary and K-12 students report liking the most? What do they like the least?
3. Do the students report increased confidence levels regarding their performance of laboratory work from participating in the activity?
4. What do post-secondary students report that they have learned through the activity?

Methods

Participants

A total of 414 (14 post-secondary and 400 grade 8) students participated in our preliminary study. Each K-12 student school had approximately 200 grade 8 students with an average of 25 students per class. The post-secondary students were divided into two lab sections with each section assigned to a partner K-12 school. Involvement in the CSL project was mandatory for the post-secondary students. Both post-secondary and grade 8 students worked in groups of 2 or 3 via student-selected friend groups with the goal of enhancing students' opportunities to learn from each other and to improve the ability to form social relationships (Takeuchi, 2016; Cooper and Slavin, 2001). Each group of 2 or 3 post-secondary students was assigned to work with 1-2 classes in the assigned partner K-12 school.

Ethics considerations

This study was approved by the institutional (internal) Human Research Ethics Board and the local (external) public Board of Education where the study took place. All participants of the study were informed of the purpose of the research and the voluntary and anonymous nature of their participation. Their informed consent to participate was obtained before data collection. There was no unsupervised communication between the post-secondary and K-12 school students. If any concern were to be raised with the water analysis data being identified during the project, we would have recommended to our K-12 school to submit another water sample to an accredited lab to check the result before further action was taken.

Data collection - Post-instructional survey

Post-instructional surveys were administered to both groups of learners. Using a convergent parallel design and a mixed methodological perspective, the elements in the survey included a combination of Likert-scale, binary yes/no, and open-ended questions. The benefit of using a mixed methodological approach is that the limitations of one type of data can be balanced by the strengths of another (Creswell, 2018). In addition, understanding is increased by triangulating across the data sources.

Design of the survey questions

For the post-secondary students, a link was provided through Blackboard (an education technology platform) to invite interested participants to complete a survey through Surveymonkey. The survey questions were based on research by Galloway and Bretz (2015). For the students at the K-12 schools, the survey questions were based on Dalgety et. al (2003) and Holstermann (2010), and the students' science teachers distributed hard copies of assent, consent, and survey forms to take home. Both surveys were anonymous, and no personal data were collected. The survey questions consisted of various types: 5-point Likert scale, with scores ranging from 1 (strongly disagree / not confident) to 5 (strongly agree / totally confident); Yes/No responses; and open-ended questions or comments. The topics of these questions focused on student attitudes toward science learning, chemistry, and preferred aspects of the project experience. The open-ended questions and comments asked for feedback about the activity, what students enjoyed about the activity, and how the activity could be improved in the future.

Project curriculum and design

The goal of the current research-practice partnership project is to expand the role of research in improving education practice (Coburn and Penuel, 2016) in terms of chemistry skills, knowledge, and identity as well as to educate the community about what is in our drinking water and how to help keep drinking water sources clean in our communities.

Water was selected as the main theme of the semester-long project to build upon students' lived experiences, provide meaningful opportunities for learning, and build natural connections within existing course curricula. Using constructivism and funds of knowledge as framework, the project is designed to make sense of prior and new knowledge, including cognitive learning, affective learning, and psychomotor learning (Novak, 2010). Students bring with them funds of knowledge from their homes that can be used for concept and skill development, while teachers focus on helping students to find meanings in activities (Moll et al., 1992). For post-secondary students that are registered in Analytical Chemistry II, one of the learning outcomes is to develop hands-on skills and the ability to execute analytical skills to achieve accurate and precise results. For K-12 students, the grade 8 Alberta Education curriculum includes a unit on Freshwater and Saltwater Systems (Alberta Education, 2014). A goal of the project is for both groups of students to learn from each other: post-secondary students gain insights on lesson planning during their dissemination and communicating with young people while the grade 8 students gain a favorable view of science, the post-secondary institution, and chemistry after a hands-on experience. Thus, this project is designed to fit the learning requirements for both groups of learners in order to maximize their learning opportunities.

