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"I am here because I wanted to shine": how poetry can be used to better understand undergraduate students' first-year chemistry or related course experiences†

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In this study we investigate how first-year chemistry/biology undergraduate students' original poetry can be used as a reflective tool for others to understand their course experiences. By inviting students from an integrated first-year chemistry/biology course to write poetry about their experiences, we use poetic content analysis as a qualitative research method to analyze the students' responses to an open-ended prompt. In analyzing the poetry, four major categories emerged: knowledge, community, emotions, and identity, each of which includes examples that reflect and enhance our understanding of well-documented milestones and ideas in the literature regarding first-year student academic experiences, therefore highlighting the extent to which poetry can be useful in this regard. In presenting these findings we also demonstrate how such an approach might be used by others to better understand student experiences, including those related to learning, belonging, and/or identity in their introductory chemistry or related courses.

1. Introduction

It is widely accepted that undergraduate student persistence in STEM disciplines is linked to factors shaped by both their background and their experiences. Student outcomes in STEM-related majors have been associated with gender identity, racial identity/ethnicity, and parental educational level (Dika and D'Amico, 2016; Estrada *et al.*, 2016; Mau, 2016; Witherspoon and Schunn, 2021), and factors that can affect students' experiences include implicit bias (Fadeyi *et al.*, 2020), student sense of disciplinary belonging (Lewis *et al.*, 2017; Witherspoon and Schunn, 2021), competency beliefs (Witherspoon and Schunn, 2021), stereotype threat (Steele and Aronson, 1995; Totonchi *et al.*, 2021), and academic preparation (Chloe and Yonghong Jade, 2017).

While chemistry is generally included within the STEM "umbrella," there are differences in these links within STEM subfields (Hazari *et al.*, 2013; Cheryan *et al.*, 2017; Blatt *et al.*, 2020), and it is therefore also important for chemistry educators to understand undergraduate student experiences specific to their discipline. Multiple studies have shown the importance of understanding student mindset and perceptions to better support their success and persistence in chemistry, which has been linked to student perceptions of ability and desire to avoid failure (Shedlosky-Shoemaker and Fautch, 2015). Moreover, a student's science identity can change appreciably within a single semester of undergraduate gateway chemistry (Robinson *et al.*, 2019), with perceptions of chemistry and chemistry self-efficacy showing potentially different and, at times, more negative, trajectories for underrepresented groups after experiencing some undergraduate chemistry (Villafane *et al.*, 2014; Odeleye *et al.*, 2022). Disparities in a sense of course belonging and in grade outcomes can also affect retention of underrepresented students in chemistry (Fink *et al.*, 2020; Harris *et al.*, 2020). Given the clear relevance of student mindset and perceptions on their outcomes, it is important to accurately and holistically gauge student experiences and perspectives to ultimately address such links and facilitate greater persistence in chemistry for all interested students.

Often, studies conducted to understand student experiences and/or such factors within chemistry and more broadly in STEM involve the analysis of quantitative student survey or institutional data (Villafane *et al.*, 2014; Dika and D'Amico, 2016; Mau, 2016; Witherspoon and Schunn, 2021) or qualitative data from focus groups or interviews (Chloe and Yonghong Jade, 2017; Elbulok-Charcape *et al.*, 2021). However, another way to understand student experiences and potentially even

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mitigate some of these factors could be through the incorporation of student writing assignments into the courses. Creative or reflective writing has been used within chemistry or biology curricular contexts for students to express – and affirm – their personal and cultural values or to provide them with avenues through which they can personally connect with curricular material (Estrada *et al.*, 2016; Canning *et al.*, 2018; Wang *et al.*, 2021), and such writing may also positively affect academic performance and persistence of underrepresented populations (Harackiewicz *et al.*, 2014; Harackiewicz *et al.*, 2016). Here, we are interested in the use of student writing to provide others with useful information about their perspectives and experiences.

In this study, we incorporate reflective, creative writing into an introductory, integrated undergraduate chemistry and biology course to facilitate our understanding of diverse student experiences. However, rather than incorporating prose writing, we incorporate a reflective poetry assignment. Poetry has been used in non-classroom settings in past studies to provide voices on scientific topics to underheard audiences (Illingworth *et al.*, 2018; Illingworth and Jack, 2018), where one of the observable outcomes was that poetry created a platform for participants to voice opinions and concerns that might otherwise have been difficult to express. As a method of communication, poetry is inherently personal, in that it provides an opportunity for each individual to express themselves in a manner that suits their own experiences, goals, perspectives, and expertise, and as such, it can lower barriers to self-expression (Illingworth, 2022b). Incorporating the reading or writing of poetry into undergraduate chemistry courses has been successfully done in other ways before (Furlan *et al.*, 2007; Herrick and Cording, 2013), and as an added benefit, it may promote inclusivity and interdisciplinary collaboration through removing the oft-perceived bifurcation between science and the humanities that implies a need for ''specialization'' (Marcum-Dietrich *et al.*, 2009; Gorrell and Colfax, 2012; Paiva *et al.*, 2013).

Our goal in this initial study, therefore, was to explore whether original poetry written by first-year undergraduate students as part of an introductory chemistry/biology course could provide useful insights into both their shared and their unique course experiences. Through a qualitative poetic content analysis framework (Soldati and Illingworth, 2020; Illingworth, 2022b) described below, student poems were coded to ultimately determine a robust set of emergent categories that characterize their experiences.

