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Capturing students' identification of the relevance of organic chemistry in writing

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Appealing to students' affect in academic settings, such as demonstrating chemistry's relevance to their life, is one strategy instructors may use to support students' in learning. This study investigates the types of connections that students make to organic chemistry when responding to an open-ended writing assignment. Students enrolled in an introductory level organic chemistry course were asked to choose and write about an organic molecule they felt was important to their life, in doing so students wrote about the molecule's relevance to their life. Analysis of the writing was supported by semi-structured interviews with a subset of the students in which they discussed their approach to completing the assigment. Conclusions from this study suggest that students successfully made connections between their chosen moleucle and their life. Considered through the lens of relevance, students can both seek and find relevance in organic chemistry topics on a personal, societal, or vocational level; and therefore may reinforce their comprehension and appreciation of chemistry.

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Introduction

Attention to students' affect when learning has increased in recent years with many studies measuring students' self-efficacy, interest, attitudes, and motivation when taking chemistry courses (Glynn and Koballa Jr., 2006; Ferrell and Barbera, 2015; Cicuto and Torres, 2016; Flaherty, 2020). After developing various instruments to measure student affect, these researchers, along with others (Reid, 2008; Ferrell *et al.*, 2016), have shown explicit connections between affect and assessment performance. Implications stemming from these studies heavily suggest that facilitating positive student affect can support student achievement. Creating opportunities that specifically appeal to students' interests, therefore, may enhance their learning of chemistry. Assignments which provide students with the opportunity to shape their response, such as deciding what topic they focus on, could serve as a vehicle for students to explore their interests and thus elicit positive affective responses.

Affect and learning in chemistry

Students have their own individual perspectives and experiences, therefore what each student finds meaningful while learning will vary. Students' learning can be supported by explicitly relating content to students' individual interests, which is directly connected to relevance. However, the Royal Society of Chemistry found that, in general, the public does not see chemistry as personally relevant (TNS BMRB, 2015). Efforts to demonstrate chemistry's relevance in education have increased as various research teams have since developed relevance frameworks to try to capture the ways in which course material can be relevant to students (Albrecht and Karabenick, 2018; Hartwell and Kaplan, 2018; Priniski *et al.*, 2018). Recognizing the importance of relevance, some studies have directly measured perceived relevance (Hermanns and Keller, 2021), whereas others have analyzed how chemistry classroom interventions appeal to students' perceptions of relevance (Broman *et al.*, 2022; Pernaa *et al.*, 2022). Transforming research into practice, classroom interventions and assignments may be designed to elicit students' thoughts on the relevance of chemistry.

Considering students' affective experiences and relevance, specific attention has been given to studying factors that influence performance of students in organic chemistry courses (Lynch and Trujillo, 2011; Villafañe *et al.*, 2016; Austin *et al.*, 2018; Liu *et al.*, 2018; Gibbons and Raker, 2019; Raker *et al.*, 2019). These quantitative studies indicate that a qualitative perspective is needed to further understand student affect, as qualitative methods may provide rich details of individual's views or experiences within a given context (Libarkin and Kurdziel, 2002). Reviewing past literature on affective studies in chemistry education, Flaherty (2020) reported that just 5% used purely qualitative methods and

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10% used mixed methods, thus further supporting the need for qualitative methods. Flaherty (2020) also described student affect as "fluid and inherently susceptible to impression from several influences." The benefits of qualitative research methods may allow us to better capture the complex nature of affect and characterize students' experiences at the individual level and not reduce them to less descriptive and less accurate depictions.

Writing to support affect

Writing is a common instructional practice in STEM, and chemistry specifically (Finkenstaedt-Quinn *et al.*, 2022b). Research related to writing in chemistry courses is primarily divided between using writing to support science communication skills (Walker and Sampson, 2013; Çetin and Eymur, 2017; Rootman-le Grange and Retief, 2018), conceptual learning (*e.g.*, Cox *et al.*, 2018; Moon *et al.*, 2018; Schmidt-McCormack *et al.*, 2019; Finkenstaedt-Quinn *et al.*, 2020), and disciplinary reasoning (*e.g.*, Watts *et al.*, 2020; Petritis *et al.*, 2021; Watts *et al.*, 2022). As a whole, these studies demonstrate that students can engage with scientific practices and chemistry content through the act of writing. Furthermore, writing is a useful practice as it captures and makes explicit the writer's thinking and reasoning (Flower and Hayes, 1981). Thus, examining students' writing can provide insight for both instructors and researchers on what and how students are learning.

