ARTICLE

Widening university participation in learning using students' contextualised storytelling in General Chemistry

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

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Many students find introductory general chemistry courses difficult because they feel alienated by traditional approaches to teaching and learning. This can become particularly problematic in laboratory sessions where students simply follow processes and procedures that students can view as being mundane and lacking creativity. Contextualised storytelling offers a novel pedagogical approach to help students connect and make sense of chemistry ideas in the context of their own life experiences. The current study implemented the CLEAR (Chemistry Learning via Experiential Academic Reflection) approach to contextualised storytelling as a sequence of four assignments across a laboratory course for first-year students. The research explored students' experiences writing contextualised stories to make sense of and learn chemistry. Using hermeneutics as a methodology, the data collected included participants' written contextualised stories, semi-structured interview recordings, and field notes. While the CLEAR approach differs from other approaches to storytelling in chemistry education, the current study suggests that CLEAR can make positive contributions to student learning. The findings showed that, although many students initially resisted or felt confused by the new approach, CLEAR helped students see the connection and relevance of chemistry concepts to their lives. Students also recognized the importance of self-directed learning while writing their CLEAR stories, which suggests that CLEAR engaged students in learning that was active and organic. Furthermore, writing CLEAR stories supported students in talking to people about scientific concepts they learned in class, which suggests that writing the CLEAR stories: (a) helped students find the relevancy of the ideas to the degree that they felt they could share the ideas in their own words outside of class and (b) increased students' interest in the course and what they were learning to the degree that they wanted to share it. Implementing CLEAR as multiple assignments across the course appears important and valuable because students refined their thinking and writing skills through iteration within and across CLEAR stories.

Introduction

Many students find introductory general chemistry courses difficult because they feel alienated by many aspects of traditional teaching practices (Gosser *et al.*, 1996). Students may struggle to learn chemistry because they don't see relevance to their lives. This is even more problematic at the chemistry laboratory level. Laboratory classes were initially intended to provide experiential learning opportunities to support chemistry lectures (Boud, 2012; Jarvis, 2006; Kolb, 1984). Unfortunately, many students perceive the laboratory sessions simply in terms of replicating procedures and memorizing information without ever acquiring a deep understanding of chemistry concepts (Bensley and Ellsworth, 1992; Nyachwaya *et al.*, 2014; Zorek *et al.*, 2010). Assessment tasks in laboratory sessions typically involve students writing reports with an impersonal focus on scientific facts rather than students' personal expressions or statements (Sherwood and Kovac, 1999). Students in chemistry courses with these disconnected procedural approaches may become disengaged and subsequently withdraw (Gosser *et al.*, 1996).

Approaches to storytelling have proven productive in chemistry education and other fields for connecting academic learning to the real world and increasing engagement (Babb and Austin, 2022; Collins, 2021). Whereas much previous work has focused on stories of scientists and discoveries, often as individual assignments, the current study explores the potential of an approach that focuses on contextualised storytelling centered on connecting academic learning to students' own experiences (the CLEAR approach) (Sherwood, 2022) across four assignments during a laboratory course. The constructivist approach was used as a framework to situate learning as student-oriented rather than subject-oriented (Dewey, 1933). Thus, the feeling of self-agency was associated with students being more willing to make an effort to study new information, retrieve information from memory, or solve a problem (Koriat, 2017).

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Storytelling in chemistry education

Storytelling can cultivate students' imagination, focus attention, and create open-mindedness, along with helping establish a positive classroom atmosphere (Eisner, 2008). Stories can reflect historical events, personal lives, or short-duration events (Dewi *et al*, 2018). Students can create their own stories, uniquely capturing ideas through imagination, while also being able to take pleasure in the act of composing (Temizkan, 2011). The process of storytelling requires students to be self-directed. Self-directed learning is defined as a process in which individuals generate ideas by diagnosing their learning needs, formulating their learning goals, gathering information, and organizing their ideas through drafting, editing, and proofreading (Knowles, 1975; Temizkan, 2011). Previous studies have shown that students contextualising their learning through writing a series of stories can improve their academic achievement and confidence (Muindi *et al.*, 2020; Sherwood, 2018). Academic achievement in this case not only refers to grade point average but also to developing meaningful connections, coherency, and a holistic appreciation of the subject learned (Sherwood, 2022).

In the field of chemistry education, Collins (2023) demonstrated that storytelling can engage students and situate them in concepts with complex messages where learning is multidimensional. Various one-time creative or personal writing activities have been previously used to nurture and capture students' understanding of concepts and their identities. For example, students have written creative reports based on their own opinions about concepts (Henary *et al.*, 2015), a story based on a selected organic molecule that relates to a student's personal life (Milne *et al.*, 2024), or a poem that combines art and science concepts (Alber, 2001).

