ARTICLE

Different Strategies to Facilitate Meaningful Reflections Among Post-Secondary Students in a Community Service Learning Water Project

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Karen Ho,*[a] Sahara R. Smith[b] and Douglas B. Clark[c]

This study explored how continuous diverse reflective exercises embedded in a Community Service Learning chemistry lab support science students' meaningful learning. The findings of this study are intended for those involved in teaching natural science in higher education, as well as those interested in Community Service Learning, self-directed learning, and reflective strategies. Fourteen students in a second-year Analytical Chemistry II lab participated in this study. Reflective exercises representing multiple modes of reflection were purposefully designed and embedded across the lab curriculum. Qualitative content analysis of data from reflective writings, scrapbook reflections, and reflective discussions demonstrates that students were able to articulate their self-directed learning from the perspective of academic enhancement, personal growth, and civic engagement in the different reflective exercises. Students indicated a high level of satisfaction, agreed that the integration of diverse continuous reflective strategies can enhance their transformative learning practice in an engaging way, and would like to continue this practice for other science laboratory courses.

Introduction

Post-secondary chemistry can be a difficult subject due to the nature of the concepts involved and the potential for misconceptions (Agustian, 2022). Furthermore, the structure of traditional first and second-year chemistry lab experiences places little emphasis on student thinking (Woldeamanuel, Atagana and Engida, 2014; Domin, 1999; Majerle, Utecht and Guetzloff, 1995). Student thinking includes the combination of students' preconceptions, existing knowledge, understanding of the content being taught, and application of synthesis (National Research Council, 2000; Özden, 2008; Szozda *et al*., 2022). Typically, students meet once a week to conduct prescribed experiments that emphasize specific procedures, reproducing a predetermined result (Bretz, 2019). Accordingly, students are often unmotivated to learn chemistry (Hofstein and Lunetta, 1982; Hunter, Wardell and Wilkins, 2000; Alaimo, Langenhan and Suydam, 2014; de Souza *et al.*, 2022). One strategy to facilitate the integration of applied learning pedagogies to help students become self-directed learners is Community Service Learning (CSL)(Ash and Clayton, 2009).

Community Service Learning (CSL)

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, 2010). For the purpose of this study, we define CSL as a form of experiential education that integrates community service with instruction and reflection (National Service-Learning Clearinghouse, 2011; Ho, Svidinskiy, *et al.*, 2021). Experiential education includes learner's perception, cognition, experience, affect, behavior, and learning (Mackenzie, Son and Hollenhorst, 2014). The goal of CSL is to build a mutually beneficial partnership for students and their community partners (Ash and Clayton, 2009). Within CSL, student behaviour, experiences, and course-aligned reflection restructure and deepen student understanding of essential course concepts (Clayton, Bringle and Hatcher, 2013). Research has shown that students are able to successfully attain the expected learning outcomes and understand societal issues when chemistry lab courses integrate CSL (Tomat, 2020; McGowin and Teed, 2019; Miller and Yen, 2005). This is because students in CSL labs use the knowledge they acquire in the classroom to solve specific community needs in a manner that deviates from traditional prescribed experiments.

Reflection in CSL

As part of the CSL process, students examine their experiences critically and articulate specific and actionable learning outcomes through guided intentional reflection. Reflection infuses "students' subjective experiences, thoughts, and feelings into content-oriented work" (Molee et al., 2011, p. 240). Having students reflect is a critical component of the CSL course as it supports them in strengthening their academic, civic, and personal growth (Ash and Clayton, 2009). The value of reflective learning is widely recognized as improving student

[a] Department of Chemistry and Physics, B276(N), 4825 Mount Royal Gate SW, Calgary, AB, Canada. E-mail: kho@mtroyal.ca; Tel:+1-403-440-5919
[b] Department of Chemistry and Physics, 4825 Mount Royal Gate SW, Calgary, AB, Canada
[c] Department of Education, 2500 University Drive NW, Calgary, AB, Canada

achievement. The key is an epistemological shift from the positivist *knowing what* perspective to a reflective *knowing how* and *why* perspective (van Rensburg *et al.*, 2018). The emancipatory relational pedagogical framework of reflection empowers learners by promoting self-direction (Hills and Watson, 2011). Self-direction is a process whereby "individuals take the initiative, with or without the help from others, in diagnosing their learning needs, formulating goals, identifying human and material resources, and implementing appropriate learning strategies" (Knowles, 1975, p. 18). For this study, we define self-directed learning as students' capability to think systematically and construct their own perspectives in order to make learning meaningful and memorable (Gilewski, Litvak and Ye, 2022; Gibbons, 2002).

Reflective practice is an essential component of effective CSL curricular integration. CSL components, however, often lack elements of reflective practice (Cooper, 2006; Bringle and Hatcher, 1999; Brown and Schmidt, 2016). Students are often unfamiliar with reflective practices and have little-to-no awareness of their own autonomy in the reflective process. Depending on the course goals and objectives, reflective exercises can be integrated into CSL individually, with peers, and/or as a group, with community partners. When students reflect individually, their thoughts are respected and invited (Nissilä, 2005). Conversely, a collective reflection involves deep listening to one another and a suspension of one's views (Nissilä, 2005).

Brown and Schmidt (2016) suggest that students can be supported in reflection through four primary modes: Reading, writing, doing, and telling. Each of these can occur before, during, or after a CSL activity. First, reflective reading encourages students to connect the texts they read to the activity in which they will be engaged (McLaughlin, Trounstine and Waxler, 1997). Furthermore, students can respond based on both their own experiences and prior knowledge. Reflective reading fosters student development of monitoring, self-evaluation, and overall reflection skills (Lasker *et al.*, 2017).

Second, writing is potentially the most common approach used for reflection. One strategy that develops reflective writing is the three-column Know-Want-Learned (KWL) chart. These charts can be integrated with specific learning objectives of CSL activities (Ogle, 1986). KWL represents what students *know* about the topic, what students *want* to know, and what students have *learned* after the activity. A KWL chart helps students to self-evaluate their learning. While many forms of KWL charts exist, the KWL chart in this study was adapted from Moll's funds of knowledge (Moll *et al.*, 1992).