This initial study was carried out within the curriculum of an integrated, introductory chemistry and biology course class that has been previously described (Beers *et al.*, 2021) and assessed (Pociask *et al.*, 2021) using more traditional methods such as transcript analysis and focus groups. This is a team-taught course intended for first-semester undergraduates that meets for more weekly contact hours than a corresponding 'standard' chemistry-only or biology-only introductory course (but for less time than the standard courses combined) and that places great emphasis on community-building, content integration, and skill-building. Piloting this study within this unique course yielded another way to assess its effectiveness at community-building and integrated learning that could be compared and analyzed along with traditional focus group data from previous years. This course is part of the chemistry and biology curriculum at Wellesley College, an all-undergraduate liberal arts institution that serves historically disadvantaged gender identities as a women's college. Students at Wellesley College come from over 50 countries of residence, with 52% of students in the Class of 2023 identifying as students of color, ~60% receiving financial aid assistance *via* the College's need-blind policy, and 18% being first-generation College students (*i.e.*, neither parent having received an undergraduate degree) (Wellesley College, no date).

Our study revealed the emergence of four categories that captured the diversity of student experiences in this introductory chemistry/biology course – (1) knowledge (*e.g.*, obtaining content and conceptual knowledge/understanding or navigating support structures in place to gain knowledge and skills), (2) community (*e.g.*, collaboration or lasting friendship), (3) emotions (either positive or negative), and (4) identity (*e.g.*, a sense or of a lack of disciplinary belonging). Each of these categories is described further below, with poetic exemplars that reflect and add to well-documented ideas within the broader scholarly context of chemistry and STEM education. To our knowledge, this study demonstrates the first systematic analyses of poetry written by chemistry students (here, as part of an integrated course) to understand their experiences in a 'gateway' undergraduate course. The categories and corresponding ideas that emerge are consistent with many found in the literature, helping to validate this novel method that can be easily implemented for other classrooms. This initial study lays the groundwork for future ones that explore the use of reflective poetry in STEM classes further, including those that compare its utility with more traditional ways of gauging student experience or those that explore whether poetry writing within a chemistry context benefits the students themselves.

2. Methods

Any approach that uses qualitative content analysis should be guided by the following seven steps: formulate research questions, select sample to be analyzed, define the codes to be applied, outline the coding process, implement the coding process, determine trustworthiness, and analyze the results of the coding process (Hsieh and Shannon, 2005). These seven steps (see Fig. 1) form the basis of poetic content analysis (Illingworth, 2022b). This research method uses poetry as a form of data to provide further insight into the interpretation of scientific topics and how they are communicated. The first six steps are described in detail below, with the seventh step (Analyze Results) discussed in Section 3. For a more detailed walk-through of the process including explicit examples for each step, please see Section 4 in (Illingworth, 2022b).

2.1 Formulate research question

Poetic content analysis is underpinned by an interpretivist perspective, *i.e.*, it does not seek to find a singular truth, but

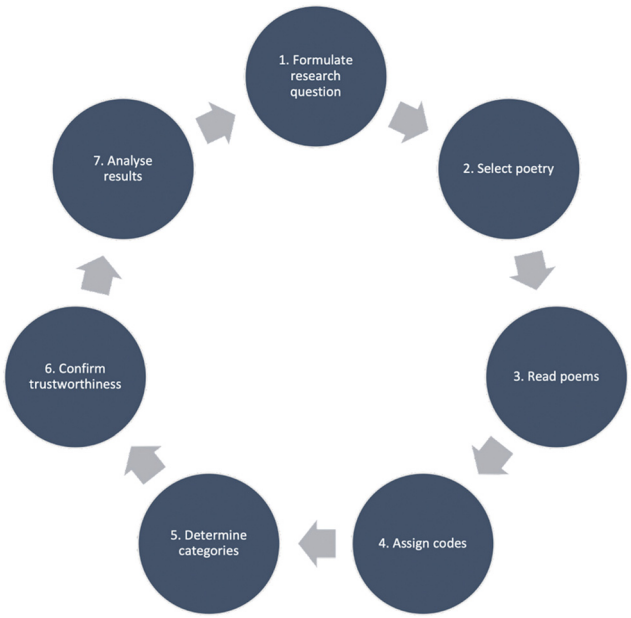

Fig. 1 An overview of the poetic content analysis method (Illingworth, 2022b).

offers a method for interpreting the diverse ways in which knowledge is itself perceived. As such, in constructing a research question it is important to be congruent with the interpretivist theoretical perspective that underpins this research method, thereby helping to ensure that there is consistency in the research methodology as a whole.

Given that this study was concerned with trying to better understand the experiences of undergraduates in an introductory chemistry course (here, integrated with biology), (see Section 1), the following Research Question (RQ) was defined:

RQ: Can first-year undergraduate students' original reflective poetry be a potentially useful tool for others to learn about their course experiences?

In this study, we aimed to see whether students' poetic responses reveal ideas and threads that have been previously observed in similar populations, as a way of validating this new method. Future studies could explore more focused questions that involve comparing the use of poetry to other more traditional ways of learning about student experiences.

2.2 Select poetry

First, we sought approval *via* the institutional review board overseeing human subjects research at Wellesley College, who determined the protocol to be IRB exempt before any poetry was collected (IRB protocol: #22020R-E).