Wally *et al.* (2005) were among the first to integrate storytelling as a pedagogical approach to engage students' interest in their chemistry learning. In the study, elementary students were tasked to create and tell stories based on the context given. This narrative teaching approach was later adopted in post-secondary education, where stories were used to create coherence among scientific theories and phenomena (Chari *et al.*, 2022; Winston, 2019). For example, Collins (2021) and Collins *et al.* (2023) use stories about the history of chemistry to draw students' attention to the compounds discussed in their class. Students watched narrative films that required them to unpack their learning through reflection and critical thinking. Similarly, Babb and Austin (2022) used stories to promote anti-racism and support diversity and inclusion in chemistry. In all instances, students take the lead in constructing knowledge through storytelling by connecting theories to practice by reflecting, exploring, and explaining (Vasilevskaya and Boboriko, 2021; Younge *et al.*, 2021). Thus, storytelling is an effective teaching and learning strategy, providing students with a deeper understanding of the content.

Whereas previous studies in chemistry education have often focused on storytelling in the form of stories of other people or events (e.g., the history and stories of scientists or discoveries), the current study involves an approach known as contextualised storytelling (Makar and Confrey, 2005) that focuses on connecting academic concepts to the experiences of the student. Furthermore, whereas many of the previous implementations of storytelling in chemistry education (and other disciplines) have implemented storytelling as individual activities, the current study explores the potential of integrating these storytelling activities progressively across chemistry laboratory sessions.

Toward this goal, the current study builds upon research by Sherwood (2022). While originally designed for economics courses (and called "Contextualised Learning of Economics via Authentic Reflection – Journal Entries"), the approach was adapted for the current study with an adapted name ("Chemistry Learning via Experiential Academic Reflection") for the new context. Central to the CLEAR design is the "creation of an inclusive assessment task which would allow all students to equally participate and learn, while also demonstrating their achievement of several course learning objectives across the course" (Sherwood, 2022, p. 97). Students wrote contextualised stories (using non-technical, everyday language) to communicate the connections they made between course concepts and their own lives. The design of the CLEAR task focused on: "authenticity, to help students develop skills required for success in the workplace; student-centered, offering choice in how students could learn; encouragement of deep, rather than shallow learning, using own personal contexts; and provision of timely and progressive feedback, informing students' next CLEAR-JE submission" (Sherwood, 2022, p. 98) The specific structure of a CLEAR assignment for the current study, which parallels the original CLEAR-JE structure with high fidelity, is detailed in the methods "Context" section. It is important to note that the CLEAR approach views contextualised stories as narrative forms of thinking wherein episodes or examples from a student's experience are considered stories following Bruner's (1986) narrative mode of thought. Contextualised stories therefore do not necessarily represent elaborate structured stories in the manner that other research on storytelling has conceptualised stories (Babb and Austin, 2022; Collins, 2021)

Research questions

The current study explores the integration of the CLEAR contextualised storytelling approach across four activities in a laboratory course. More specifically, the current study contributes to the understanding of the following research questions:

1. What are students' initial reactions to and experiences with the CLEAR assignments?
2. How are students able to connect chemistry ideas to their experiences in their CLEAR stories?
3. How do students use their CLEAR stories to engage in self-directed learning?
4. How do students use their CLEAR stories to communicate with others about scientific concepts they learned in class?
5. How do students reflect on their writing skills as they engage with the CLEAR assignments?

Theoretical framework

Epistemological Foundations of the CLEAR approach

The CLEAR approach is based on Bruner's (1986) perspectives on narrative, or storytelling, modes of thought that support students in making meaning of the world. In the current context, the goal is to help students connect their own experiences with new ideas encountered in their chemistry laboratory class to create meaning. Bruner (1986) suggested that knowledge was not solely constructed internally or externally, but rather was co-constructed with the interactions with environmental stimuli. Each student's mental representation of the world is different, and how they shape and personalize their narrative expression is also different. Thus, the process of contextualized storytelling can support students in connecting authentic thoughts, emotions, and desires with the ideas and experiences from the chemistry labs as part of their 'self'.

Hermeneutics and interpretive phenomenological analysis

This study adopted hermeneutics as a methodology. Hermeneutics is a form of interpretive phenomenological analysis (IPA). IPA more broadly is a qualitative research approach to examine how people make sense of their life experiences (Smith, 2009). IPA draws heavily on interpretation as researchers attempt to understand other people's relationships to the world and their attempts to make meaning from their own experiences. This interpretative endeavor is informed by hermeneutics, which is defined as the theory of interpretation (Smith, 2009). In this framework, IPA researchers engage in a double hermeneutic by bringing their own understanding and experiences to the research process (Walters, 1995). There is a dynamic relationship between 'the whole' and 'the part' and involves a back-and-forth movement between these two until a better understanding of the phenomena is achieved (Smith, 2009). In other words, 'the whole' is the researcher's evolving understanding and 'the part' is the text created by the participants. In the current study, the text analyzed was drawn predominantly from participants' experiential descriptions in their CLEAR contextualized stories and interviews, but also from the lead researcher's personal experiences as a starting point in consultation with the literature.

Context, Data, and Methods

Structure of the course and the CLEAR contextualised stories

As shown in Table 1, students enrolled in the course were required to write a series of four contextualised stories using the CLEAR format across a semester. Because the writing format of CLEAR would be different from the typical scientific laboratory report, a workshop was hosted by the laboratory instructor in Week 1 to introduce students to the process of translating technical terms into everyday language. Each CLEAR required students to write 400-500 words using chemistry concepts from specific pairs of laboratory lessons. As shown in Figure 1, a comprehensive task description was provided to help scaffold students' learning.