The third and fourth reflective strategies are doing and telling. Doing involves collecting learning artifacts and compiling them into a portfolio for learners to reflect upon their work (Brown and Schmidt, 2016). Similarly, telling is a form of narration that helps learners articulate and understand themselves (Brown and Schmidt, 2016). Both strategies are created and structured as group projects that enable students to socially construct knowledge with autonomy and self-expression. Students find doing and telling more enjoyable and beneficial because they bring life experiences into context and support diverse learner needs and preferences (Brown and Schmidt, 2016; Phillips, Bassell and Fillmore, 2017). Across the four reflective modes, students connect with others by sharing their own experiences, thoughts, and emotions. This process can lead to an improved mindset because of the reciprocal approach to learning. The affective element of this study has been documented in students' reflective artifacts.

Relationship to overarching research project and research questions

This research study is the third part of a multi-year project focusing on enhancing post-secondary chemistry labs. The first study focused on post-secondary and K-12 student attitudes in a CSL water analysis activity (Ho, Svidinskiy, *et al.*, 2021). The second study investigated how reflection in the CSL Chemistry laboratory setting affects post-secondary students in their learning (Ho, Smith, *et al.*, 2021). This third study extends from the second study by exploring how different reflective strategies facilitate post-secondary students' meaningful learning by promoting self-directed learning. We define meaningful learning in alignment with Novak's theory of education (1998). He defines meaningful learning as "the constructive integration of thinking, feeling, and acting, leading to human commitment and responsibility" (Novak, 1998, p. 15). In the context of Chemistry Education, this means that true learning occurs when there is an overlap of affective, cognitive, and psychomotor domains in students' thoughts and actions (Bretz, 2001; Galloway and Bretz, 2015; George-Willams *et al*., 2019). For the purpose of this study, meaningful learning thus refers to students' natural motivation based on perceived relevance and connection between what is being learned in the lab class and their personal and life interests (McCombs and Miller, 2006).

While reflection is integral to CSL, there is little research that captures students' learning processes as they engage in different reflective strategies in a CSL science activity. In chemistry education, much of the literature employs only one or two of the four reflective modes, primarily writing and telling, as strategies to support student engagement and academic success in CSL (e.g., Donaghy and Saxton, 2012; McGowin and Teed, 2019). For example, students might write reflective passages in replacement of lab reports (Saitta, Bowdon, and Geiger, 2011). Similarly, students in Donaghy and Saxton (2012) write a reflective paper and participate in an oral presentation. Read *et al.* (2019) focus on integrating reflection in Chemistry labs using photos to reflect on the development of practical skills in the laboratory and talking about marking schemes to self-assess their understanding of organic reactions. We did not, however, identify studies that integrated all four reflective strategies in a CSL lab course to support students' diverse needs in learning. Thus, the design of these multifaceted dimensions of reflective strategies in juxtaposed sequences throughout the course may create an interesting opportunity to reimagine the learning environment of a post-secondary CSL chemistry laboratory. Figure 1 outlines the conceptual framework used in

this study. The cycle begins with the learner bringing their previous experience, perceptions, attitudes, and opinions toward their classroom learning experience. Building on Kolb's (1984) Experiental Learning Theory, each learner goes through a four-stage holistic model that includes learning experience, reflection, abstract conceptualization, and active experimentation. The learner can potentially change their perceptions, attitudes, and opinions in each stage of the cycle. Clearly, different learners will progress through the model in different ways. Learners who engage in the full cycle can enhance their academic, personal, and civic growth, which potentially leads to self-directed and meaningful learning.

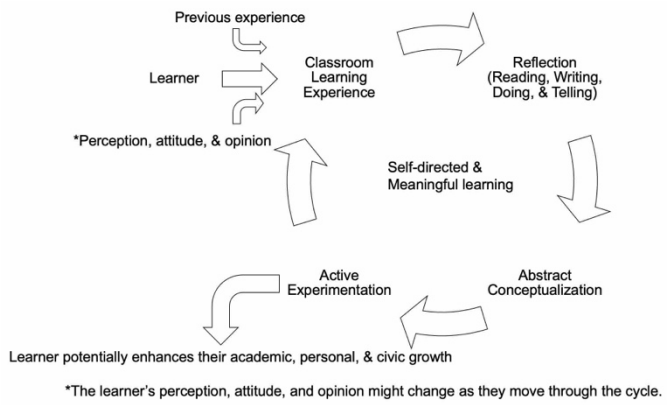


Figure 1 Self-directed and Meaningful learning (adapted from Kolb)

This study aims to evaluate how students develop their awareness of self-directed learning through course-embedded reflection, utilizing different continuous reflective strategies. Using reflective writings, scrapbook reflections, and reflective discussions as exercises and data sources, the research questions are as follows:

1. How do science students feel that the reflective exercises affected or changed their learning experience?
2. What are science students' attitudes toward using each reflective strategy in terms of facilitating their self-directed learning?
3. What are science students' opinions about the group nature of many reflective exercises?
4. How do science students' artifacts demonstrate self-directed learning in terms of academic enhancement, personal growth, and civic engagement?

Methodology and methods

A qualitative content analysis methodology was selected for this study. Data include both text (reflective writings and reflective discussions) and visual images (scrapbook reflections).

Participants

A purposive sample strategy was used from students who were registered in Analytical Chemistry II during the winter 2021-22 semester in a mid-sized institution. Twenty-three students were enrolled in this course, which was further divided into two lab sections. There were fourteen students who participated in this project, giving a response rate of 60.9%.

Ethics considerations

This study was approved by the Institutional Faculties Research Ethics Board (Ethics clearance number: 101819). All students were informed about the purpose of the research and the ethical issues of ensuring the protection and confidentiality of participating in this study.

Design and procedures of the study

The current study engages students individually and collaboratively through all four of Brown and Schmidt's modes (Table 1).