In the project's initial implementation, both post-secondary students and their K-12 students worked separately to determine various physical and chemical properties as well as Total Dissolved Solids in the water fountain from the K-12 students' school. The K-12 students were provided a protocol with the addition of an in-house educational video on how to collect water samples properly and how to conduct some of the water testing. Collectively, based on the learning outcomes of the Alberta Science Education curriculum and the Analytical Chemistry II course, both groups of students were asked to complete an open-ended worksheet based on the topics of safety, water, and selected conceptual topics of geography and chemistry. This open-ended approach can develop ideas, creativity, and critical attitudes. Learners may develop a variety of ways to obtain an answer, making the process more important than the result (Romli, 2018).

Using participatory learning approaches as a framework, the project was designed to integrate a real-world context for both post-secondary students and their K-12 students as scientists. This is a valuable aspect of the learning experience because both groups of students gain experience by helping with troubleshooting problems as they arise. The post-secondary students develop transferable research skills by remotely using a post-analysis pre-recorded video conference to introduce the K-12 students to the process of water testing using instrumentation and data analysis. The K-12 students develop lab skills by providing the samples using proper water sampling guidelines and develop data collection skills obtaining measurements, within a limited time after sample collection (before degradation occurs), for data such as appearance, odor, pH, and turbidity. Collaboratively, both post-secondary students and their K-12 students compare the experimental data from the school samples and the city's water treatment plant's annual report using the mapping system to match results appropriately.

Considering the physical distance between our institution and the K-12 students' schools, the requirement for post-secondary students to undergo background checks to enter the partner schools, and the cost and resources involved in K-12 students' visiting our site, the decision was made to incorporate technology to facilitate remote interaction, teaching, and learning (Saitta, Bowdon and Geiger, 2011). The technologies used in this project include producing our own educational video, video conferencing, and Geographic Information System (GIS) spatial analysis. The use of educational video is well suited to explain hard-to-visualize phenomena, especially in chemistry. While watching the video, learners can engage with small pieces of new information and control the flow of the new information (Brame, 2016). Studies have shown that the effective use of online videos as a supplement to face-to-face teaching leads to higher student satisfaction with the learning experience and better performance outcomes (Forbes et al., 2016). In this project, educational video was used to introduce how the concentration of various ions in drinking water are determined. Video conferencing was used during the dissemination to the K-12 students. The use of video conferencing expands prospective post-secondary students' didactic and methodological repertoires, building on and developing their abilities to analyse teaching and learning processes (Drexhage et al., 2016). GIS is a field of study that involves data mapping. GIS combines expertise in geography, data analysis, and computing (Mayalagu, Jaafar and Kuok Choy, 2018).

Learners in this project were able to use GIS to explore the concentration of various ions of drinking water across the city. The integration of educational video, video conferencing, and GIS into the project supports transdisciplinarity and allows learners to enhance both cognitive knowledge and spatial thinking skills.

The post-secondary students were assessed using both individual and group components. For the individual assessment, each student was asked to write several purposeful critical reflections at the beginning, during, and after the activity was completed. For the group assessment, there were two parts. The first part was the preparation of dissemination and the second part was an assessment of student accuracy on the hands-on experiment using the known sample concentration prepared by our institution's lab technician. The lab schedule for post-secondary students is shown in Table 2. Labs were scheduled for 4 hours per week and students were required to spend an extra 1-2 independent learning hours for every 2-3 weeks. Students completed their reflective essays and obtained their raw data from the instruments outside of lab hours because the Ion Chromatography process required approximately 3 hours to complete each set of samples.

Table 2 Lab schedule for post-secondary students

/eek	Activity
1	ıeck in & Introduction of CSL
2	ɔw to write critical reflections
3	ater hardness lab & reflective essay 1
4	ו chromatography – known sample concentration prepared by lab technician
5	ו chromatography – K-12 school partner & reflection essay 2
6	omic absorption spectrophotometry - known sample concentration prepared by lab technician
7	omic absorption spectrophotometry – K-12 school partner & reflective essay 3
8	ıta analysis, mapping
9	eparation of pre-recorded video conference
10	deo conference & reflective essay 4