More recent studies have examined student affect related to writing assignments, with some specific studies indicating that students' recognition of the relevance of course content can be facilitated *via* writing. Ho *et al.* (2021) described the results from implementing a service-learning intervention which incorporated reflective writing into an analytical chemistry course. They found that the reflective writing supported positive engagement and attitudes. Within an organic chemistry context, two studies have looked at students' affective experiences with scaffolded writing-to-learn assignments (Gupte *et al.*, 2021; Petterson *et al.*, 2022). Using a combination of surveys and interviews, both studies found that students had positive affective learning experiences, partially attributed to the assignment helping students identify the relevance of course content to authentic contexts. Additionally, the assignments helped students to recognize the connections between course concepts and prior coursework. Finkenstaedt-Quinn *et al.* (2022a, 2022b) reported similar findings in a biochemistry course context for a science communication assignment designed to support students' recognition of the relevance of course content. Also using qualitative methods to analyze surveys and interviews, they found that translating a research seminar for the general public led students to recognize the relevance of course content beyond the course. Outside of chemistry, Balgopal and Wallace (2013) described a series of assignments centered around socio-scientific issues (*i.e.*, issues important to both society and science). They identified that in addition to supporting conceptual learning and argumentation, the framing of argumentative essays in locally relevant socio-scientific issues led to increased agency for students. These reports are consistent with principles for writing assignment design, which indicate that providing students with opportunities where they can exercise agency is important for creating meaningful writing experiences for students (Eodice *et al.*, 2017).

Study aims

Organic chemistry has a reputation as a "gatekeeper" course for many students who struggle with its abstract nature (Lynch and Trujillo, 2011; Austin *et al.*, 2018; Liu *et al.*, 2018). Therefore, we have chosen to provide students with an assignment that will encourage them to identify the relevance of course content in organic chemistry. We designed this study to examine how students identified organic chemistry as relevant when responding to an assignment. Furthermore, given the benefits of qualitative methods (*e.g.*, the ability to gain a more nuanced view of student affect) our investigation focuses on an analysis of students' writing and interviews. Our study is guided by the following research questions:

1. What types of connections are students making between their lives and organic molecules?
2. How do students approach selecting and describing their connection to their organic molecule?

Conceptual framework

This study is guided by Stuckey *et al.*'s (2013) relevance in science education framework. This framework is situated within theories of the affective domain of learning and motivation, where the relevance of course content to students and society can function as a motivator to students' learning (Keller, 1983; Turner and Paris, 1995). In their framework, Stuckey *et al.* (2013) synthesized the ways in which relevance has been conceptualized in the field of science education to create a three-dimensional model that incorporates individual, societal, and vocational relevance. Each of these dimensions is presented as having two axes: one capturing intrinsic *versus* extrinsic relevance to the student and the other capturing present *versus* future relevance to the student. The individual dimension considers what students identify as relevant for themselves, either based on their interests or the knowledge and skills they recognize as important for progress and success. The societal dimension considers what is important for students to know to behave in a socially conscious way (*i.e.*, actively contributing to the current and future society). Lastly, the vocational dimension considers what is important for students to know or learn to pursue a vocation, as well as providing students information on the range of vocations available to them. Together, the three dimensions capture what students deem and recognize as relevant, but also what others (*i.e.*, educators, policymakers) deem relevant to their development.

In the context of this study, students complete the writing assignment by describing their reasons for identifying their molecule as important to their lives. Through the act of selecting and writing about a molecule, students make the relevance of chemistry to their lives explicit, which may support the affective domain of learning.

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Methods

Context and participants

This study examined how students responded to a low stakes writing assignment developed to support students as they recognize the relevance of organic chemistry through identification of a personal connection to an organic molecule. The writing assignment was incorporated in a first-semester introductory organic chemistry course at a large, research-intensive university in the midwestern United States. The assignment was given to students at the beginning of the semester and they had roughly a month to complete it. The course objectives are directed at students gaining an understanding of fundamental principles of organic chemistry. Major topics covered in the course include structural representations, stereochemistry, organic reactions involving functional group interconversions, spectroscopy, and aromaticity. Students attend lectures taught by the primary course instructor three times per week and a discussion section led by a graduate teaching assistant once per week. Approximately 150–200 students are enrolled in the course each semester. The course primarily consists of chemistry, biochemistry, and chemical and biomolecular engineering majors. Data collection occurred during the Fall 2020 semester, during which time the lectures and discussion sections were held remotely. Of the 147 students enrolled in the course, 143 completed the writing assignment and consented to participate in the study. Of these students, 11 students were also recruited to participate in an interview about the assignment. This study received institutional review board approval and all data were deidentified prior to analysis. Pseudonyms are used when discussing student responses.