In informed consent documents, we acknowledged that some students may find the process of reflective writing psychologically or emotionally powerful and/or cathartic. We aimed to address these risks by naming on-campus support resources students can access if needed. Students might also have become stressed and anxious about writing poetry in a science course – something they would not predict would be a requirement in such a course. To address these concerns and to engage and excite students about writing poetry, we provided many examples of poetry throughout the course and held a bespoke workshop to introduce students to the mechanics of writing poetry. This workshop was an interactive 90 minute session (that can also be adapted to be an hour) in which students were invited to read and discuss poetry and then to consider how it might be used as a reflective tool. The methodology that was adopted for this workshop is outlined in a recent article (Illingworth, 2022a).

All the students in the class were asked to submit a poem, approximately 80% of the way through the course, which responded to the following prompt:

''Reflect on your experiences in this course. Write a poem in which you capture and/or communicate these experiences. You can choose to focus on any individual aspect or on multiple aspects of this course. Your focus/foci can be academic, social, both, or something else entirely. The form you choose for your poem is also entirely up to you. You can use the poetic forms we looked at throughout the course as inspiration, but ultimately, you can choose or create a structure that works best for you to communicate or capture your thoughts and/or feelings.''

The submission of a poem was a required assignment for the course, although the 'quality' of the poems was not graded. Rather, all the poems were read by one of the authors to determine if they met the threshold of reasonable effort (which they all did). Through grading this assignment only on completion and reasonable effort as opposed to poetic quality, we thus allayed student anxiety about their performance on this task.

On submitting their poems, students were shown a description of the study and any potential risks and how we aimed to ameliorate them. Students were then asked for their informed consent to include their poems in the study and for excerpts to be shared for illustrative purposes, and it was made clear that they would not be negatively affected if they did not agree for their poems to be used in this manner.

2.3 Read poems

The collected poems need to be read through initially so that the researcher(s) can become comfortable with them as a data set. When doing qualitative content analysis with any textual data, it is important that this familiarity occurs before the assignment of any codes (Dey, 1993). Doing so helps to give confidence in managing the poetry, and it is also an essential step to help 'clean' the data set before beginning the next stage of the research method.

In our study, during this initial reading phase, one of the authors first removed and/or redacted any potentially identifying information prior to the second author's initial reading. Out of a class of 31, 30 of the students consented for their poems to be used in this study, and their poems comprised the resulting data set. It should also be noted that none of the poems were ever 'corrected' for spelling or grammar, as to do so would have potentially undermined the richness and authenticity of the poetry.

2.4 Assign codes

A traditional approach to coding data during qualitative content analysis would be to begin by identifying meaning units in the text, condensing these down to smaller units, and then labelling these units with codes. However, poetic content analysis utilizes a different approach to its treatment of condensed meaning units, negating them in favor of broader labels. This is because poems, unlike more traditional qualitative data sets, can be crafted by the author so that every line has 'meaning.' As such each line of the poem could already be a meaning unit and should not be condensed further.

This process was conducted independently by both authors. As new codes were realized, we each checked back through the poems that had previously been coded to see if these also contained any lines that could be labelled with any newly emergent code. Of the codes that were determined, the poems were then read in full again to make sure that each had been coded accurately. We each then read the individually coded segments again and made sure that they were appropriate for the code to which they had been assigned. The independent coding tables of both authors are shown in Tables S1 and S2 (ESI†), respectively

2.5 Determine categories

Following our independent assignment of codes, we both met to discuss how these might be grouped into broader categories that collect codes containing overlapping issues related to the RQ. The resulting categories are shown in Table 1. To improve the trustworthiness of our approach, following this joint classification, we both independently read all the poems again and made sure that the previously coded lines could be assigned to at least one of these four emergent categories and also determined whether any previously uncoded portions may now be coded within existing codes, given the broader categories. We also both independently confirmed that there were no newly emergent categories.

2.6 Confirm trustworthiness

All qualitative content analysis involves a degree of subjectivity in both the coding and the analysis, as it is not possible for any researcher to detach their own lived experiences from the process. Given this subjectivity however, it is still necessary for the whole research process to be verifiable, to help ensure the integrity of the approach.

The validity and reliability (and hence the trustworthiness) of poetic content analysis can be established by ascertaining a strong auditing trail throughout the process, including a justification for the selection and cleaning of the poetry and being open and transparent in the creation of any codebooks. As can be seen from Tables S1, S2 (ESI†) and Table 1 and the surrounding discussions, there is clear documentation for all the steps that we have taken during the poetic content analysis in relation to the RQ. This detailed auditing means that other researchers could follow the steps that we have taken in arriving at the four emergent categories shown in Table 1 (Illingworth, 2022b). The interpretivist nature of this research method means that such researchers may arrive at distinct categories, but that does not invalidate the trustworthiness of the approach (Morse *et al.*, 2002; Cypress, 2017). As will be evidenced in Section 3, the analysis of the results and the contextualization of the four emergent categories with additional research literature, alongside evidential segments of the coded poetry, help to give further confidence that the way in which we have answered the RQ is a useful (and thus valid) interpretation.

3. Results and discussion

As can be seen from Table 1, four major categories emerged from the poetic content analysis. We will now discuss each of these emergent categories, how they relate to the research question (''Can first-year undergraduate students' original poetry be used as a reflective tool to understand their course experiences?''), and how they compare to other research that has been conducted in terms of student experiences of undergraduate chemistry and related courses.

3.1 Knowledge

The first category to emerge was termed 'Knowledge' and included references relating to learning disciplinary content and skills as well as general study skills. These poems revealed a diversity of ways in which students were engaging with, understanding, or confused by either course content or the learning process in general.