Water analysis activity. During the beginning of the semester, the researcher delivered sampling kits with water sampling procedures to the K-12 students' schools. The water sampling procedure is based on the protocols defined by the Canadian Council of Ministers of the Environment (CCME, 2010). Along with the sampling kits, student worksheets, consent and assent forms, surveys, and envelopes were included. Due to the nature of the short hold time of various parameters in water, careful planning had to be established between the lead researcher and science teachers at the K-12 students' schools to ensure that the water testing was completed within a suitable time frame. In addition to the short testing window, aligning content delivery within the appropriate course curriculum timelines was considered. The grade 8 students were in groups of 2 and were assigned by their science teachers from which of the water fountains in their school to obtain samples. There may have been overlap due to the number of students involved, but it was insured that all water fountains were being sampled. The physical and chemical properties of water were tested on-site, allowing the K-12 students to develop hands-on experience with basic laboratory skills. Then, the water samples were brought back to our institution for the post-secondary students to complete further testing using Ion Chromatography and Atomic Absorption based on in-house protocols modified from the United States Environmental Protection (EPA, 2020[a]; EPA, 2020[b]). Both protocols were developed by the lead researcher's prior Independent Project students. The tested parameters comprised the levels of calcium, potassium, sodium, magnesium, iron, lead, nitrate, fluoride, chloride, and sulfate ions. All ion data were to be collected and analysed within 3 weeks. To ensure that the data provided by post-secondary students were accurate and precise, each group of students repeated the activity twice. The first trial was a known sample concentration prepared by our institution's lab technician and the second trial was the K-12 students' water sample. Because of the large number of water samples involved, each group of students randomly drew three water samples from each K-12 school for full analysis. To promote a productive zone of proximal development (Vygotsky, 1978), students were asked to upload all their raw data and computer-generated graphs on a shared Google Drive with a protected password to compare each other's work supported by appropriate guidance.

In-house educational video. To ensure that both groups of learners understood the theory and practical aspects of how drinking water is collected, tested, and analysed, the lead researcher wrote a script and filmed a video in collaborative partnership with our institution's Academic Media Group and the lecturer of the Analytical Chemistry II course. Elements of active learning were considered during the process of script writing in terms of embedding interactive and guiding questions within the video. Self-regulated learning from educational videos requires learners to monitor their own learning, identify learning difficulties, and respond to these judgments (Brame, 2016). The video was uploaded and is available to watch in YouTube, titled *Adventures in Atomic Absorption & Ion Chromatography*, and emailed to all school partners (Mount Royal University, 2020).

Web conferencing plans and adjusting to pandemic. Our original plan was to have post-secondary students use web-conferencing to present their results to the K-12 students and the larger community. Due to the 2020 coronavirus pandemic, however, our institution and the K-12 students' schools were physically closed during the dissemination period. Therefore, instead of being completed by both groups of students, the lead researcher entered the experimental results into a database on a geo-mapping software using ArcGIS (Ho, 2020[a]). For dissemination, post-secondary students pre-recorded themselves via video conference to present their results, and the recordings were uploaded to YouTube, titled *Analytical Chemistry II Oral Presentation* (Ho, 2020[b]). All 14 post-secondary students contributed to the video conference. In it, they compare their experimental data with the annual summary of water quality provided by the local water treatment plant (Statistics Canada, 2019). Using division of labor, groups of post-secondary students were assigned to go over particular questions in the open-ended worksheet provided to the K-12 students earlier. The resulting feedback became part of the pre-recorded video from the post-secondary students to the K-12 students. This was a follow up communication to the assigned worksheet from the post-secondary students to the K-12 students. Post-secondary students participated in civic engagement by sharing their test result findings with the K-12 students and educating the K-12 students on the importance of having clean drinking water and what it means to have clean drinking water.

Data analysis

Response Rate. A total of 14 post-secondary students and 400 grade 8 students received the post-instructional surveys. From these, 8 post-secondary students and 123 grade 8 students participated, giving a response rate of 57.1% and 30.8% respectively.

Quantitative Analysis. Data were analysed using Microsoft Excel and analyses were performed to examine how post-secondary students and K-12 students perceive this activity in general and how it affected their self-confidence levels. The post-secondary and K-12 students' student surveys contained 37 and 5 questions respectively. Most of the sub-questions consisted of several items where participants could indicate their level of agreement. The use of a 5-step Likert scale with a neutral option was provided for answers. A neutral option was included because omitting the neutral option might force our participants to have an opinion, thus jeopardizing the validity of the conclusions.