Table 1 Reflection map for the CSL water project

	Before CSL activity	During CSL activity	After CSL activity
Reflect individually	Writing	Writing	Writing
Reflect with peers	Reading	Doing	Doing & Telling
Reflect with community partners	-	-	Telling

Students registered in the Analytical Chemistry II class were provided with a lab schedule, as shown in Table 2. All reflective exercises were embedded in the course. The lab component had a 50% weighting that includes instrumentation techniques and different reflective exercises. The lecture component had the other 50% weighting that includes homework assignments and exams.

Table 2 Lab schedule for Analytical Chemistry II course

Week	Lab Schedule	Reflective exercises
1	Check-in & Introduction of CSL	
2	Online lab	
3	Reading – Reading circle	Writing – Individual reflective writing exercise: KWL Column 1 – What you *K*now & 2 – What you *W*ant to Know
4	Water analysis lab I	
5	Water analysis lab II	
6	Workshop on scrapbooking	1. Writing – Individual reflective writing exercise: KWL Column 3 – What have you *L*earned so far 2. Doing – Joint scrapbook exercise

7	Water analysis lab III	
8	Water analysis lab IV	
9	Video conference preparation	
10	Telling – Oral presentations	1. Writing – Individual reflective writing exercise: KWL Column 4 – What have you *L*earned throughout the semester 2. Doing – Completion of joint scrapbook exercise
11	Telling - Reflective discussion	

Data collection

A variety of data was obtained to collectively provide validity of how post-secondary students articulated their learning through reflection using different strategies.

Reflective writings. To capture individual voices during the CSL activity, a three-column Know-Want-Learned (KWL) chart was provided as shown in Table 3. Students completed each question in full sentences with approximately 200-300 words per table cell. We developed the textual prompts in the first column of Table 3 to correspond with Ash and Clayton's (2009) three categories of desired learning outcomes of CSL. They are academic enhancement, civic engagement, and personal growth. In addition, we considered and modified these textual prompts based on our previous phase of the study (Ho, Smith, *et al*., 2021). Students were asked to complete columns 1 and 2 of the Know and Want to know columns (the K and W in K-W-L) in Week 3 and columns 3 and 4 of what they had Learned (the L in K-W-L) in Weeks 6 and 10 respectively.

Table 3 Sample of student's KWL reflective writing exercise

	Column 1	Column 2	Column 3	Column 4
	Record everything you know about the topic	Record what you want to know	Learning process – What you have learned so far	Learning product – What you have learned throughout the semester
Identify and explain what you have known (or learned) in the lab and what CSL means to you.				
How does this project help you improve your individual well-being?				
Discuss 2 things that you will need to develop (or have developed) for this project.				
Open comments that you would like to share.				

Students submitted their reflective writings through an online education platform. Through formative and summative assessments, the lab instructor provided effective, encouraging, and positive feedback to each reflective writing to deepen students' learning and improve students' writing and reasoning skills for the future.

Scrapbook reflections. To promote group reflection, students created digital scrapbooks in small peer-selected friend groups. The lab instructor hosted a workshop in Week 6 to introduce students to the process of expressing themselves through scrapbooks. This includes the sharing of experiences, thoughts, and emotions. Using Canva, a digital scrapbook software program, students documented their CSL experiences, expressed their feelings, and articulated meanings from the process. Students used a combination of photographs, quotations, drawings, pictures, and other media. Students were asked to provide a short description, supporting the lab instructor in understanding their perspectives.

Reflective discussions. Small group reflective discussions bring together people with different perspectives (Cohen, Manion and Morrison, 2017). The lab instructor divided the students into groups of three to four. One-hour Google Meet discussions were scheduled. Four open-ended questions explored how different innovative and creative reflective strategies might support students in developing thinking and reasoning skills. The questions were:

> Of all the reflective strategies, which one was *most* preferable and why?
>
> Of all the reflective strategies, which one was *least* preferable and why?
>
> How did the different reflective strategies facilitate your learning?
>
> How did your learning unfold over the course of the semester?

Data analysis and procedure

A qualitative content analysis approach was employed to analyze the data (Elo and Kyngäs, 2008; Elo *et al.*, 2014; Bloomberg and Volpe, 2018). All participants had their names replaced with alphanumeric codes for confidentiality. The research team involved the lead researcher and an undergraduate research assistant. For RQ1-3, an inductive coding approach was used from reflective discussions to collect students' attitudes toward the different reflective strategies that affected their learning experience in a lab course. To be more specific, rather than deductively applying a coding

scheme, an inductive content analysis was conducted to identify key themes in the data. The data were transcribed using Meet Chat Transcribe; an extension of Google Meet. Transcripts were uploaded to Microsoft Word for data analysis. The lead researcher was responsible for the analysis, and the undergraduate research assistant collaborated in the whole analysis process.

For RQ4, a deductive coding approach was used by student participants in their reflective writing and scrapbook reflections to illustrate their articulation of self-directed learning in terms of academic enhancement, personal growth, and civic engagement. We developed the codes based on research from Molee et al. (2010) and Ash and Clayton (2009) (see Appendix for a list of codes and their sources). The codes for academic enhancement and personal growth were developed by the team based on the work of Molee et al. (2010) and the codes for civic engagement were developed based on the work of Ash and Clayton (2009). Microsoft Excel was used as a repository for the database and was organized into individual cells with their accompanying codes. The lead researcher randomly selected several reflective writings and scrapbook reflections for each researcher to code individually. The intraclass correlation (ICC) was determined to be 0.83 by using intercoder reliability. The intercoder reliability divided the number of agreements by the total number of agreements plus disagreements. In this process, 1 indicates a high level of agreement between the ratings and 0 indicates no agreement shown between ratings amongst the coders (Miles and Huberman, 1994).

Results

The results are organized by research question with data being presented.

RQ 1. How do science students feel that the reflective exercises affected or changed their learning experience?