Table 1 Semester laboratory schedule for general chemistry students

Week	Laboratory Schedule
1	Check-in & Introduction to CLEAR
2	Measurement and Density
3	Limiting reactants and excess reagents & CLEAR No. 1
4	Atomic spectrophotometry
5	Quantitative determination of food dyes in powdered mixes & CLEAR No. 2
6	Determination of Allura Red concentration in PLAX dental rinse
7	Characteristic properties: Melting and boiling point & CLEAR No. 3
8	Periodic trends
9	Flame tests; Identifying unknown substances from characteristic properties & CLEAR No. 4
10	Lab Assessment

Be sure to **give your CLEAR a title** to convey a sense of the focus of your CLEAR. Then address each of the following five (5) criteria to create an **individually written CLEAR that is your own work.**

1. **Chosen context:** *(Guideline: < 70 words)*
   Describe the ***context*** for your CLEAR using **two or three sentences**. Your context needs to help establish a sense of personal relevance for the required CLEAR learning materials. The context needs to **identify a very specific example**, something you have experienced or is of interest to you.

2. **Theoretical concepts/ideas:** *(Guideline: 50 - 70 words)*
   Identify **two *theoretical concepts*** directly related to what was introduced for the first time in the lab material relevant to the CLEAR. Theoretical concepts are defined as being based on academic abstract ideas, notions, or principles, in a particular discipline or subject area (Medin, 1989). State the concepts as **dot points** that include the relevant Lab number.

3. **My prior assumptions:** *(Guideline: 80 - 100 words)*
   In thinking about your **chosen context,** identify two or three ***prior assumptions*** you might have made, or you think others might have made, in any of your decision-making **before** being exposed to the learning materials for the particular CLEAR.

4. **What I learned:** *(Guideline: 130 - 150 words)*
   State ***what you have learned*** from applying the CLEAR learning materials by outlining **how your thinking** about the chemistry concepts used in your context **has changed**. Focus on **why** you now realize your preconceptions/assumptions were "wrong" or "right" according to the theoretical concepts you chose in point 2, thereby helping to demonstrate your learning.

5. **Reflecting on what I learned:** *(Guideline: 130 - 150 words)*
   Concisely ***reflect on what you have learned*** using non-technical, plain language. Do **not** rewrite/repeat the details in the 'What I learned' section in the 'Reflecting on what I learned' section. Instead, the reflection section is intended to be a **generalization** of your **new understanding.** Thus, it needs to **extend/go beyond** what you already mentioned in point 4.

Fig. 1 Description of the CLEAR story structure and instructions.

Participants

All participants in the study were first-year university students. The majority of the students were non-chemistry majors. They were registered in a general chemistry course where 300 students were enrolled during the Fall 2023-24 semester at a mid-sized institution. All students wrote a series of four contextualised stories as part of the assessment for the laboratory sessions. All students were invited to participate. Nineteen participants provided consent to be interviewed and to allow their CLEAR stories to be used and were included in the study. The study was approved by the institutional Human Research Ethics Board (Ethics clearance number: 103347) at the university where the study took place. All participants of the study were informed of the purpose of the research and the voluntary nature of their participation. Their informed consent to participate was obtained before any data collection. Participants were given pseudonyms to ensure anonymity.

Researcher Positionality

The study team consists of the chemistry laboratory instructor and coordinator for the course in which data was collected (KH), one undergraduate student researcher (YL), one economics faculty member (CS), and one education research faculty member (DC). One author designed the CLEAR assignment (CS). Two authors of the research team bought their prior experience in chemistry learning by refining and implementing the CLEAR assignment, recruiting participants, and collecting data (KH and YL). The data analysis and writing was led by one author (KH) in collaboration with another co-author (DC). The prior research experience from the authors (KH, CS, and DC) shaped the lens through which they viewed and analyzed the data collectively as a whole.

As the primary researcher of this study, the lead researcher was cognizant of her positionality as she came to this topic with experience and pre-understandings (or prejudices) about this topic, as did the rest of the team. She is a chemistry laboratory instructor. She is also an instructor who is interested in enhancing chemistry laboratory experiences to make them more inclusive and welcoming to students who traditionally have not been well-served by the status quo. Her experiences within the topic of chemistry teaching and learning and her experiences as a woman and an immigrant in the Canadian educational system shape how she 'sees' and 'hears' things in a manner that may be different from the experiences of others. The positionalities of the rest of the team also shaped the research in terms of YL's personal and ongoing experience as an undergraduate chemistry student and CS's and DC's extended experience as more senior faculty with long-term commitments to designing environments that ground disciplinary learning in students' experiences.

Data Collection

Participants' contextualised stories and field notes were obtained for this study along with an interview with each participant. Hermeneutics typically involves in-depth interviews with participants who have experienced the phenomenon of interest (Bloomberg and Volpe, 2018). The value of the interview is that it permits an explicit focus on the researcher's personal experience combined with those of the participants by focusing on meanings that guide actions and interactions (Bloomberg and Volpe, 2018).