Qualitative Analysis. The open-ended questions in the surveys for the K-12 students were coded using the data analysis software program NVivo Version 12 (QSR International Pty Ltd., 2018). The researcher began with open coding of the response data following the constructivist grounded theory method (Charmaz, 2014). The responses revealed five emergent dominant themes in terms of how students related to the activity: hands-on learning, authentic learning, inquiry learning, kinesthetic learning, and interpersonal learning. Each of these emerging themes was defined in a coding dictionary prior to the coding process to encourage consistency. The data were coded twice using the same definitions with a two-week time difference. Using an investigator triangulation, the data was coded first by a researcher and then by the lead researcher two weeks later. The intrarater reliability was determined by using the intraclass correlation coefficient (ICC) (Kegeles et al., 2000). The choice of method allows the reliability to be compared within and between categories. The ICC was calculated based on the total number of responses in each theme for both sets of time. The coding for the five learning strategies showed substantial intrarater reliability with an agreement rate of 0.96, where -1 is perfect negative correlation, 0 is no correlation, and 1 is perfect correlation.

Results

Finding 1. Post-secondary students and K-12 students expressed favorable enjoyment, attitudes, and interests towards learning chemistry.

We expected that the post-secondary students might be more resistant to the semi-structured lab setting because most students have had limited previous experiences with this type of pedagogy. According to the post-secondary students' survey responses in Table 3, however, 6 students (3 "strongly agree" and 3 "agree") indicated that they enjoyed in the course. Furthermore, 5 students indicated "strongly agreed" and 2 students "agreed" that they were excited to do chemistry. When students are excited to do chemistry in the lab, it motivates them to learn more on the subject matter (Saribas and Bayram, 2009). One student commented on how this project was meaningful to them as an individual and how the constructivist learning approach used as a teaching pedagogy helped to develop and enhance their scientific skills.

> I really enjoyed the CSL project and felt like it was a better representation of a professional lab than my previous labs. I feel like it has helped me grow as a scientist and a person. (Student A, survey, April 2020)

Overall, as a result of the positive experience of this lab activity, at least 5 post-secondary students (3 "strongly agree" and 2 "agree") agreed that they would consider taking further chemistry courses that have a CSL lab component. Similarly, 89.0% of K-12 students also expressed an interest in further future partnerships as shown in Table 4. Thus, there is a strong alignment in both groups of students that shows positive impacts from their experiences with the water project.

Table 3 Post-secondary student survey responses for developing favorable interest (n=8)

When I performed experiments in my chemistry lab this semester, I…	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Perceived enjoyment of this course.	3	3	1	1	0
Was excited to do chemistry.	5	2	0	0	1
Consider taking another chemistry course that has a CSL component.	3	2	2	0	1

Table 4 K-12 student responses towards expressing interest in future partnership (n=123)

Question	Yes	No	Abstained
Would you participate in another project with MRU if there is an opportunity?	109 (89.0%)	11 (8.9%)	3 (2.4%)

Finding 2. In terms of aspects of the project they reported liking the most, post-secondary students reported being engaged and developing cooperative skills most frequently while K-12 students reported hands-on learning aspects of the experience most frequently. In terms of aspects of the project that the students emphasized liking the least frequently, the post-secondary students least frequently reported critical thinking while the K-12 students least frequently reported interpersonal skills.

This project is structured to allow students to learn to work in a group and develop skills such as the willingness to collaborate, transferring knowledge within the group, and working out interpersonal dynamics. 7 post-secondary students liked that this project allowed them to be more engaged and able to develop these cooperative skills. The development of a group attitude was also highlighted in the open-ended comments.

> This was a very nice way to handle labs. I think if there are more labs where there is a final end goal, and everyone is allowed to just work with everyone else in the lab, science would be more fun. (Student B, survey, April 2020)

Another aspect of the project focused on developing a group dynamic through the participatory learning approach with the K-12 students. 6 post-secondary students expressed enjoying this type of learning environment as they felt it more fun to engage with learners outside their institution. This sentiment was also supported by the open-ended comments. “It was more participative than other things we’ve done and more fun” (Student C, survey, April 2020).