Students expressed that the integration of reflective exercises helped to cultivate a shift in their learning habits toward becoming more self-directed. They were more motivated because the reflective exercises built upon their own interests, intentions, and goals. Furthermore, students liked that these reflective exercises guided them to think slowly.

> 06: *Learning with reflection was a slow process, but I understood the content better. In other chemistry classes, I felt like I didn't understand what was going on in the lab all the time. For example, in [my earlier chemistry class], when people asked, "What are you doing in the lab today?" My response usually was "Oh, I don't know, some experiment". However, for this CSL activity, I could explain the process to people. I could explain why it's important and I would want to talk about it, for like, multiple minutes. Just for fun, not necessarily for school.*
>
> 07: *Reflective exercises, like scrapbook reflections and reflective discussions, push me to learn new topics and work harder [in comparison to writing traditional lab reports].*
>
> 20: *I think it [the lab] was well planned out because of my previous online lab experiences due to Covid… I was able to conduct experiments and then reflect upon them. The diverse reflective exercises were introduced in a step-by-step format which, as a learner, became more comfortable and engaging over time.*

All students (14 out of 14 students) expressed to varying degrees that reflection enhanced their knowledge, learning, and capabilities. Many said that having reflective exercises in a CSL laboratory helped them to develop their 'self' in terms of self-awareness, self-acceptance, and holistic self in the learning process. Student 06 explained, for example, that they struggled in other chemistry labs to understand and remember the concepts being taught because they didn't have reflective activities. This is echoed by Student 07's comment that reflective exercises boosted their motivation to learn more and work harder to fulfil their course obligations.

The reflective exercises assisted students by spurring them to think about their study habits, such as creating or innovating, and learning how to learn. Student 20 indicated that introducing a wide variety of reflective exercises in a step-by-step format was very effective. The variety and format helped them to be more comfortable and engaged in learning. They reported that they paid more attention to the learning process and perceived a deeper connection to the concepts being taught. Despite the fact that learning with reflection takes more time and requires deeper thought than what academic assignments typically require, students found themselves more engaged in their learning. Both Students 06 and 20 indicated that reflection also brought them positive feelings and a sense of accomplishment. This inner satisfaction motivated them to share their CSL activity with individuals beyond the classroom.

RQ 2. What are science students' attitudes toward using each reflective strategy in terms of facilitating their self-directed learning?

During the reflective discussions, students were asked which reflective strategy they liked the most and least. The students expressed a range of preferences. Students discussed what they liked and did not like about each reflective strategy.

Reading Circle

Many students (11 out of 14 students) indicated that having a reading circle before the service activity provided them with an introductory lesson on reflection and created a sense of community in the classroom.

> 22: *The reading circle provides a greater purpose. It wasn't just like a lab manual. The articles we read actually affect all of us that live here in Calgary.*
>
> 05: *The reading circle is a nice introduction to why we are doing the project [CSL] and how we are going to do it [lab testing and reflection exercises].*
>
> 20: *The reading circle helps us as students to understand the text we read and make sense of what we're going to learn or talk about while discussing with others.*
>
> 07: *It was a nice way to start off the semester with the reading circles as the topic was introduced and I began to know my classmates.*

As shown by Student 22, the reading material helped students see how lab work could be related to real-life applications. Furthermore, as seen in Student 05 and 22's responses, the learning environment in the classroom provided students with

autonomy in terms of purpose (i.e., goals). Students began to ask *why* and *how* they could articulate their bench work with reflective exercises. Student 20 indicated that reading circles helped to make sense of chemistry tasks. Student 07 identified that having students sit in close proximity to one another during a reading circle fostered intimacy.

A few students, however, found a significant challenge engaging in reading circles.

03: *I just don't enjoy reading circles. I felt that it was like a chore that we must do. I guessed that I just wasn't engaged with the reflection.*

21: *Personally, I want to do my own things [reflective writing] and express them on my own time. I am not into talking and don't want to express my reflection out loud.*

19: *Reading circles is the least effective. It does have value if the exercise is done more than once.*

The statements above show that not every student was deeply involved during reading circles. Some students (3 out of 14 students) expressed discomfort with the new modes of reflective information processing when asked to share their thoughts with others. This resulted in one-word answers when discussing questions. In line with structured traditional stepwise teaching in the chemistry labs, students may have expected a linear process in reflective practice. Some of these students may have felt uncomfortable when requested to transition outside their comfort zone. In a subsequent response, Student 19 suggested that they might see reading circles as a valuable exercise if they were encountered consistently across other chemistry courses so that students were more familiar with them.

Reflective writings

Many students (11 out of 14 students) suggested that reflective writing (the KWL chart) was their preferred reflective mode because writing helped them to set clear goals and clarified their understanding of concepts on a personal level.

12: *I feel like reflective writing had a more personal touch to it.*

17: *I think that having reflective writing early in the semester helped me set intentions of my learning goals and how I may navigate the work.*

09: *Documenting my work through reflective writing gives me more clarity on what to work on.*

06: *I liked that reflective writing provides specific questions for me to express and expand my thought[s].*

Student 12 indicated that they liked reflective writing the most because there was an opportunity to gain self-knowledge. They were encouraged to recall their previous knowledge and connect with new information. The process of reflective writing also provided students with a sense of purpose through goal setting that helped them to shift their mindset. During reflective writing, students focus on their thoughts by clearly thinking about the why perspective as shown in Students 17 and 09's responses. Furthermore, Student 06 suggested that the prompt questions provided in reflective writing helped them to broaden their perspective.

Conversely, there were other students (3 out of 14 students) who found reflective writing less effective because of their perceptions about what reflective writings entail.

07: *Reflection is like a regurgitation of information.*

02: *Personally, reflective writing is very challenging. As a science student, I hate to write about my emotions.*

23: *I think the KWL was effective, but less from the perspective of a creative outlet.*

The above statements show examples of common misconceptions about reflective writing that students often have when initially engaging in reflective practices. Firstly, some students perceived reflective writings as simply describing an event. This showed that they, such as Student 07, were at a superficial level of reflective learning. Secondly, students such as Student 02 perceived reflection as a fluffy conceptual idea. Lastly, some students, such as Student 23, did not know that reflective writing can take many forms. Depending on students' experience with reflection, there are different levels and forms of reflective writing that allow students to situate their learning experiences.