Interviews. A one-on-one interview was scheduled for an hour with each participant. The interview adopted a semi-structured approach and was scheduled after CLEAR No. 4 was submitted. Conflict of interest was considered because of the dual roles of the lead researcher being the instructor. Thus, the undergraduate student researcher set up the interview schedules and led the interviews with the participants who were enrolled in the lead researcher's class. Furthermore, data analysis was not initiated until after the course grades were released. Five open-ended questions guided the interviews. The interviews aimed to generate a dialogue where participants could reflect on their learning experiences of writing their contextualised stories. To help create reflective dialogues, the interviewer read the participants' CLEARs before the interview and used the five open-ended questions to probe participants' previous experiences, perceptions, opinions, attitudes, and explanations. The five open-ended interview questions used to help generate the participants' reflective dialogues were:

- You chose a particular context to make sense of your learning. Can you tell me more about why you chose that context?
- The context you have chosen for your contextualised story is used to make sense of [*a particular theoretical concept*]. Why did you choose this particular concept? Was it difficult to choose the context you did, and if so, why or why not?
- You listed various assumptions you made about [*a particular theoretical concept*] prior to studying it in the course. Based on your own real-world experiences, why did you make these assumptions? What did you base these assumptions on?
- Your CLEAR highlighted how your thinking about [*a particular theoretical chemistry concept]* had clarified using contextualised storytelling. What do you think was happening here to clarify your thinking?
- You reflected on what you learned at the end of your assessment task based on your own chosen context. What role do you think contextualised storytelling played in helping you make sense of [*a particular theoretical concept]*?

CLEAR Contextualised Stories. Participants' contextualised stories created through each CLEAR exercise became artifacts that directed the interview questions. These artifacts provided an opportunity to gain valuable insights into addressing the study's research questions with the participants generating the data (Bloomberg and Volpe, 2018). Each participant was required to write four contextualised stories during the semester as an assessment task (see Table 1). The epistemological framework employed in CLEAR is constructivism in terms of encouraging participants to find relevancy from ideas presented in class in their learning process (Dewey, 1933). Learning is seen as an organic process where the participant constructs their own knowledge and meaning. This occurs through a dynamic interaction of an experience and the participant's existing knowledge. A description of the CLEAR exercise, template, and marking rubric were shared with students to convey work quality expectations (see Figure 2 and Appendix).

Field notes. Field notes were employed as a tertiary source of data to gain an understanding of a phenomenon of interest (Bloomberg and Volpe, 2018). Field notes were taken during the interview, especially when encountering key ideas, personal feelings, and experiences affecting the research (Fleming *et al.*, 2003).

Data Analysis

Hermeneutics aims for the systematic analysis and understanding of texts or other bodies of work (Muhammad and Thomas, 2022). Heideggerian hermeneutics advocates that "researchers interpret the data collected in terms of their own experiences and knowledge" (Mapp, 2008, p. 308). In line with hermeneutic research foundations, the principal investigator is a chemistry laboratory instructor who could bring their own understanding and experiences to the research process. The researcher becomes part of the spiral moving repeatedly between interpretations of the shared understandings through the interview data and the text written in a participant's CLEAR. Thus, the results we provide from our analysis identify various themes regarding students' experiences with the CLEAR stories.

Diekelmann (1992) devised a step-by-step process for analyzing narrative text as a team that could serve as a method of bias control. This includes reading and re-reading interview transcripts and participants' contextualised stories, reviewing field notes, reflecting on the narrative text, and generating interpretations (Gadamer, 2013). Selected participants' interview transcripts and CLEARs were analyzed by the individual members of the research team prior to being discussed by the whole team. During this process, each member of the research team wrote interpretive summaries. The team compared and contrasted texts, and the recurring themes were identified and described. In order to understand and bring forth meaningful interpretations from the data, the concept of the fusion of horizons and the hermeneutic circle was of assistance (Koch, 1996). The hermeneutic circle represents the space where the interpreter shifts between the whole and part of the context (Gadmer, 2013). Shared understanding occurs when the interpreter must experience the parts and entirety of the context being examined. The researchers are constantly understanding and interpreting experiences, and do not have a fixed horizon as a result. The fusion of horizons, or the coming together of two or more understandings of the topic, coupled with the genuine curiosity of the researchers and desire to understand the topic in new ways. Through openness and participation in a dialogue, different interpretations of phenomena are brought together. When disagreements arose, researchers returned to the text to compare and contrast the possible meanings.

Trustworthiness

Determining the trustworthiness of an interpretative portrayal of a phenomenon is largely a matter of judgment. This judgment was arrived at by putting together a case of whether the data captured the lived experience of the participants. To increase the trustworthiness of the data, data triangulation and investigator triangulation are used.

Data triangulation. In this study, we used multiple data sources, CLEAR contextualised stories, interviews, and field notes. We also used our own experiences and references in the literature.