Positionality statement

The study team consists of the instructor for the course in which data was collected (SCZ), one graduate student researcher (SLM) and a former graduate student researcher (NFG), a research scientist (SFQ), and a chemistry education research faculty member (GVS). One author designed the assignment and implemented it in their classroom with the goal of making organic chemistry less abstract for students and increase engagement (SCZ). Three members of the research team (NFG, SFQ, and GVS) brought their prior experience with designing, implementing, and researching non-traditional writing assignments in chemistry classrooms to this project. This experiential background informed how we thought about the refinement and implementation of the assignment and how to best incorporate it into the course. It also informed our qualitative approach to the study where we have found from prior studies that the writing is a rich source of data that complements the context gained through interviews. Much of the data analysis was led by one member (SLM); this was their first chemistry education research project and thus they approached the analysis with a blank slate and searched for patterns within the early stages in the analysis. The primary research focus of the other member of the research team involved in the data analysis (SFQ) is on the use of writing-to-learn in STEM courses, with a recent trend towards affect and engagement related to writing. Their prior research experiences shaped the lens through which they viewed and analyzed the data, such as suggesting the use of the relevance framework (Stuckey *et al.*, 2013) to analyze the interviews and consider the data as a whole.

Assignment description

A few years prior to data collection for this study, the primary instructor for the course (SCZ) designed the writing assignment to help students identify how organic chemistry was relevant to their daily lives. The assignment is described in Garza *et al.* (2022) and presented in full in Appendix – writing assignment description; students were asked to identify an organic molecule that is important to their life and describe how it was related. Intended to be a low stakes assignment, it made up 8% of student's course grade. As long as the student's connection to the molecule was clear and they provided a correct 2D and 3D representation of their molecule they received full credit. Each student's molecule choice was reviewed by the primary instructor of the course to ensure that they chose a different molecule than their classmates and to ensure that it was an organic molecule. Students were required to choose a unique molecule because the instructor felt it would encourage students to focus on their own connection rather than hearing from a classmate and following their lead if their molecule or story was different. This also assured that there would be no duplicate submissions of the same assignment. Additionally, the strength of the connection between the student and the selected molecule was strongly emphasized in the assignment description. As the purpose of this assignment was to lead students to explore the significance of organic chemistry to them personally and not about content accuracy, students were not required to include chemical descriptions or research on the molecule aside from an image of the molecule's 2D and 3D structure. Students were given the writing assignment at the beginning of the semester and had approximately a month to complete it. All assignments were submitted remotely in the form of a pdf or document. The primary instructor for the course (SCZ) read each submission and provided individualized feedback to students.

Data collection and analysis

The data for this study consisted of 143 writing assignments and 11 interviews. The primary course instructor shared the writing assignments with the research team, and they were deidentified prior to analysis. The writing assignments served as a rich source of data as the writing revealed what types of connections students were making with an organic molecule and how they described it. All students were emailed with the opportunity to participate in an interview about their experiences with the writing assignment. There were no incentives affiliated with participating in the interview. Eleven students agreed to participate. The interviews were semi-structured in form and conducted remotely *via* Zoom by a member of the research team (NFG) not affiliated with the institution where the assignment was implemented. Questions prompted

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students to think about whether and how the assignment guided them to recognize the relevance of organic chemistry when they were selecting and writing about their molecules. They were asked to think about the timeline of their connection with the molecule, distinguishing whether the connection with their molecule was tied to their past, present, or future. The interviews ranged from approximately 10 to 20 minutes in length. The interview protocol was previously published in Garza *et al.* (2022). Data from the interviews provided insight on each student's approach for identifying their molecule and describing how they saw chemistry as relevant outside of the academic course.

The 143 student responses to the assignment were analyzed inductively to capture the nature of the connections that students were making. The coding scheme used to analyze the writing assignments is presented in Appendix – writing assignment coding scheme. The writing was first coded for the connection students made to their molecule of choice; each connection was identified as a *medicine, food*, or *other*. The assignments were then coded to capture the type of descriptions students wrote about their molecule. Three types of description codes were developed: *application, function*, and *chemical basis*. The definitions for the three types of description codes varied slightly depending upon the connection code due to inherent differences in how students discussed the molecules based on the connection they made, which also served to increase the reliability of the coding. Generally, the *application* code was applied when a student gave a brief general description of the use of the substance or object in which the molecule is found. The *function* code was applied when a student described the function of the molecule and its effects. The *chemical basis* code was applied when a student incorporated a description of the underlying chemical or physical properties of their molecule or the processes that it undergoes in their chosen connection. Each writing assignment was considered a unit of analysis and could receive one connection code and as many types of description codes as applied.