The most direct examples of poetic content within this category are those in which students explicitly mention learning about or understanding certain scientific content:

Table 1 The combined categories that were used to classify the initial codes of SI and MR

Category	Definition	Codes
Knowledge	These lines make reference to the construction or search for knowledge.	Hard work (SI), improvements to knowledge (SI), rewarding (SI), specific concept (SI), late night studying (MR), learning (MR), confusion (MR), formal support (MR), worth it, rewarding (MR), study skills/time management (MR), interdisciplinary (MR)
Community	These lines refer to an aspect of community or community spirit.	Collaboration (SI), community (SI), pastoral care (SI), caring professors (MR), community/friendship (MR), collaboration/help (MR), admiration of Peers (MR)
Emotions	These lines make reference to a specific type of emotion.	Fun (SI), pride (SI), triumph/pride (MR), pain/frustration (MR), confidence/nervousness (MR), fun (MR), stress (MR), overwhelmed (MR)
Identity	These lines make reference to a sense of personal or shared identity.	Identity (SI), prior uncertainty (SI), self-doubt (SI), challenges (MR), good fit? (MR), unfamiliar (MR), belonging (MR), hopes for future/excitement for opportunities (MR) adjusting/uncertain (MR), stability (MR), identity (MR), growing (MR), routine/familiarity (MR), perseverance (MR), competition (MR)

I learnt how to calculate
Avogadro's constant
And understood how DNA ended up
Becoming a protein
(Poem 2)

My ideas of the natural sciences grew and developed...

And lastly, the material of this course
From electron orbitals to DNA replication
From the myriad of models with their grand limitations
From spending hours on Pymol staring at amino acids
To deciphering PCR lanes in evaluation

I had so much fun learning about you...
(Poem 8)

Students also commonly described being confused about course material. The following excerpts describe instances of shared confusion, initial confusion that was resolved, and individual ongoing confusion:

when I close my eyes at the end of the day,...
...I hear shared confusion
(Poem 11)

I went to office hours with a sense of confusion
Because I just couldn't visualize what was asking to be proven...
(Poem 20 – start)

...It seems obvious to me now that a half-life of a first order reaction doesn't depend on an initial concentration
But previously I had been stuck because I was only looking at my graph with focused examinations
So simple yet I had never taken a step back to look away
From what the math and numbers might display
(Poem 20 – end)

What we just learned? Can't tell
Still don't understand the material well
Constantly confused these months I've been
(Poem 28)

In some instances, there was also occasional mention of the emotional consequences of gaining knowledge (*e.g.*, learning was "fun," shown in Poem 8 above). In other instances, however, students focus even more explicitly on the positive feelings experienced (or anticipated) upon obtaining knowledge and understanding, demonstrating a clear appreciation for the power and pleasure of success after great effort:

I am waiting for that sweet release
The bliss of unconscious competence
Is what this class
Has taught me to ultimately seek.
(Poem 3)

Until
The golden glorious
Moment of scientific understanding
Eureka!
knowledge
is rightfully your at that moment
(Poem 19)

While emotions will be the focus of Section 3.3, their intersection with obtaining knowledge is clear through such excerpts.

Taken together, these excerpts highlight the process-oriented view of learning that has been described in certain models of learning relevant to chemistry and more broadly (Broadwell, 1969; Burch, 1970; Perry, 1999; Dweck, 2006; Gute and Wainman, 2019). Indeed, in Poem 3 above, a student explicitly mentions the "Conscious Competence" learning model of Broadwell and Burch (Broadwell, 1969; Burch, 1970) Being self-aware of one's confusion or being able to articulate one's lack of a skill ("conscious incompetence") are crucial parts of the process to learn and can be used as an opportunity to discuss and practice effective strategies such as a growth mindset (Dweck, 2006), which has been shown to benefit underrepresented minority students in a general chemistry context (Fink *et al.*, 2018). Moreover, previous work has shown benefits of metacognition and self-assessment toward student learning in chemistry, and in particular, reflective writing (Burke *et al.*, 2006; Poock *et al.*, 2007; Gupta *et al.*, 2014; Gere *et al.*, 2019) as a means of accomplishing such metacognition. It is therefore possible that poetic reflections may also have similar benefits, which can be explored as part of future work. As a side note, the course instructors called weekly group-based assignments "Intellectual Journeys" (IJs) to highlight the idea of learning as a process, and this term was used by multiple students in their poetry, suggesting their successful adoption of it.

Within the poems, we also found multiple explicit references to formal academic support structures, with students often highlighting their benefits. Such support structures include faculty-led office hours and review sessions. They also include Supplemental Instruction (SI), a program initially developed and ultimately used for multiple subjects, including chemistry, at the University of Missouri at Kansas City (Blanc *et al.*, 1983; Arendale, 1994). It consists of optional, weekly sessions facilitated by an SI leader (usually a near peer who has taken the course in a prior semester), in which students work toward mastering content while also learning essential collaboration and study skills in a faculty-free environment:

Walking at night coming back from SI
I just got answers to my questions "why"
(Poem 4)

With hours in office hours
Deciphering the puzzles
(Poem 8)

Review sessions and extra study have my progress on a positive derivative path
I learned that in [course name], not math.
(Poem 13)

Academic support structures such as office hours and Supplemental Instruction can have a positive effect on student academic outcomes (Blanc *et al.*, 1983; Guerrero and Rod, 2013; Skoglund *et al.*, 2018), with multiple studies highlighting the benefits of Supplemental Instruction on chemistry students in particular (Gattis, 2000; Congos and Mack, 2005), especially at the introductory level (Rath *et al.*, 2012). These excerpts demonstrate that students who utilize them indeed recognize and tangibly sense their value, in agreement with the established idea that the social learning and development of students is extended by the support of someone who has a better understanding than the learner (Vygotsky, 1980).