Investigator triangulation. The lead researcher consulted with co-researchers to confirm findings in order to add rigor to the study.

In terms of the interpretivist paradigm in hermeneutics, "there is no method that can ascertain an interpretation is correct or incorrect, true or false" (Freeman, 2011, p. 549). Cho and Trent (2006) stated that the purpose of hermeneutic inquiry is to provide opportunities to think out loud through conversations, but not as a way of confirming or validating shared understandings. This results in a clarification of the condition in which understanding takes place. Galdmer (1989) used the term 'horizon' as a range of vision that includes everything that can be seen from a particular vantage point. The different horizons of the conversations resulted in a shared common understanding of the subject matter.

Results

The following sections present the results in terms of the five research questions guiding this study.

RQ1. What are students' initial reactions to and experiences with the CLEAR assignments?

The majority (fifteen out of nineteen) participants initially resisted and struggled with the CLEAR assignment to make sense of and learn chemistry in laboratory settings. They expected the structure of post-secondary science courses to be similar to high school where their past successes in academic performance were based on their number-crunching abilities to solve problems. These participants felt uncertain when they were asked to relate scientific concepts presented in class with their lived experiences. They struggled to understand the connections to fundamental chemistry concepts. For example:

> *When I first heard about the storytelling assignment, I didn't quite enjoy it because I wasn't sure about how to do it…I usually don't relate things that I do every day with chemistry. (Patricia Interview)*

> *I think it's really difficult because there ain't a lot of actual real-world examples that could link to theoretical concepts. To me, I learn better by doing than by thinking. (Anika Interview)*

> *It took me more than six hours in the first CLEAR assignment to figure out what topic to select and [how] to make connections with the chemistry concepts. (Martine Interview)*

As Patricia stated above, she wasn't enjoying the storytelling assignments at the beginning of the semester because she didn't know what to expect. This could be related to her previous experiences in high school, where learning might have been teacher-centered and based on completing right-or-wrong tasks. Patricia's perception of chemistry laboratory sessions appears to be one based on following recipe-like, experimental instructions, while performing simple mathematical calculations. Anika, similar to Patricia, expresses a more traditional perspective initially on how chemistry lab classes should be structured in higher education by repeating similar bench experiments weekly. Thus, there was some resistance when the CLEAR assignments were introduced because participants were uncertain about how storytelling could help them learn chemistry. Students like Martine needed to spend time brainstorming to try and think of an experience that could be connected to chemistry.

RQ2. How are students able to connect chemistry ideas to their experiences in their CLEAR stories?

All participants (nineteen out of nineteen) were eventually able to connect chemistry ideas to their experiences. Participants selected the theoretical concepts that were closest to their lived experience in the CLEAR stories. As Samantha explained in her interview:

> *I have always been interested in criminal investigation shows. After conducting the identifying unknown experiment, I learned that density, melting point, and solubility tests can be used to identify substances. This is like collecting forensic evidence, where crime scene investigators collect evidence such as fibre residues, fingerprints, hair etc. (Samantha Interview)*

Samantha felt emotionally connected to her interest in crime movies. She connected her chemistry experiment with forensic science, where chemists need to use a variety of identification techniques as part of criminal investigations. The CLEAR assignment captivated Samantha's attention, engaging her on an emotional and personal level. This demonstrated that students could situate chemistry in the sociocultural context of their everyday interaction, group life, and cultural world through the CLEAR assignments. These connections are also demonstrated in some of the excerpts from CLEAR stories below by Tavneet, Patricia, Tanish, JP, Alyana, and Gloria:

> *After experiment 1, I learned that different measurement tools have different levels of accuracy. For example, when preparing horse food, '2 handfuls of beet pulp' and 'half a bucket of water' are often shown on the instruction label. I previously assumed that a 'handful' was a consistent and reliable measurement, disregarding the fact that everyone's hands are different sizes. Furthermore, different people use different sizes of buckets, ending up with uncertainty and poor accuracy (Tavneet CLEAR 01).*

> *After learning about concentration, I started to make the connection between alchemy [a brew potions video game] and chemistry [in real life]. In alchemy, you [need to control the concentrations and ingredients by] adding or subtracting. If adding too much or too little of a material [the ingredients], then the potion becomes either too strong or too weak. (Patricia CLEAR 02)*

> *When I tried making chocolate-covered cake pops, they ended up tasting good, but the outer layer of chocolate was not what I wanted. Rather than being a hard outer shell, the chocolate didn't stick to the cake and fell right off. From the melting and boiling points experiments, I learned that it is important to know the freezing point (or temperature) of a substance. In this case, having an accurate temperature to control the texture of the chocolate (Tannish CLEAR 03).*

> *One of the fondest memories I had as a child was starting my cold mornings with baths, with the help of my mom adding a bath bomb. Through recent lab experiments, I grasped the science behind bath bombs and their functions. The bubbles that are formed come from the release of carbon dioxide, an outcome of the bath bomb's acid-base reaction between citric acid and sodium bicarbonate rather than just air pockets (JP CLEAR 04).*