Table 5 Post-secondary student survey responses for preferred pedagogy (n=8)

When I performed experiments in my chemistry lab this semester, I…	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Enjoy this participatory learning approach.	3	3	2	0	0
Feel more engaged.	2	5	1	0	0
Develop cooperation skills.	3	4	1	0	0
Practice professional competence in a research environment.	3	3	2	0	0
Make decisions about what data to collect.	1	3	1	3	0

The lowest results came from the question on “make decisions about what data to collect” (1 “strongly agree,” 3 “agree,” and 3 “disagree”) as indicated in Table 5. During this water analysis activity, through interactions with group members and reflections, students could attain cognitive skills such as scientific thinking. The types of decisions on data collection that were required eliminated any outliers in the data collection and identified types of errors associated in the lab experiment. This may be due to two reasons. Most likely, the low results on data collection decision making are due to the little previous experience in this type of learning environment. Some students may find it challenging to accommodate the change from instructionism in their first-year lab to constructivist learning in their second-year lab. Post-secondary students typically spend most of their time in labs on data collection, data analysis, and presenting their findings. They usually don't have time to pose questions on their own.

The K-12 students' responses to the question "What did you like about this project?" are summarized in Table 6. The frequency indicates how often the comments were coded into the different aspects of the project, which resonated with the students. The grade 8 students most often mentioned hands-on learning because it helped them to feel more engaged and stimulated and to want to learn more (42.4% of comments). Engagement in an authentic task also appealed to many students (23.0% of comments), as did being able to be physically engaged (11.5%) and the opportunity to engage in inquiry (9.7%). Interpersonal learning was the least mentioned aspect of the experience for the K-12 students (with a frequency of 3.5%). This may be due to the pandemic, where the grade 8 students were not able to interact with post-secondary students via web-conferencing during the later parts of the project.

Table 6 K-12 student survey responses for the preferred pedagogies (n=123)

Teaching	Definition	Representation quotation	Frequency
Hands-on	Learning by physically handling the subject matter and witnessing the results (Sullivan, 2009).	"I like testing the water and see the different outcomes."	42.4%
Authentic	Increased sense of meaningfulness obtained by using real-life subjects during the learning process (Hofstein and Lunetta, 1982).	"I liked the fact that it was testing things we use every day."	23.0%
Kinesthetic	Using physical, full body movement to develop understanding and skills (Frey, 2018).	"We got to move around the school instead of sitting in class."	11.5%
Inquiry	Learning by developing questions of interest and pursuing the answers (Caliskan, 2012). The topic of interest may be facilitated by a third party (An, 2015).	"I like trying to figure out what is in the water."	9.7%
Interpersonal	Gaining social skills and an understanding of self by interacting with others (Leong, 2008).	"I like that we got to work with other people, and it was pretty interesting."	3.5%

Note. The frequency was calculated out of 113 responses (28.0% response rate).

Finding 3. Both groups of learners self-reported that their self-confidence levels on lab skills increased through participating in the activity.

Post-secondary students self-evaluated that their confidence levels on lab skills and problem-solving skills improved through this project as indicated in Table 7. Lab skills include lab safety, the use of equipment, record keeping, and measuring weights and volumes of chemicals. Post-secondary students felt "totally confident" (3 students) and "confident" (4 students) to complete tasks in the lab setting. When working with equipment, 5 post-secondary students felt confident or totally confident.

Table 7 Post-secondary student survey responses for confidence level (n=8)

When I performed experiments in my chemistry lab this semester, I...	Totally confident	Confident	Moderately confident	Slightly confident	Not confident
Developed confidence in the laboratory.	3	4	0	0	1
Was confident when using equipment.	1	4	2	1	0
Felt confident about the purpose of the procedures.	0	4	2	2	0

Table 8 K-12 student survey responses for confidence level (n=123)

Please indicate how confident you feel about...	Totally confident	Confident	Moderately confident	Slightly confident	Not confident	Abstain
Determine pH value.	36 (29.3%)	55 (44.7%)	26 (21.1%)	5 (4.1%)	0	1 (0.8%)
Explaining something that you learned in this project to another person.	12 (9.8%)	35 (28.5%)	48 (39.0%)	21 (17.1%)	7 (5.6%)	0
Use ArcGIS and look up a specific value.	18 (14.6%)	26 (21.1%)	40 (32.5%)	24 (19.5%)	14 (11.4%)	1 (0.8%)
Learn chemistry theory.	4 (3.3%)	25 (20.3%)	50 (40.7%)	34 (27.6%)	8 (6.5%)	2 (1.6%)
Look up elements using periodic table.	35 (28.5%)	37 (30.1%)	31 (2.4%)	16 (13.0%)	3 (2.4%)	1 (0.8%)