The writing assignment coding scheme was developed by two members of the research team (SFQ and SLM) through iterative application and refinement of the codes. During refinement of the coding scheme, the two research team members coded the writing in 16% subsets of the data and determined the reliability of the coding. The final inter-rater reliability values for this subset of data were a Cohen's kappa of 0.85 for the connection codes and a fuzzy kappa of 0.85 for the type of description codes, both of which are considered to indicate strong agreement (Watts and Finkenstaedt-Quinn, 2021). Once acceptable inter-rater reliability values were determined for both the connection and type of description codes one member of the research team (SLM) coded the remaining data. The finalized coding was then thematically analyzed by connection by one member of the research team (SLM; Braun and Clarke, 2006).

The interviews were transcribed and analyzed using NVivo (2018) and were initially coded deductively based on the relevance in science education framework (Stuckey *et al.*, 2013) and further refined through inductive coding. The adapted

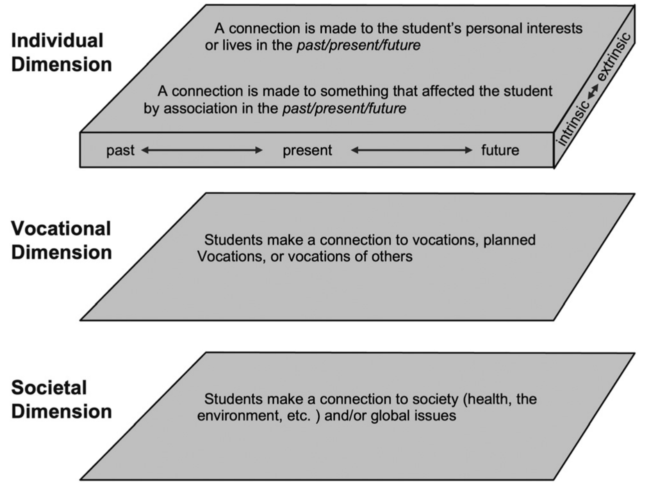

Fig. 1 Adapted relevance in science education framework.

framework that served as our coding scheme for the interviews is shown in Fig. 1. The full coding scheme for the interviews is presented in Appendix – interview coding scheme.

The coding scheme is divided into the three dimensions described by Stuckey *et al.* (2013): individual, societal, vocational. During preliminary analysis of the interviews and the initial development of the coding scheme, it became apparent that the assignment was primarily eliciting relevance aligned with the individual dimension, with minimal societal and vocational relevance. As such, the portions of the interviews that aligned with the societal and vocational dimensions of relevance were coded just along the dimension code. The individual dimension of relevance was more nuanced and thus subcodes were included to incorporate the intrinsic/extrinsic and temporal aspects of the dimension. The intrinsic subcode related to molecules that impacted the student directly whereas the extrinsic subcode was used when the molecule related to the students' environment or individuals they had close relationships with. In addition, although the relevance framework considers relevance in the present and future, many students described a meaningful connection between their chosen molecule and their past. To address this discrepancy, a past temporal element was also incorporated into the coding scheme for the individual dimension. Thus, the resulting codes to characterize student responses along the individual dimension included *individual – past, intrinsic; individual – past, extrinsic; individual – present, intrinsic; individual – present, extrinsic; individual – future, intrinsic;* and *individual – future, extrinsic.*

The units of analysis used when coding the interviews were defined as transitions between speakers and each unit could receive as many codes as were pertinent. The coding scheme was developed by two members of the research team (SFQ and NFG) through iterative application of the codes to the interviews, discussing differences in how the codes were applied, and refinement of the code definitions. The final coding scheme was then applied to all the interview transcripts by both members of the research team (SFQ and NFG) who then discussed their coding and resolved any differences to reach a

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final consensus on the applied codes (Campbell *et al.*, 2013; Watts and Finkenstaedt-Quinn, 2021). Another member of the research team (SLM) then thematically analyzed the results of the coding (Braun and Clarke, 2006).