Students in a first-semester undergraduate course are also often transitioning from having several hours of structured class time in high school classes to having far fewer such hours in college. Consequently, students suddenly need to implement strategies to engage with coursework independently of their instructors during their unstructured time (Morales, 2012). In some poems, students explicitly note making choices that demonstrate proactively practicing study and time-management skills:

> It was a Thursday morning over zoom,
> My first time waking up early, and getting myself out of my room
> I came prepared with my papers all marked
> As if it were a piece of bad contemporary art.
> (Poem 20)

> . . .texting my IJ group
> ''Can you guys meet Tuesday evening?''
> (Poem 26)

Finally, in addition to more direct references to gaining knowledge or understanding, poetry also provides an opportunity for students to use course content in a more abstract, creative way to generate or display an understanding of certain aspects of scientific concepts that might not be adequately highlighted by more traditional assessments or assignments (Pollack and Korol, 2013; Brown, 2015; Brown, 2019; Wardle and Illingworth, 2022). We found multiple examples of students using specific chemical or biological concepts metaphorically or to draw analogies to some aspect of their experience or identity. While many of these examples were not coded in the category of 'Knowledge' because they were tied more directly to other categories, we mention them here because they show indirectly that students may be engaging with concepts *via* synthesis, analysis, or creation based on conceptual knowledge, or other higher levels of thinking *via* Bloom's Taxonomy and related models (Bloom *et al.*, 1956; Krathwohl, 2002):

> Since September, my life has been a transition state
> Where nothing feels permanent
> (Poem 9)

> Do they know that dreams are better accomplished together?
> That atoms are stabilized when they're bonded together?
> That worlds form when one clashes against the other?
> That activation energy barriers are lower when enzymes are used together?
> That DNA cannot be replicated without one polymerase or the other?
> That science is the study of things together and not alone?
> (Poem 16)

> Am I truly stable-
> the noble gas I wish?
> Or am I decaying
> losing everything
> my very nucleus? . . .
> . . .My brain's too full
> but my octets not
> (Poem 5)

Poetry-writing clearly provided several students the freedom to ''spontaneously'' practice making connections between certain aspects of the science they were learning and their personal thoughts and feelings. In this way, writing or engaging with poetry enables a window into certain, more personalized ways (Paiva *et al.*, 2013) in which students are constructing their knowledge and incorporating it into their existing schemes, *via* a constructivist (Bodner, 1986) model. The ability of poetry to catalyze these personal connections may be enticing for some students in scientific domains, which many perceive as objective or impersonal fields.

3.2 Community

The second category to emerge from our analysis was 'Community,' a result that is expected as a successful outcome of this unique course for which an explicit underlying principle was Community Building (Beers *et al.*, 2021). Community and teamwork building were accomplished through both in-class/in-lab exercises as well as through multiple, voluntary out-of-class informal social experiences.

The following poetic excerpts explicitly refer to this sense of community:

> The dear community of this class
> My friends through [dorm name] debriefings and Sci dreaming
> Who I could not have gotten through this class without
> (Poem 8)

> Luckily the community in biochem will help
> And so will the professors who kindly offers her a guiding light
> (Poem 12)

> A community builds
> To create a guild
> Amongst the ordinary.
> (Poem 17)

Students also indicated through their poems that the course served as a catalyst to create friendships that they believe will last well beyond the course:

> [course name] was tough
> Biochemistry is sure no easy stuff
> Yet,

I met friends here
And while it might still not be clear
I am sure someday we will share a beer
Reminiscing the days so dear
(Poem 2)

But everyone showed that they indeed really cared
For the professors, the class, and also to me
I have found friends I can sit with under a tree
A hug a day keeps all of the pressure away
Every time we meet I have so much to say
I can't help but imagine, us the chaotic bunch
When we're old ladies gossiping over lunch
(Poem 4)

Nevertheless, we note that not everyone felt an unwavering sense of community, that there were instances in which students wondered if they were truly part of the community they observed or may at times have felt insecure within it, demonstrating a more conflicted intersection between community and identity (Section 3.4):

My friends molded far earlier than I in their puzzle pieces
Clicking our pencils in unison in the library
Tapping our toes
The eraser and paper creating a harmony of friction
Like a symphony of trial and error
Hoping not to become a comparer
(Poem 18)

I began to wonder if I even deserved to see the wonders of their world
Especially because everyone else seemed to play all around me
Why couldn't I have a good time, but everyone else did?
(Poem 14)

A major aspect of the course involved collaboration toward academic achievement, which involves the intersection of 'Community' with 'Knowledge.' There were many instances of students whose poems highlighted learning as a collaborative, team-based effort, where class members supported each other's success. Notably, students express the idea that friendship and community made their academic journeys more enjoyable and productive:

Of course I love class, and the professors are great
But it's nights like these where sometimes I wait
And pinch myself thinking that I'm really here
Laughing and learning with all of my peers
(Poem 7)

Yet my classmates stray away from being ''schoolmates''
And we become teammates
We explore
(Poem 18)

The following weeks I see the same 30 scientists every day
We study, eat, laugh, cry, complain, and support each other through the stress
First-years navigating through the academic and social pains, as they say
A tight and inclusive group, we truly wish well for each others' progress
(Poem 25)

''Make it home!'' said a tone,
''Pre-labs, IJs and 'celebration'
We won't be your competition''
So here they go, hand in hand
Explore in the magical Bio/Chem wonderland
(Poem 27)

The use of the word "explore" in more than one poem suggests that students might have felt a collective curiosity for science as part of this community, again suggesting the positive connection between community and disciplinary engagement. Past work has shown that using a holistic strategy of advising, peer leadership, and community-building during the initial year of college can increase student success (Greenfield *et al.*, 2013). Toward this end, learning communities such as this one or those created by paired or linked classes (Soven *et al.*, 2011) can be beneficial by helping to break down the somewhat artificial boundaries that often emerge between in-class academic experiences and out-of-class social ones (Upcraft *et al.*, 2004).