As shown in Table 8, K-12 students reported that their self-confidence levels were in general moderate to high in terms of practical and scientific skills. The practical skills involved handling chemicals, learning proper standard operating procedures, and measuring the solvent precisely and accurately. Scientific skills involved observation and interpretation, such as measuring pH value, which students reported feeling confident in conducting (74.0% with 29.3 % “totally confident”, and 44.7% “confident”). K-12 students also reported feeling somewhat confident in explaining how drinking water was tested after the activity (38.3%, with 9.8% “totally confident” and 28.5% “confident”). The students felt less confident, however, about the GIS software. The survey responses for GIS were spread across the full scale, with nearly as many reporting “not confident” and “slightly confident” (31.3%) as reported “totally confident” and “confident” (35.7%). The largest percentage of the students in a single category reported “moderately confident” (32.5%). We hypothesize that this is due to the fact that the students were learning the software from the pre-recorded conference on YouTube at home during the pandemic whereas they engaged in the other aspects of the lab together at school. Furthermore, K-12 students reported feeling “not confident” (6.5%) and “slightly confident” (27.6%) in learning theoretical chemistry, such as chemical bonding and chemical reactions. This may be because students are first introduced to the subject of chemistry in grade 8 based on the Alberta Education curriculum (2019). In general, the K-12 students reported feeling more comfortable in the rote scientific tasks and less comfortable with the theoretical aspects behind those tasks.

Finding 4. Post-secondary students reported that they were engaged in critical thinking and practical application of chemistry skills in this water project.

Post-secondary students self-evaluated that this water project allowed them to learn and evaluate themselves critically (7 “agree”) as indicated in Table 9 even though they reported critical thinking least frequently as a resonant aspect of the project in Table 5. An important aspect of critical thinking in this context involves students taking the initiative to teach themselves the subject matter when students identify a problem that requires new information and to evaluate their self-directed study and problem-solving skills prior to presenting. Furthermore, 1 post-secondary student self-reported “strongly agree” and 6 “agree” that this lab activity helped them build awareness of the real-world contexts of chemistry.

Table 9 Post-secondary student survey responses for what they have learned in the activity (n=8)

When I performed experiments in my chemistry lab this semester, I…	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Learned critical thinking skills.	0	7	1	0	0
Learned problem solving skills.	1	5	1	0	1
Learned chemistry that will be useful in my life.	1	6	0	0	1

Discussion

Summary of the results and answers to the research questions

RQ 1 and 3: On completion of the CSL project, both groups of students reported that this project provided a positive experience and increased confidence levels towards learning chemistry. A positive learning experience and the feeling of confidence can motivate students to learn more, which can result in higher performance levels and academic success (Knox, Gillis and Dake, 2019; Ferrell and Barbara, 2015; Besterfield-Sacre et al., 1998). In this project, confidence levels and engagement were also demonstrated through the willingness of the post-secondary students to spend long hours in the lab in order to obtain good results to present to the K-12 students.

The open-ended questions or comments in the post-instructional survey allowed post-secondary and K-12 students to speak for themselves, providing researchers with rich data. Academically, both groups of students were able to make connections with what they had learned previously in other disciplines and their lived experiences in real-world situations. Furthermore, post-secondary students reported advancing their scientific knowledge through engaging with the lab activity as well as the development of technical skills such as the use of different instrumentation, the ability to explain chemistry phenomena to K-12 students, and enhanced thinking and planning. Critical thinking is important to students as part of the analytical skill of recognizing aspects of experimental data that inform their conclusions (van Brederode, Zoon and Meeter, 2020). In the open-ended comments, post-secondary students reported that this CSL project supported these outcomes to a much greater degree than the typical expository experiments from lab manuals to which they are accustomed.

RQ 2 and 4: Post-secondary students reported that this CSL project helped them be more engaged and develop cooperative skills while K-12 students reported liking the hands-on experience the most. In terms of what they liked least, the post-secondary students reported critical thinking while K-12 students reported interpersonal skills. In chemistry, enhancing students' sense of the meaningfulness of their projects is essential because science is a process-oriented field that requires effective problem solving (Lieber and Graulich, 2020). Overall, both groups of students expressed favorable enjoyment, attitudes, and interests towards learning chemistry. Furthermore, post-secondary students developed a sense of what is involved in being a professional scientist from this CSL project.