Scrapbook reflections

Some students (8 out of 14 students) found scrapbook reflections to be the most engaging reflective exercise because of the autonomy involved.

21*: I enjoyed the scrapbook very much. I can explore ideas about water, learned and explained the concepts.*

20: *The scrapbook tied the connections between theory and CSL activity. I took a lot of meaningful pictures that I further used in my scrapbook. The use of scrapbook reflections can communicate and share my thoughts and feeling[s] in a unique and different way, which I thought was interesting and creative.*

07: *The scrapbook exercise really gives me a driving force to learn new topics. It is the most exciting reflective exercise of all.*

As shown in Students 21 and 20's responses, scrapbooking was an interesting and creative way to organize their thoughts, feelings, and goals. Students shared their experiences by collecting their photos and other artifacts (e.g., poems, songs). The different ways of presenting the work also developed students' multimodal literacy skills toward becoming independent learners. Students expressed greater motivation to learn because they were able to explore scientific concepts by relating them to their own experiences and interests as seen in Students 07 and 20's responses.

The freedom offered by scrapbook reflections was also a limitation. Many students (6 out of 14 students) found scrapbook reflections a struggle because they did not have a tightly bound structure. This lack of structure can be intimidating for some learners with less experience.

12: *Scrapbook was a new experience for me, especially in the science laboratory. Like I've never had that before, and I felt like it was a difficult exercise.*

09: *There's no way I can see myself doing the scrapbook because I would have no idea what I am doing.*

23: *I thought the scrapbook was a little bit difficult because our work was assessed the way it was. I felt that it was very*

subjective. Like it could be purely just an idea, or a random product put into a scrapbook.

18: *Group dynamics is a limitation in reflective discussions. This is because everyone has their own perspective of things, and sometimes it is not a representation of my perspective.*

Many science students did not have experience with scrapbook reflections. For those students who were new to reflection, such as Student 12, they considered scrapbooking a difficult task. This may have been because the student's prior experience with other chemistry labs was surrounded either by typical right-or-wrong tasks or number-crunching kinds of assessments. This was echoed in Student 09's response. Furthermore, Student 23 suggested that scrapbook reflection was very subjective.

Student 18 indicated that discussion during scrapbooking was challenging because different ways of knowing can create a lack of team cohesion. Students who look for only prescribed certainty in science may feel a strong cognitive dissonance when faced with the proposition that differing views may be equally valid. These differing views can still lead to the scientifically correct answer. A key distinction to make is the difference between getting the right answer and understanding how one might get to the answer. Also, students who have not been exposed to this type of personalized learning may not have had experience negotiating meaning within a collective setting.

Reflective discussions

Many students (11 out of 14 students) suggested that having reflective discussion enhanced their learning by talking and listening.

11: *We talked to each other a lot of times to understand how to interpret the data prior to presenting our findings to the community partners.*

17: *At first, I thought the discussion wasn't as effective compared to other reflective practices because I didn't know what was going on. This seemed like all new to me…At first, I was kind of confused, but as the semester went on, it made more sense to me.*

23: *As a student, the reflective discussion feels like I'm being heard and valued because the lab instructor was taking the time out of their day to listen. I think that a lot of people just don't listen enough. This does not just apply in academics but in life in general.*

05: *Going forward, maybe use the extra time after the experiment in the lab to have group discussions on how to make the experiment better.*

13: *Having more group discussions can help expand the topic… Maybe, it will give us more ideas when preparing for the oral presentation for K-12 community partners.*

As Student 11 suggested, the reflective discussion provided them with opportunities for subsequent retrieval of content matter. By talking and listening to each other's perspectives, students co-negotiate and reinforce learning. Comments from Student 17 suggest that these group discussions often acted as an impetus for them to reflect on their own thinking. As Student 23 indicated, students in traditional chemistry labs mainly focused on question-answer exchanges rather than relational and non-instructional aspects of concept learning. As shown in Students 05 and 13's comments, reflective discussions were viewed as excellent opportunities for brainstorming ideas.

Interactions across reflection exercises

While the sections above discuss the reflection exercises individually, students reported that having a combination of different reflective strategies in a lab course positively impacted their emergent learning.

18: *I think they [all reflective exercises] worked together. Like, back when we did the reading circle, that brought into my desire to learn more… The KWL [reflective writings] was good because I built on a foundation that I already started with at the beginning of the semester. That's why we've split it into different columns, right? And the L column at the end of the semester really checks on what I did know before.*

12: *For me, the discussions in the reading circle helped me to initial my thought in terms of what I learned and what I didn't know. Then, I used those pieces of information to write my KWL [reflective writing]. KWL seems to be a more common technique when it comes to reflection. The scrapbook gives me a chance to express everything in a more visual way. So, they worked together.*

02: *I found what was nice and exciting about them [reflective exercises] was that we developed the skills to articulate the same information in different ways.*

These comments indicate that having a combination of reflective exercises, such as reading, writing, doing, and telling, provided students with the opportunity for forward-looking, backward-looking, inward-looking, and outward-looking reflection. These statements also suggest that having diverse reflective exercises can help students understand the interconnectedness of knowledge. Finally, as demonstrated by the earlier sections, different students resonate with different formats. For all of these reasons, including a range of reflective formats appears valuable both in terms of potential synergies as well as individual students' needs and preferences.

RQ 3. What are science students' opinions about the group nature of some of the reflective exercises?

Groupwork was part of some of the reflective exercises. Groupwork was intended to build collegiality among group members and to increase student understanding of the content. There were some exercises that required students to break into small groups of three or four, while other exercises required students to speak about their work and express themselves to a larger group.