3.3 Emotions

The third category to emerge from the poetic content analysis relates to specific 'Emotions' that were expressed by the students in relation to their course experiences. A wide variety of emotions were addressed by the students in their poetry writing, ranging from what might broadly be categorized as positive emotions (*e.g.*, pride, determination, and even fun):

And at night, atop a pillow
I gaze outside through a small window
And to myself I proudly say
I'm glad I went to [course name] today
(Poem 15)

Yet I surge onward undeterred
Finding molar mass chemical formula referred
Unwinding DNA for replication
Good work ethic becomes fascination
(Poem 15)

I walk to [course name] and I'm stunned
Friends and teachers make class fun
Fun in the morning? How odd?
Like Mendel's peas! We're peas in a pod
(Poem 22)

to negative emotions (*e.g.*, sadness, frustration, and anxiety):

When your self-esteem's wrapped up in whether you do good or bad, it gets kinda hard to not get so sad.
(Poem 23)

When the results come back she was a little devastated
The number on the paper got her a little frustrated
(Poem 12)

I blink and the next moment I see my classmates already building connections
It seemed as though the elite 30 others had already left me behind
I am preoccupied with anxiety as the two strangers jump right into the directions
(Poem 25)

and those that might be thought of as conflicted, ambivalent, or a mixture of extremes:

This class has been an ''intellectual journey''
full of days of both triumph and agony,
an experience only understood by those of us in [course name].
(Poem 1)

Intellectual Journeys
Might occasionally be arduous
But always full of pHun
And so were thinking about workshops
Before they had begun
(Poem 2)

While the course made me very stressed and stupefied
It also taught me how to truly understand science topics
So I'll take the good with the bad
And know I wouldn't trade this time, and be glad
(Poem 8)

These excerpts help to demonstrate the extent to which students felt comfortable expressing their emotions in this format. By expressing these emotions in the poems, the students first had to reflect on such feelings and in turn display a level of emotional intelligence (*i.e.*, the ability to recognize, use and manage emotions) that may not otherwise have been engendered by a typical chemistry undergraduate class. Learners with higher levels of emotional intelligence have been shown to experience increased wellbeing, retention, and academic achievement (Thomas and Zolkoski, 2020), yet as highlighted by Bay and McKeage (Bay and Mckeage, 2006), attempts to increase the emotional intelligence of students often require targeted educational interventions. The degree to which emotions were expressed in the poems suggests that encouraging students to reflect on their learning experiences using poetry might offer a way to explore and nurture emotional intelligence in a classroom environment, an idea that can be explored as future work.

The poems indicate that the students mostly found the course to be demanding but worthwhile, demonstrating a link between knowledge (see Section 3.1) and emotions. Similarly, the fact that several students wrote about experiencing similar emotions in an equivalent way is further evidence of the sense of genuine community and emotive support that was also found to emerge from the data (see Section 3.2), as is evident from the following two excerpts of poetry:

This week's IJ was especially hard
We learned 'bout reaction rates with greeting cards
Mine's in my binder and it's smiley face
Reminds me this Journey is one I will ace
(Poem 7)

Yet there's no joy without a toil
Seen in my folder covered in foil
For every great grade, signs of progress
Sometimes, I cannot pass a test
(Poem 15)

Furthermore, by encouraging students to write poetry, it is possible for instructors to observe when students might need signposting to mental health or welfare support. Even if such poems are read without identifying information, then depending on the emotions that emerge from the data, discussions can be had in class that might not otherwise take place. This idea is in line with Jack and Illingworth (Jack and Illingworth, 2017), who found that encouraging students to write poetry as part of a reflective process can potentially improve quality care provision and emotional health, which might in turn lead to a reduction in both stress and attrition.

3.4 Identity

The final category to emerge from the poetic content analysis was 'Identity.' This category relates to aspects of identity that were expressed by the students in relation to their integrated chemistry/biology undergraduate course. Here, we interpreted ''identity'' as inward reflections about one's longer-term potential or sense of self either prior to or whilst undertaking this first-year course. We found some overlap with 'Emotions' (see Section 3.3), as some of the exemplars shared below also have labels ultimately coded within the 'Emotions' category, although ''Emotions'' as a category refers more to the immediate feelings themselves rather than the underlying sense of self that might lead to them.