> *I have been involved in the construction field because of my family. Previously, I identified construction materials, like wood, concrete, and metal as strong and sturdy. I never knew that strong and sturdy are based on chemistry-related traits, such as their composition and properties. This can be tested in chemistry experiments like density, viscosity, and flame tests. (Alyana CLEAR 04).*

> *I always loved it when my father took me to watch fireworks for Canada Day celebrations. After the Flame Test experiment, I came to understand that certain metals emit specific, colourful light when lit in a flame. For example, sodium is yellow, strontium is crimson, potassium is lilac purple, and barium is yellow-green (Gloria CLEAR 04).*

These excerpts from students' CLEARs demonstrate a range of experiences that students connect to chemistry concepts and practices from the labs in terms of measurement practices, concentration, freezing point, acid-base reactions, composition and properties, and flame tests and spectra. Some participants were able to make nuanced connections earlier than others.

RQ3. How do students use their CLEAR stories to engage in self-directed learning?

The connection between chemistry concepts and participants' everyday lives was taken a step further by engaging in self-directed learning. Fourteen out of nineteen participants demonstrated or described engaging in self-directed learning during their CLEAR assignments.

> *My mom designs and makes clothes. I have always wanted to teach myself how humans perceive and interact with color. The CLEAR assignments are helpful in terms of relating to [my] everyday life. I learn[ed] that dye is related to mixing color as it absorbs light. I will look online, jot down some notes, and then put them into my own words in writing, just like the CLEAR. (Aldrich Interview)*

> *I have kids and they are home-schooled, so I am familiar with researching online materials to teach my kids about science that align with the science curriculum. This is similar to the storytelling assignment, where I need to read other sources beyond the lab manual in order to understand the experiment better. (Mikael Interview)*

Aldrich described connections between the self-directed learning he does with color science and the self-directed learning he does in the CLEAR assignments. Similarly, Mikael described applying self-directed learning skills from his prior experience to the storytelling assignment as he mastered the subject material. These examples suggest that the integration of storytelling in chemistry laboratory classes can build participants' awareness which subsequently promotes their self-directed learning. Awareness is seen as a sense of identity, especially in terms of the values, attitudes, and beliefs possessed by each student (Chadwick *et al.*, 2018). Students become independent learners when they are aware that they can control their own learning. This involves participants setting and evaluating their own goals, choosing their own strategy in terms of what and how they are composing their story, and reflecting on and making adjustments as needed. Participants build self-consciousness during the process of storytelling and create meanings for their individual experiences.

RQ4. How do students use their CLEAR stories to communicate with others about scientific concepts they learned in class?

The CLEAR stories affected participants' attitudes toward their connection with chemistry learning. Sixteen out of nineteen participants discussed their willingness to talk to people about scientific concepts they learned in class.

> *I told my little brother who's five years old about my CLEAR assignment. I think he would understand it much better than explaining to him in scientific terms. He also likes it much more because it's about video games too. (Patricia Interview)*

> *When I was explaining the term, absorbance, to my mother. She doesn't know what it means. Then, I used the analogy of how onion absorbs the heat to form caramelization…I can easily*

understand this concept and explain it to others. That being said, I have a good understanding of the content. (Martine Interview)

The idea about spectroscopy in my CLEAR assignment came from my friend who messaged me about whether they should buy a game console from [a consignment store]. I told them no because the laser components were probably busted as I was trying to explain the difficulty in analyzing a second-hand console in simple words. (Jayden Interview)

The statements above showed that students are willing to communicate their chemistry stories with non-scientific audiences outside of laboratory classes. This seems to be a function of how the personal style of CLEAR supported students' understanding of the concepts. Students seem to have developed a deeper understanding of, as well as a positive affect toward, the ideas such that they voluntarily shared their chemistry views with others. Patricia shared her stories with her younger brother, who is curious about science and loves video games. Martine and Jayden used everyday experiences, like cooking onions and analysing a second-hand retro game console, to show their ability to communicate science in their everyday lives in connection with their CLEARs (excerpts of which are shown below):

When sauteing onions, for example, the heat received by the onions reacts with metal ions in the onion, giving it a brownish tint. The relationship between flame testing and the colours we see when cooking, as well as understanding absorbance and its function in flavouring food, has changed my approach to cooking and given me a better understanding of what I've learned. (Martine CLEAR 02)

When analyzing a console, I can pinpoint an issue using spectroscopy as I have determined an element using its spectra while in the lab. I can compare the spectra of light from more specific parts of hardware to a console with no issue (which I could treat as my theoretical value). If there is a discrepancy between the spectra of two optical or laser diodes, then I can determine the damaged component instead of replacing the entire hardware. (Jayden CLEAR 02)

Participants converted the ideas presented in class and chose the appropriate vocabulary and words to represent their experiences. This made the content personal and relatable for them. The stories were then retold, which further reshaped their experiences. These examples suggest that the CLEAR stories supported the students in finding the relevancy of the chemistry ideas and sharing and applying the ideas in their lives to the degree that they were interested and willing to communicate these ideas with others.

RQ5. How do students reflect on their writing skills as they engage with the CLEAR assignments?