03: *After this semester, I found that I am more inclined to work in [small friend] groups as I have seen the benefit that it can bring. My group members made me feel comfortable and I was able to work to the best ability.*

07: *The engagement toward working with groups was livelier…We were trying to find out, like what's happening with everyone else that worked on the same activity.*

05: *During the web conference, I found that I have become an expert on what I was doing in the lab. This was because I can answer questions [from the community partners and K-12 science teachers] after the presentation.*

Students 03 and 07 show that having a small group can facilitate a dynamic and non-threatening environment that promoted student improvement. Student 03 identified a greater inclination to work in groups and noticed the benefit of working within student teams. Student 03's statements suggest that there was a level of trust among the small friend group. The group work conversations allowed students to realize that their peers were having similar challenges and that they could work together to resolve a problem as shown in Student 07's response. Another situation was when students took on an instructor role to disseminate their work and provide scientific information to the K-12 students. The audience posed questions after the presentation. The presenter needed to understand the meaning of the question, reflect, and reply in a clear and concise manner. As Student 05 suggested, the presenter gained confidence when they were able to express themselves effectively to a large group of people.

There were also other students who preferred to learn individually, perhaps due to limited experience with group work or feelings of discomfort when sharing feelings or personal perspectives.

11: *I think because we didn't have experience working with other people. It was very difficult to have group reflection; learning-wise and trying to understand what was going on.*

17: *Group reflection is limiting me… I had to fit in my ideas with other people and it wasn't really my stuff.*

21: *I love to think of my own ideas myself, instead of like expressing them out loud.*

Some students found that managing group work was a frustrating experience and it impacted their learning. Both Students 11 and 17 found conflicts often arose in loosely defined exercises. There were tensions created among group members because not every individual was working towards the same goals or shared the same perspectives.

There were other situations where some students felt discomfort in sharing their ideas out loud with others. For example, Student 21 felt that they learned better through individual reflection because they would be able to freely shape their thinking, learning, and understanding of the content. These students sometimes purposely withheld what they knew because they were concerned that their perspectives would be criticized.

RQ 4. How do science students' artifacts demonstrate self-directed learning in terms of academic enhancement, personal growth, and civic engagement?

Student's reflective writings and scrapbook reflections were analyzed to understand potential CSL learning outcomes in terms of academic enhancement, personal growth, and civic engagement. All students (14 out of 14 students) were able to articulate all of the learning outcomes in at least one or more reflective exercises, even though there was a great deal of individual variety.

Academic enhancement: There are different reflective strategies that can be used to improve student understanding of chemistry concepts and/or the ability to explain and reason about theoretical phenomena. Below are examples of science students who felt that reflection can enhance their academic growth shown in their artifacts.

13: *On the topic of discussing fluoridation [during reading circle reflective exercise] in drinking water, at first, I was against it because back in the Philippines we do not mix any chemicals in our drinking water, and so I was appalled to know that they [Calgary Water Treatment Plant] will add chemicals in my tap water. After the lab, I learned that fluoridation of water is beneficial to our teeth. My stand on fluoridation is now neutral, although not against it [but] I still have some doubts.*

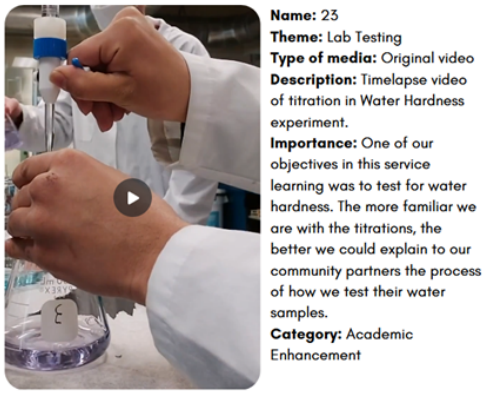
04: *After the course, I was able to gain a deeper understanding of water analysis. I learned about the benefits and potential drawbacks of adding fluoride back into the water, such as dental fluorosis…Another thing I was able to develop over the course was the opportunity to learn in other ways – by learning independently and working with my peers to find answers to our problems.*

01: *Currently, an issue with the state of scientific reporting is that there is an overabundance of not-commonly known vocabulary, as well as a "matter-of-fact" tone, leading many individuals to lose interest and give up on learning some of the sciences altogether… I believe that the ability to represent information by conveying meanings through reflection can help other individuals [to be] interested in science again.*

Students learned about the health benefits and risks of water fluoridation during the reading circle reflective exercise. As shown in both Students 13 and 04's reflective writings (KWL), they pondered the meaning of water fluoridation and how it would affect human health. This challenged both Student 13 and 14's customary ways of understanding or explaining an experience about water quality. After the lab class, students researched more information to explore the topic. This interest in further exploration is a key element of self-directed learning that Students 13 and 14 demonstrated.

Another example where students demonstrated academic enhancement is understanding the importance of having reflective practice in their learning. Student 01 suggested that the lack of student interest in sciences is due to the overabundance of difficult concepts when reading textbooks, lab manuals, and literature. The endless list of factual memorizations that seems to have no relevance to students can make them feel overwhelmed. The ability to think actively and organically in real-time through reflection may help students to deal with learning difficult concepts.

Figure 2 Student 23 scrapbook presenting their academic enhancement



The reflective exercises enhanced some students' academic growth by helping them better understand their learning preferences. As shown in Figure 2, Student 23 personalized their learning needs using a visual style. They learned by partaking in the titration activity and video recording themselves. Students reflected on their task performance through reflection-in-action. Reflection can thereby help students to identify early which preferred learning method best helps them to understand and retain the content material.

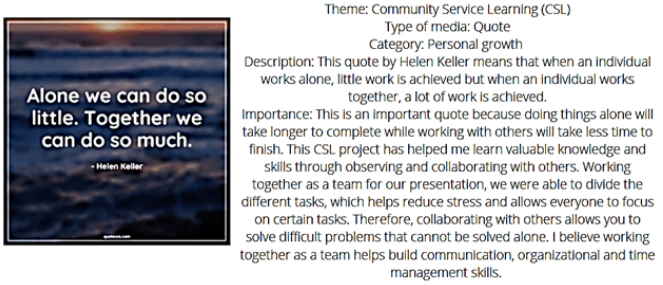
Personal growth: Identifying learning gaps can help some students gain confidence and knowledge and provide lifelong learning (i.e., continual) opportunities. These opportunities also help students improve certain aspects of their self-directed learning skills, allowing students to take ownership of their learning by documenting and tracking their learning progress.