Those poems that referred to identities prior to beginning the course often referred to self-doubt, and of the student being unsure if they would 'fit in' or be as 'intellectually capable' as their future classmates, as demonstrated by the following excerpts:

When I stepped into the classroom
I thought I was doomed
I couldn't sing
Let alone know a single thing
(Poem 2)

I came to this course thinking I'd struggle. But I never believed I'd have this much trouble.
(Poem 23)

Other aspects of prior identity that were expressed in the poems made reference to the extent to which the students had (or had not) felt a sense of belonging to their schooling and home lives, the opportunities for science that they had (or had not) experienced, and how they had hoped this might change when starting their undergraduate work, and in particular this course:

I came here to escape
From my house of horrors
One where science doesn't see my gender
As an explorer
(Poem 21)

In the 9th grade, my tiny school didn't offer any engineering classes.
I spent a semester
(taking apart)
(rebuilding)
(losing screws to)
A lawnmower motor-
"Small Engine Repair" was the best I could do.
I mean, SOMEONE engineered this motor.
Close enough.
(Poem 6)

These emergent narratives highlight the weight of expectation that students place on both themselves and their undergraduate experiences prior to enrollment (Schmitt *et al.*, 2013; Meaders *et al.*, 2019), which serves to perhaps put further pressure on both student and course when term begins. This is also further evidenced by other exemplars that belong in this category, and which explore the extremely symbiotic relationship that students express between this chemistry/biology undergraduate course and their sense of identity for both their current and future selves:

Plagued with indecisiveness,
I hope that the class gives me clarity
and solidify if the sciences are really for me.
(Poem 1)

The course's name implied so much potential and hope
Of what I could learn in a condensed amount of time
Knowing that my two favorite worlds would collide,
Excited my passion to learn
(Poem 3)

The role that a first-year chemistry (or biology) undergraduate course can play in defining a student's future career and identity is further evidenced by the following excerpt, which was written by a student who presumably had originally decided to take classes designed to allow a progression to medical school, and may be reconsidering this decision based on the experiences of this undergraduate course:

Future classes in chemistry I initially did foresee
Yet writing balanced nuclear equations isn't for me
Both profs teach with such passion and enthusiasm
Creating visuals to depict structures such as the cytoplasm
While I gave it a try, [course name] isn't my cup of tea.
Guess I'd better stick to Grey's Anatomy
(Poem 28)

College is clearly an extremely formative experience for the mostly young adults that attend (Scanlon *et al.*, 2007; Lairio *et al.*, 2013). These poems and the subsequent analysis provide further evidence of the potential role that a chemistry undergraduate course can play in helping students to explore and come to terms with their own identities. This is true not only with regards to future career paths, but also in terms of self-judgment, belonging, change, and STEM identity, as evidenced by Poem 21, Poem 5, Poem 9, and Poem 29 respectively, some parts of which again demonstrate the intersection between identity and community:

I am here because I wanted to shine
In a mass of women
Who are equally so sublime
But when we bond
Their touch burns
And my heart turns solid
My stomach churns...
...Sometimes I ask if I should even be here
As my peers look at me in spite...
...I belong here
No matter what paradoxes come in sight
Even blackholes
Won't stop my fight
(Poem 21, excerpted throughout)

Sometimes I feel I don't belong
I should learn to be less
My energy is just a sign
of my unstableness
(Poem 5)

Since September, my life has been a transition state
Where nothing feels permanent...
...I have so many different versions of myself in my head
They create resonance...
...Maybe I'm not meant to live in a quantized state
Maybe I'm meant to go through the peaks and troughs
If we're all made up of waves
How can we ever have an identity that's static?
(Poem 9, excerpted throughout)

...I have pondered if I should quit.
Is STEM truly the right fit?
(Poem 29)

Many of the explorations of identity that are expressed in the poems are also concerned with imposter syndrome (Kolligian and Sternberg, 1991), and indeed this is even explicitly acknowledged by one of the students in their poem:

Doubts stir,
Thoughts whirl,
Imposter syndrome occurs.
(Poem 17)

3.5 Intersectionality and totality of categories

As discussed above, these four emergent categories (knowledge, community, emotions, identity) are not mutually exclusive, but intersecting, and poetry can offer a way for students to concisely explore these intersections, as further evidenced by this excerpt, which highlights the integrated academic, personal, and social experience of this student:

And on my walls, art posters hang stable
You'll find my periodic table
And as I understand the trends

I find myself with many new friends
(Poem 15)

Returning to our RQ ("Can first-year undergraduate students' original reflective poetry be a potentially useful tool for others to learn about their course experiences?"), we have shown evidence that the poetic excerpts and their emergent categories indeed demonstrate ideas that are echoed in literature based on more traditional methods. Taking these four overlapping categories holistically, we see evidence that undertaking a chemistry or related degree involves the pursuit of knowledge, but in doing so it is also necessary to explore the development of one's identity and how community and emotions can support such a voyage (Reyes, 2011; Blackley and Howell, 2015).

4. Implications and future work

This work has presented an initial study into how poetry might be used as a reflective tool for others to understand first-year undergraduate students' chemistry or related course experiences. By inviting students from such a course to write poetry, we have demonstrated how this approach can help students and their educators to fully consider the multiple journeys that they embark on when undertaking such a course. We demonstrate that student poetry can provide valid and useful information by showing how emergent themes echo and support many ideas from the broader literature that emerged from different, complementary methods. Importantly, the excerpts above collectively highlight how poetry can provide – in a manner that does not specifically solicit these particular ideas – insight into many factors mentioned in Section 1 that are linked to student outcomes, including student competency beliefs, sense of belonging, perceptions of gender bias, science identity, and student perception of grade outcomes. Our findings result from the use of an innovative research method (poetic content analysis) which we hope others will consider in their own future work to better understand student experience along many dimensions.