Storytelling is a combination of writing, thinking, and creative expression. This integration of skills needs to be mentored and practiced over time in order to build continuity. Writing is a complex process where students must not only focus on the skills of writing but must also engage in the development of both cognitive and metacognitive thinking skills. All participants (nineteen out of nineteen) indicated that the iterative cycle within and across CLEAR assignments supported them in making connections to scientific phenomena and writing. Further, they claimed that the CLEAR assignments clarified their thinking and improved their writing skills, which induced a positive experience in learning chemistry.

I struggle to write concisely and to the point. Sometimes when I am excited about a topic, I tend to go off on tangents. Thus, I rewrite and revise my stories many times, so that they become clearer and presentable to my instructor. (Jayden Interview)

When I wrote my CLEAR 01, I was nervous, and it took me a long time to complete. The constructive feedback that I received from my instructor made me feel more confident with my writing. I realized that I spent less time writing my CLEAR 02 assignment. (Martine Interview)

Storytelling required participants to reflect by deliberately looking back at their chemistry learning process in their work. During the process of contextualising their stories, students needed to integrate their thinking and writing skills. For example, Jayden revised his work many times in order to bring clarity, conciseness, and organization to his work. He added, subtracted, moved, and changed words to ensure that he accurately conveyed his experience of learning chemistry.

Another element within this process, as described by Martine, is where students receive feedback. The laboratory instructor can mentor students toward the ability to deconstruct, question, reconstruct, and ultimately connect first-person narratives to chemistry education. At the same time, the laboratory instructor can also guide students through the different stages of writing. This is an individual process which requires participants to choose the appropriate syntax, grammar, and vocabulary to express and re-express themselves competently during the process of creating their stories. Such empowerment offers an opportunity to cultivate students' learning habits to help them become reflective thinkers and transform their lifelong learning mindset.

Limitations

While the study shows promise, there are also limitations. First, hermeneutics involves the active use of dialogue, looking at texts, and the researchers' point of view in the creation of theory or new knowledge; generalizability is therefore limited accordingly. Second, the authors' potential bias may influence findings because hermeneutics focuses on how the researchers make sense of the data. Third, this style of assignment is relatively new for students. As a result, it might influence the extent to which students engage with the assignments despite the potential learning benefits of storytelling. Fourth, this study's findings represent a small number of students' perspectives and perceptions in a general chemistry initially laboratory. Last, the limitation of the ethical guidelines meant that participants had to volunteer for the study to allow their data to be used. Students who are motivated to volunteer tend to be more engaged learners. These limitations should be explored further in future research.

Discussion and Conclusions

The CLEAR approach to storytelling in this study diverges from how storytelling has been conceptualized and enacted in most other studies in chemistry education. Whereas many previous studies have focused on storytelling in the form of stories of other people or events (e.g., the history and stories of scientists or the development of science ideas), the current study focused on an approach known as contextualised storytelling that emphasizes connecting academic concepts to the experiences of the student. Furthermore, whereas many of the previous implementations of storytelling in chemistry education (and other disciplines) have implemented storytelling exercises as individual activities, the current study explored the potential of integrating four storytelling writing exercises progressively across chemistry laboratory sessions. The CLEAR approach views contextualised stories as narrative forms of thinking wherein episodes or examples from a student's experience are considered stories following Bruner's (1986) theories on narrative mode of thought. Contextualised stories therefore do not necessarily represent elaborate structured stories in the manner that other research on storytelling has conceptualised stories (Babb and Austin, 2022; Collins, 2021), but CLEAR still emphasizes narrative modes of thinking.

While the CLEAR approach differs from other approaches to storytelling in chemistry education, the current study suggests that the non-traditional CLEAR writing exercises can make positive contributions to student learning. The findings showed that although many students initially resisted or felt confused by the new approach, CLEAR helped students see the connection and relevance of chemistry concepts to their lives. The process of writing helped students clarify their thoughts and deepen their understanding of the subject matter (Kingir, 2013). Students also recognized the importance of self-directed learning while constructing their narrative text, which suggests that learning with the use of storytelling was an active and organic process. Furthermore, writing CLEAR stories supported students in talking to people about scientific concepts they learned in class. This may be because the process of writing shares parallels with verbal communication, which also involves expressing one's ideas and describing and discussing chemistry concepts coherently and clearly (Brownell *et al.*, 2013). Thus, the finding suggests that writing CLEAR: (a) helped students find the relevancy of the ideas to the degree that they felt they could share the ideas in their own words outside of class and (b) increased students' interest in the course and what they were learning to the degree that they wanted to share it. Implementing CLEAR as multiple assignments across the course appears important and valuable because students refined their thinking and writing skills through iteration within and across CLEAR stories.

Applying CLEAR in the chemistry laboratory classes thus appears promising based on the findings of the current study. The integration of storytelling provided opportunities for students to link chemistry ideas to contexts with which they were familiar from their everyday lives. Based on each student's personal experiences with reflection and storytelling, each found their own connections as they made sense of their learning (Sherwood, 2022). In this environment, students had the opportunity to make use of and search for information that was relevant to them at any given time (Komorek and Duit, 2004), with their progress based on their experiences with previous tasks, lessons, or assignments. Furthermore, students could communicate with their peers, family members, and broader community without the need for traditional power relations such as between teacher and student (Lemke, 1990). Thus, students developed meaningful connections by linking abstract concepts to larger systems of thinking (Orgill *et al.*, 2019; Galloway and Bretz, 2015).