> 07: *During this semester, I have developed a better insight into technical and interpersonal skills. This includes learning how to operate the new Ion Chromatography. In terms of interpersonal skills, I have learned that I should allocate responsibility by assessing group members' strengths and weaknesses.*
>
> 12: *These [reflective exercises] give me the chance to put these essential work experience [skills] in my resume, which will open more opportunities for me.*
>
> 10: *Ever since the pandemic, I have felt that I started lacking in my studying skills and laboratory skills. The CSL activity and reflection exercises in this course, gave me a sense of accomplishment, gained more confidence, and solidified my well-being.*

Some students grew to own their learning by developing self-awareness of their strengths and weaknesses over the semester. As shown in the above statements, Student 07 was able to diagnose their learning needs through a reflection-in-action moment by thinking about what worked, what didn't work, and what could be improved. Student 07 gained technical skills and teamwork skills. As a result, Student 07 could potentially use their skills independently, transferring these skills and applying knowledge to other science courses. A similar comment was shown in Student 12's reflective writings. Their ability to reflect on skills development and on the connection between theory, practice, and learning can provide opportunities for employment. This study was conducted during the pandemic. Student 10 indicated that the pandemic had impacted them negatively in their academic achievement due to the shift to online learning. Student 10 expresses that the CSL activity and reflection exercises gave them a sense of accomplishment and confidence in their learning and abilities.

Other students personalized and contextualized scientific knowledge by communicating the information with a bigger audience. As shown in Figure 3, this is an example of how a student implemented an appropriate learning strategy in their self-directed learning in terms of civic engagement. Student 03 created a short video on TikTok as part of their effort to educate a wider and younger audience in raising awareness about water issues. The process of telling a story helped Student 03 integrate new information and make sense of their experience.

Figure 3 Student 20 scrapbook presenting their personal growth



Civic Engagement: Nurturing an awareness and knowledge of community needs is one of the learning goals for CSL. In this water analysis activity, some students were able to identify public issues related to drinking water and to learn the importance of interacting with their community.

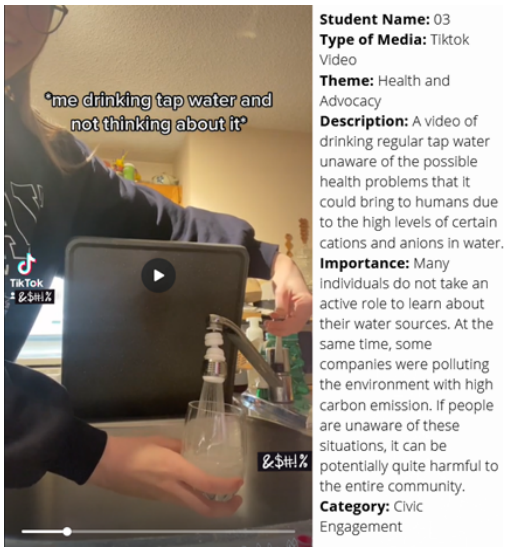
> 01: *Although adding fluoride is effective in preventing cavities, adding too much can also be harmful to residents who drink this water daily. I learned [through reading circles] the importance of testing fluoride levels.*
>
> 07: *From our scrapbook reflections, my group has researched a lot of information about the effects of water pollution. We also conducted water testing in K-12 schools' fountains. We hope that we could share and educate this valuable information with K-12 students about water quality.*
>
> 04: *I think that this CSL activity will ignite young [K-12] students to be interested in taking chemistry classes and conducting research.*

Student 01 showed that they understood the importance of monitoring fluoridation in drinking water. Student 01 reflected on civic issues that helped them to evaluate and think more deeply about their shared world and the value of science. Similar examples of nurturing civic knowledge were expressed in both Students 07 and 04's reflective writings. The CSL water analysis activity helped students to develop stronger empathy and ties to their community. Furthermore, Student 04 suggested that they were able to build mentoring relationships

to ignite and encourage K-12 students in taking chemistry courses when considering post-secondary education.

Similarly, other students felt they experienced personal growth through group collaborations. As shown in Figure 4, team collaboration in this CSL activity supported some students to develop intellectual skills and teamwork skills. As students exchanged, debated, and negotiated ideas and thoughts during discussions, Student 20 was able to rethink their interpretations in the light of explanations from their peers. Student 20 also suggested that they gained teamwork skills by being able to allocate responsibility to their group members equally.

Figure 4 Student 03 scrapbook presenting their civic engagement



Student Name: 03
Type of Media: Tiktok Video
Theme: Health and Advocacy
Description: A video of drinking regular tap water unaware of the possible health problems that it could bring to humans due to the high levels of certain cations and anions in water.
Importance: Many individuals do not take an active role to learn about their water sources. At the same time, some companies were polluting the environment with high carbon emission. If people are unaware of these situations, it can be potentially quite harmful to the entire community.
Category: Civic Engagement