Limitations of the current study include the unavoidably subjective nature of qualitative data analysis. Through applying the research method described above, we aimed to reduce subjectivity, and our goal here is not to generalize widely from this first study but to demonstrate a useful process and generate hypotheses that can be built upon in future studies. Of course, our sample size here was small, involving only one course that was atypical in its time-intensive, integrated, and community-focused nature, therefore limiting the transferability of the particular categories found here to other classrooms. Nevertheless, a future goal is to implement this methodology, which itself is highly transferable, in a broader range of courses, including more traditional chemistry courses, providing a method to analyze and ultimately compare student experiences from different classroom approaches.

In addition to broadening the implementation of this method, this study provides the initial basis for many future studies. Now that we have introduced poetry as one means to gauge student experience, it would be important in the future to compare this method with other more traditional methods. Indeed, an analysis of student experiences had been previously conducted on prior cohorts of this course using focus groups consisting of a subset of students across three years (Pociask *et al.*, 2021). In that study, students were reflecting on the course one or more years after enrollment. While a formal comparison between that study and the current one is beyond the scope of this work, the current study suggests that student-written poetry can both corroborate and complement data obtained from other traditional means. Both studies revealed the crucial importance of community, collaboration, and skill-building to the student experience (with the prior study additionally revealing how students found those attributes helpful in future courses). However, based on this study, we hypothesize that the poetry may provide even more insight into the wide range of 'raw' emotions or identity development students are experiencing in a course, and that students might potentially be more comfortable in discussing emotions through poetry than *via* other more traditional ways. Combining poetry and other creative means of reflection with more traditional assessments can potentially provide a holistic window into student experiences and provide more avenues and data for improving outcomes. Indeed, as future work, we plan to collect and analyze student reflective poetry in conjunction with or longitudinally with other, more traditional forms of qualitative data such as focus groups or survey responses to continue to validate the information obtained *via* poetry. Importantly, as another goal of future work mentioned in Section 3, we plan to use these more traditional tools to better understand how, if at all, reflective poetry writing may directly benefit the students themselves, in part by considering its relation to metacognition and emotional intelligence.

Additionally, one could test a future hypothesis that sharing such student poetic excerpts amongst and with other students may benefit them by increasing the visibility of potentially shared experiences, such as the frustration and ultimate reward felt during the requisite stages in the learning process or the strong, sometimes conflicting emotions felt while learning. Indeed, if the many students who wrote about imposter syndrome or self-doubt (either explicitly or implicitly) could read poetic excerpts by their (many) classmates who also believed that they were not as competent as others perceive them to be, then this may help to counter such attitudes and help improve self-belief amongst the cohort. Also, the poetic public sharing of the benefits of collaboration and formal academic support structures such as office hours could also benefit students. Given the evidence that lower-income students who went to under-resourced high schools often are more hesitant to participate in such opportunities or are less aware of their purpose and benefits (Jack, 2019) and that lower-income and first-generation students may initially be less likely to engage in certain academically beneficial behaviors, such as studying in groups, when compared with their peers (Engle, 2008), sharing relevant poetic excerpts broadly could catalyze more diverse student engagement in

behaviors potentially leading to their increased academic success.

Finally, we can also envision future studies that bridge the use of poetry to self-reflect with those that use poetry to communicate scientific content. Indeed, the common student use of content-based analogies and metaphors in their poetry (discussed in Section 3.1), when not even prompted or explicitly solicited here, suggests that even reflective poetry may be a way to further probe the strengths and limitations of metaphor and analogy as pedagogical tools, which is itself a rich area of study (Beall, 1999; Orgill and Bodner, 2004; Sarantopoulos and Tsaparlis, 2004; Niebert *et al.*, 2012; Didiş, 2015). Additionally, students' poetic use of analogy or metaphor between course concepts and their experiences can also bring to light student misconceptions about course concepts or terminology, exemplified here:

> Like a enzyme binding to a active site
> This puzzle piece must collide
> In the right orientation
> Your hand with enough energy to overcome the barrier
> Can I see myself succeeding?
> (Poem 18)

This very creative excerpt shows deep understanding of certain concepts while also highlighting a confusion between the meaning of ''active site'' (which is a region on the enzyme itself) and the potentially more fitting term here, ''substrate'' (the key reactant molecule in a mechanistic elementary step with which the enzyme initially interacts). Like prior work using creative and reflective writing in chemistry classrooms (Cooper, 1993; Rhoad, 2016) and poetry in biology classrooms (Mcvey and Pechenik, 2020) for a different purpose, our study also suggests that such exercises can provide windows into student confusion or misconceptions that may be hard to access by traditional assessments. Relatedly, prior work suggested that students can benefit from and enjoy using poetry (and art) to convey concepts in chemistry (Furlan *et al.*, 2007). Though not the goal of the current study, assessing the use of spontaneous content-specific metaphors through self-reflective poetry to gauge student content understanding, identify conceptual confusion, and even improve student content understanding could be interesting future work.

Data availability

All coding tables and categories are readily available upon request as well as all poems with identifying information removed, assuming participant permission.

Ethics and human subjects research approval

The Institutional Review Board overseeing human subjects research at Wellesley College approved the ethics for this study and determined the protocol to be IRB exempt (IRB protocol: #22020R-E).

Author contributions

We are using the CASRAI Credit system to acknowledge the different roles of the different authors. SI was involved in conceptualization, data curation, investigation, methodology, visualization, writing the original draft, and review and editing. MR was involved in conceptualization, data curation, investigation, methodology, visualization, writing the original draft, and review and editing.

Conflicts of interest

The authors declare no competing interests or conflicts of interest.

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