Moving forward, we would like to investigate post-secondary and K-12 students' metacognitive learning during the CSL project in terms of self-efficacy from personal, academic, and civic engagement perspectives. Students will write critical reflections before, during, and after the activity in order to reflect on potential gaps in knowledge and practice with the intent to improve on both. In addition to what is demonstrated directly through the data, the data also suggest other important affective outcomes of the project in terms of learners' experiences. Through this water activity, students reported developing a group feeling, responsibility to others, and interpersonal relationships. Through sharing experiment data between groups, the students supported each other and co-constructed understandings of chemistry concepts and communication skills (Heeg, Hundertmark and Schanze, 2020; Lawrie et al., 2016). We are also interested to learn if there are any unintended outcomes of how this CSL project influenced students, such as whether their career choices were affected in terms of their aspiring to be chemists or science teachers after completing this project. These affective outcomes around collaboration and community will also be a focus of future work for this project.

Conclusions

CSL projects involve student-community engagement and incorporate the academic with the experiential. The current project is broadly collaborative, engaging faculty colleagues and schools, post-secondary students, and K-12 students. The structure is technology-rich, inquiry based, and collaboratively participatory. Technology can enhance students' learning, retention of knowledge, and attitude about learning science (Pekdağ, 2020; Watson, Dubrovskiy and Peters, 2020; Kelly and Akaygun, 2019). Post-secondary students are provided with an opportunity to learn about civic engagement and academic and social skill development. The lab activity involves educating post-secondary students to develop a sense of responsibility through teaching and learning with the K-12 students and facilitates skill development (Fredericksen, 2000; O'Hara, 2001; Groh, Stallwood and Daniels, 2001). Post-secondary students learn chemistry concepts, acquire lab skills, and understand the importance of cleanliness in drinking water. For the K-12 students, it is an opportunity to build an interest and a natural curiosity about the world and to learn more about science through facilities that may not be available in their classrooms. Recent studies show that declining numbers of young people are choosing to pursue careers in science (Kahveci, 2015). It is also anticipated that the project may encourage some young learners to begin to consider higher education as an achievable goal by allowing them to interact with post-secondary students. Based on the data from post-instructional surveys, we argue that this CSL project can provide positive impacts for both post-secondary and K-12 students in the community that result from the mutual benefits of the partnership.

Implications for Practice and Research

All the experimental data generated could potentially be shared through a database such as a geographic information system under a creative common licence. Furthermore, this CSL approach was found to take longer to apply in comparison with a set of traditional laboratory practices. The additional time requirement, however, occurs mainly for the preparation during the first year of implementation. For those who are interested in implementing a similar CSL project at their institutions, there are minor expenses for the post-secondary institution to support the project (e.g., photocopies of the sampling procedures and for travel (e.g., dropping off and picking up of the water samples). These costs are quite manageable, though, considering the potential benefits for the post-secondary students, K-12 students, and relationships between the post-secondary institution and the community.

Conflicts of interest

There are no conflicts to declare.

Appendices:

Exemplary samples of post-secondary students' surveys and K-12 students' worksheets, sampling procedures, and surveys are provided in the Appendix. Interested parties may contact the corresponding author to request the full version of the materials.

Appendix 1: Exemplary samples Post-Instructional survey for post-secondary students

In relation to the CSL project, I…

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Perceived enjoyment of this course.					
Consider taking another chemistry course that has a CSL component.					
Enjoy this participatory learning approach.					
Experiencing work overload, but also a sense of accomplishment.					
Enabling self-awareness and reflection.					

Feel more engaged.

Depth of learning is more in comparison to other non-CSL project.

Practice professional competence in a research environment.

Open comments.

Appendix 2: K-12 students' worksheets

Group Name: ________________________________

Assigned Element: ________________________________

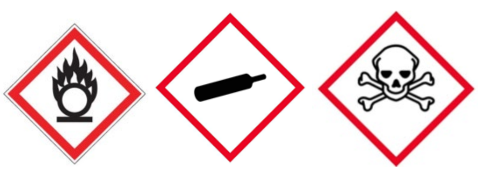
Grade 8 students' worksheet

Elements: Calcium, Potassium, Sodium, Magnesium, Iron, Lead, Nitrate, Fluoride, Chloride, Sulfate

1. Where is your assigned element found in nature?
2. Where is your assigned element on the periodic table and what are some scientific facts about this element?
3. What are some interesting facts about your assigned element?
4. How much of your assigned element was found in the water from Bearspaw/ Glenmore Treatment Plant?