Future research might consider expanded opportunities across the chemistry laboratory curriculum, such as organic, inorganic, physical, and analytical chemistry. The use of digital storytelling and CLEAR, for example, might be investigated. Digital storytelling is the combination of art and stories with different mediums, such as images, audio, and video (Wolfel *et al.*, 2020). This type of learning strategy might enhance students' interest, engagement, and retention because students are increasingly comfortable with the use of technology and digital information literacy (Grant and Bolin, 2016). In addition, students could share the digital stories they produced more widely, which might enhance the student experience through personal relevancy and accomplishment.

Overall, CLEAR stories, and storytelling more broadly, helped students make sense of the chemistry in a transdisciplinary manner grounded in their experience rather than as isolated concepts and bits of information (Ho, 2023). Future research should continue to explore the potential of storytelling in various formats to enhance students' learning, engagement, communication, self-directed learning skills, and overall learner identity.

Author Contributions

All authors contributed. The authors' CS and KH contributed to the conceptualization and the design. KH and YL contributed to data collection, implementation of the assignment, and revision. KH and DC contributed to the data analysis. The manuscript was written primarily by KH in collaboration with DC. All authors read and approved the manuscript. Funding acquisition was contributed by KH.

Conflicts of interest

There are no conflicts to declare.

Appendix: CLEAR marking rubric

Marking Criteria (* be sure to stay within the word limit guideline indicated)	Mark
1. Chosen context: *(Guideline*: < 70 words)* a. Uses about two or three sentences to establish a **clear** context. The context described establishes a sense of relevance for the required CLEAR learning materials (1 mark). b. The context described is clear. However, it **does not** help to establish a sense of relevance for the required CLEAR learning materials (0.5 mark). c. The context described is **unclear** and **does not** help establish any sense of relevance for the required CLEAR learning materials (0 marks).	/1
2. Theoretical concepts/ideas: *(Guideline*: 50 – 70 words)* a. Lists **two theoretical concepts** using dot points. The concepts are directly related to what was introduced for the first time in the lab material relevant to the CLEAR. Concepts are applicable to the established context (1 mark).	

	b. Lists only **one relevant theoretical concept** that is **directly related** to what was introduced for the first time in the lab material relevant to the CLEAR. Alternatively, the concepts are **not clearly applicable** to the chosen context (0.5 mark).	
	c. Lists **no concepts** that are **directly related** to what was introduced for the first time in the lab materials relevant to the CLEAR (0 marks).	/1
3.	**My prior assumptions:** *(Guideline*: 80 – 100 words)*	
	a. Concisely outline **two or three assumptions** that had been made prior to identifying the learning materials relevant to the CLEAR. The assumptions make sense in terms of the context described and the chosen theoretical concepts (1 mark).	
	b. Does outlines **two or three assumptions** that had been made prior to identifying the learning materials relevant to the CLEAR, but it is somewhat **difficult to link** the assumptions to the context or the identified theoretical concepts (0.5 mark).	
	c. Outlines **none or one assumption only** made prior to identifying the learning materials relevant to the CLEAR (0 marks).	/1
4.	**What I learned:** *(Guideline*: 130 – 150 words)*	
	a. Concisely conveys learning to satisfy all three requirements: **First**, comparisons between prior understanding (perhaps as someone with no chemistry background) and new insights from learning to think like a chemist are evident. **Second**, in making such comparisons, each of the theoretical concepts listed in section 2 (above) is at the centre of outlining what was learnt. **Third**, the linkages between learning and scientific thinking are clearly conveyed through building on the chosen context (1 mark).	
	b. Compared to a., above, **only two** of the three requirements are clearly satisfied (0.5 marks).	
	c. Compared to a., the above, **none** of the three requirements are clearly satisfied (0 marks).	/1
5.	**Reflecting on what I learned:** *(Guideline*: 130 – 150 words)*	
	a. Concisely reflects on what was learnt to satisfy all three requirements: **First**, it shows **clear connections** with the chosen context in section 1 and the theoretical concepts in section 2. **Second**, the reflections show an ability to **extend** what was learnt more generally (e.g. to a manager, a politician, parents, friends, workplaces, society, or everyday decision-making). **Third**, the **practical benefit(s)** that emerge from the reflection are highlighted and linked to the ideas in section 1 and section 2 (1 mark).	
	b. Compared to a., above, **only two** out of the three requirements are clearly satisfied (0.5 marks).	
	c. Compared to a. above, **none** of the three requirements are clearly satisfied (0 marks).	/1
	Total	/5

Acknowledgements

The authors would like to thank students from the general chemistry Fall 2023-24 semester for their participation in this research project. We would like to acknowledge the Mount Royal University Marshall Family Foundation Literacy Grant (Grant No. 103790).

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