Discussion

The integration of CSL and diverse reflective exercises in post-secondary Chemistry settings can potentially improve students' self-directed and meaningful learning. This is demonstrated in the data by students' application of concepts learned in lab class to real-life situations. For example, post-secondary students analyzed drinking water and compared it with the data in the water treatment plant. They then designed and prepared an oral presentation that was suitable for K-12 students' level. This is a multi-year project, and this phase of the study explores students' attitudes toward having diverse reflective exercises in a CSL chemistry lab. The focus of the reflective exercise is intended to help focus students' attention on the learning process, facilitating an epistemological shift away from "knowing what" to a reflective "knowing how and why". Furthermore, the sequence of reflective exercises supports students in reflecting on their affective experience, which is central to meaningful learning. Reflection is intertwined with self-directed learning. It is a cognitive process where students can increase their awareness by connecting previous knowledge to new information learned (van Rensburg *et al.*, 2018). In a traditional chemistry lab, students gain practical lab skills, transferable skills, and intellectual stimulation (Carnduff and Reid, 2003). The coordinated set of integrated reflective assignments during this study, however, supported students in self-directed learning over and above the baseline experience. This support includes helping learner's diagnose their own needs, formulate goals, identify human and material resources, and implement appropriate learning strategies (Knowles, 1975). Students were given time, structure, and expectations for each reflective exercise (Killion and Todnem, 1991). The deliberate process of reflection motivated and engaged science students to take ownership of their learning (Isacsson and Ritalahti, 2014). Students monitored their learning progress through reflection to achieve mastery of the subject matter (Ertmer and Newby, 1996). In this study, students self-reported that they had achieved a greater performance in their learning and a stronger sense of self-knowledge and accomplishment along with a greater sense of civic engagement and purpose in their learning. Self-knowledge refers to self-managing goals, self-monitoring the learning progress, and self-modifying continual learning (Costa and Kallick, 2004). The findings are in line with the literature that reflection can support learners' self-confidence, unity of purpose, and sense of direction (Killion and Todnem, 1991). Our work added a piece to the puzzle where scaffolding different reflective strategies (reading, writing, doing, and telling) in a CSL lab has the potential to help all students find relevancy and meaning (Gabel, 1999).

Limitations

The limitations of the study arise from a combination of the design, the participants, and its settings (Flyvbjerg, 2006; Cohen, Manion and Morrison, 2017). First, this study was conducted over one semester as a continuation of a larger research project exploring CSL and reflection for chemistry labs. Therefore, this study is an incomplete snapshot of the potential spectrum of experiences that other post-secondary students might have in this type of activity. Furthermore, the reflective exercises chosen are not all-inclusive. Other reflective exercises could be used to engage students in critical reflection, such as concept mapping, critical incidents, and action learning (van Rensburg *et al.*, 2018). The creative reflective strategies in this study were particularly chosen to match diverse student learning needs in a second-year lab setting, but future research should incorporate a broader range of modalities. Second, the sample may not be representative of the full student body of the class because students needed to opt in to allow their data to be used, and these students may have had a more favorable experience than students who did not agree to participate. Some degree of self-selection bias may therefore have potentially skewed results to make the reflection exercises appear in a more favorable light. Third, the sample size for this study was small, which may have contributed to premature thematic saturation. Fourth, the study used self-reported data rather than direct measures, which might skew results in terms of social desirability bias (Nederhof, 1985). Overall, this was a small qualitative study, and thus does not confirm generalizability, but the nature of the course context as a

standard-year chemistry course for majors suggests the possibility of generalizability that should be explored in future research.

Conclusions and Next Steps

The second-year Analytical Chemistry II lab curriculum was developed to include multiple integrated reflective strategies with the intention of supporting science students in meaningful learning. The findings demonstrate that each reflective strategy has its own advantages and disadvantages and that combining a range of reflective formats appears valuable both in terms of potential synergies as well as in terms of individual student needs and preferences. Students also were more engaged in their learning, experiencing greater civic awareness and sense of purpose. This study builds on existing literature by demonstrating the impact and value of integrating diverse reflective models in a CSL lab in terms of enhancing opportunities for self-directed learning. This includes supporting students' increased performance in their learning, a strong sense of self-knowledge and accomplishment, and a greater sense of civic engagement and purpose in the learning. Teaching self-directed learning leads to greater student awareness and reflective learning capabilities. Future work will provide opportunities to better leverage reflection and CSL to facilitate essential change in support of lifelong learning for chemistry students across the curriculum.

Conflicts of interest

There are no conflicts to declare.

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Appendix

Appendix 1: Codebook for deductive content analysis

The following is the coding system used for data analysis. The lead researcher was responsible for the codebook editor that created, updated, reviewed, and maintained the master list for the group.

Theme	Codes	Description and Examples	Literature Support
Academic enhancement	1A	Dialogue amongst students generates a new, more nuanced understanding of academic contextual learning · Bringing their own thoughts or work to a group discussion · Showing more creative ways of understanding the project or course after a group discussion	(Molee *et al.*, 2011)
	1B	Students challenge each other's thinking and knowing within group work · "Through discussion we learned…" · "Came to an understanding" · Things became clearer after group work · "We initially assumed __, but…"	
	1C	Students utilize their thoughts and reasoning ·Explaining opinions or answers · Making connections · Support valid conclusions with explanation or evidence	
	1D	Students show an improved understanding of course concepts or theory · "I now understand this more thoroughly…" · "I used to think ___, but now…" · "After doing ___, I learned…"	
Personal growth	2A	Individuals show understanding of their traits in relation to the CSL project · Self strengths and weaknesses · Describing a sense of identity · Acknowledging assumptions · Sharing beliefs and convictions · Other personal traits	(Molee *et al.*, 2011)
	2B	Individuals show signs of self-discovery because of the water project · Critical thinking about personal traits · Connecting personal traits to what was learned during the CSL activity	
	2C	Individuals change their traits during the water project (seemingly because of the water project) · Changing likes/dislikes · Changing self-confidence · Changing goals/aspirations · Changing awareness of self · Changes in values or attitudes	
Civic engagement	3A	Students can extrapolate meaning from the CSL project and apply it to other areas of life · Identifying public issues related to the project	(Ash and Clayton, 2009)

	· Discussing how the project explains public issues · Politics · "Calgary water services need to test the water more often" · Organizations · "People should send their water samples to a professional lab"
3B	Students discuss approaches for long-term and sustainable service and how it relates to the well-being of others · Effective communication with the public/raising awareness · Showing an interest in what the results will mean for people outside their cohort
3C	Students offer personal commitments to facilitate change · "We should continue this project because…" · Discussing with the community (family, friends, and others) · Showing interest in civic issues beyond the scope/timeline of the CSL project

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