Safety:

5. What does "WHMIS" stand for?
6. What is MSDS and what is the purpose of it?
7. What do the following symbols stands for?



Water Sampling:

8. How does the temperature of water affect its ability to hold oxygen? (warm vs cold)
9. What would be the pH values (above, at or below 7) of the following:
   Fresh Water: Milk:
10. How do the following become dissolved in water?
    Nitrates:
    Iron and copper:
    Calcium and magnesium:

Mix and Flow of Matter:

11. If apple juice, soy sauce and jam were mixed together. What kind of substance was made? A) Element b) mixture c) molecule
12. The universal solvent is ________. A) acid b) base c) water d) fluoride
13. The ability to dissolve in a particular solvent _______.
14. 2 or more pure substances which appear to be one _______.

Atomic Absorption:

10. Which components make up fire?
11. At what temperature does paper burn?
12. How hot is a wood bonfire?
13. What temperature is a fresh lava flow from a volcano?
14. Atomic absorbance measures the concentrations parts per million (ppm), what is ppm equivalent to? A) mg/L b)g/L c)g/mL d)ug/L

Geography:
Procedure:
Open 'https://arcg.is/01bGSv' on the computer and sign-in.
a. Click on 'water project' and open in MapViewer.
b. Under search at the top right-hand corner, enter the address "825 Mt Royal Gate SW, Calgary, Alberta, T3E 6K6, CAN"
c. Click on the (·)
10. What is the concentration of <u>your assigned element</u> at Mount Royal University?
11. What is the concentration of <u>your assigned element</u> at the Treatment Plant?
12. Do you expect that the concentration of <u>your assigned element</u> is same/higher/lower than the Treatment Plant? Why?

Appendix 3: K-12 students sampling procedures

Group members: _____________
Letter of Sample: ________

A. Sampling Method
1. Check for the correct sample tube and label.
2. Record location of where sample is taken.
3. Record time of when sample is taken.
4. Turn on cold water tap at maximum flow and start timing.
5. Let water flow for 30 seconds then take sample
6. Open cap of the sample tube.
7. Keep holding the sample tube cap in one hand while sample is being collected to ensure it does not come into contact with anything to avoid contamination.
8. Fill the sample tube carefully to prevent overfill (Figure 1).
9. Carefully put the cap back on the sample tube.
10. The following should be noted during sampling:

i. Never rinse the tube; the sampling tube shall be so held that the water does not come in contact with the hand before entering into the tube.
ii. Make sure that all samples are correctly labeled (sampling location, time).
iii. Store water samples in iceboxes with freezer packs to be picked up to test in laboratory for the next day.

(B) Please take note of the conditions of the water
1. Take pH of the sample with litmus paper. Record color of litmus paper and the pH range.
2. Record physical qualities of water (example is the water cloudy? Does it have a smell?

Figure 1
Fill the sampling tube carefully to prevent overfill.

Observations:
Location Sample was taken
Time Sample was taken
Physical Observations
pH of Sample

Appendix 4: Post-Instructional survey for K-12 students

Please indicate how confident you feel about…

1. Explaining something that you learned in this project to another person.

   1 2 3 4 5

   Totally confident Not confident

2. Learning chemistry theory.

   1 2 3 4 5

   Totally confident Not confident

3. Determine pH value.

   1 2 3 4 5

   Totally confident Not confident

4. Use ArcGIS and looking up value.

   1 2 3 4 5

   Totally confident Not confident

5. Look up elements using periodic table.

   1 2 3 4 5

   Totally confident Not confident

6. This CSL project inspire my interest in taking Chemistry in the future.
   - Strongly Disagree
   - Disagree
   - Neither/Nor Agree
   - Agree
   - Strongly Agree
7. This experiment was interesting.
   - Strongly Disagree
   - Disagree
   - Neither/Nor Agree
   - Agree
   - Strongly Agree
8. Would you participate in another project with MRU if there is another opportunity?
   - Yes
   - No
9. What did you like about the project?
10. What did you not like about the project?
11. Any other comments you would like to share with us?

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