Limitations

The qualitative study relied on a large data set including 143 assignments and 11 interviews. However, there are limitations associated with the assignment design and methods within this study that influence the results and discussion. Broadly, while this study is bounded by the qualitative methods used, the methodological approach was chosen in order to better capture the richness of students' experiences than is allowed through quantitative data. The data was restricted to a single course and there may be a self-selection bias in the students who agreed to participate in an interview. As such, the findings are not generalizable beyond the context of the study but can inform how this type of assignment may support students' ability to identify the relevance of chemistry to their lives in other courses and institutional contexts. Per the assignment description, students were limited in their choice of molecule as they were advised to choose a nonobvious molecule (*e.g.*, not caffeine or ethanol) and were further required to select a unique molecule from their classmates. Requiring students to each choose a unique molecule encouraged the students to focus on their connection rather than following the lead of one of their classmates. Because of this design, some students were restricted from their first choice of molecule if it had already been claimed by another student. Additionally, students may not be familiar with this type of writing assignment (one that gives them agency over their writing topic) in STEM courses and thus may need time to become comfortable with new genres of writing (Bazerman, 2009). This may have led to students being unsure of how to respond to the writing assignment.

Results

The aim of this study was to identify what connections students made to organic chemistry and to capture students' perceived relevance of the molecule they chose. We begin by presenting results from the writing assignments. To clarify students' connections, each student quotation will be followed by the connection code and a short description of how the molecule relates to the student's life. Next, we present the interview results which discuss how students expressed their perceived relevance of their molecule. Each student quotation in the interview section will be followed by both the assigned connection code and relevance types.

Student writing

Upon assigning each molecule one of the connection codes, we noted several themes that emerged across students' assignments. These themes were deemed significant because they either showed up across all three connection codes (*e.g.*, biological impacts, hobbies, or relationships) or they were strongly emphasized when students discussed their connection (*e.g.*, students highlighting their culture when discussing a food). Fig. 2 depicts how these themes mapped onto the connection codes along with their frequencies. We first describe findings from examining the connection coding of students' choice of molecules. Then we shift to the analysis characterizing how students described their molecule.

Students identified unique connections to their chosen organic molecule. Students identified a connection between organic chemistry and their lives by selecting a molecule related to an important aspect of their life. About a third of the students (n = 47) chose a molecule that aligned with the *medication* code. These students most commonly chose molecules that were an active ingredient in a medication related to a meaningful moment in their lives (*e.g.*, anesthetics or pain killers related to a surgery, antibiotics to treat infections) or that they or someone close to them take on a regular basis (*e.g.*, allergy medication, anxiety medication, hormone regulator). For example, one student reflected on how the molecule impacts their family's health:

"[Exemestane] is important for it being a way to treat breast cancer, however it is important to me personally because in my family breast cancer is hereditary in the women on my mother's side of the family and family is very important to my life." [active molecule in breast cancer treatment, medication]

This student's assignment is an example of when the molecule they chose also impacted their family, and therefore aligns with both the medication code and the "relationship" theme shown in Fig. 2.

Another student discussed a medical-related molecule that was more commonplace (*i.e.*, falling under the "common

	Connection Codes		
	Food	Medication	Other
Themes		*common medication* 38	
	9	*memory* 5	24
	2	hobby 6	18
		medical setting 15	6
	3	*relationship* 4	14
	biological impact 8		*biological impact* 10
	scent 11		*scent* 6
	culture 15		
		hormone 1	9
			plant 8
			disinfectant 7

Fig. 2 Themes by connection codes for the writing analysis. The themes are listed, from most to least frequent, such that the themes at the top were the most prevalent. Assignments were labelled with as many themes as applied; the numbers indicate the frequency of the theme across all connection codes.

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medication'' theme). Explaining their past with allergies, they wrote:

''Levocetirizine has dramatically improved my quality of life. From my daily dose of this drug, my allergy symptoms are under control, and I was able to get my energy back.'' [ingredient in allergy medication, medication]

The range of medically-relevant molecules that were selected demonstrates that across students, they were able to identify the relevance of chemistry in different settings and with varying degrees of impact on them or their family's well-being.

The second most frequent connections students made were molecules related to food. About a quarter of the students selected this type of molecule (n = 37). Within the assignments in which students discussed a molecule that received the *food* code, many of them identified their molecule as meaningful to their cultural background and identity:

''This is the chemical that gives coconuts many of its qualities and I feel like it is one of the main factors that identifies my ethnicity and identity as a result [...] While it is just a simple fruit, [delta-nonalactone] was my main introduction to my culture and has helped me to be okay with being different than other cultures.'' [found in coconuts, food]

This student closely tied their molecule to their culture, and thus would be found under both the food code and the ''culture'' theme.

Alternatively, some students selected their food-related molecules because the molecules are responsible for particular smells, which students often linked to significant memories – These assignments therefore related to the ''scent'' and ''memory'' themes. In other cases, students identified the physiological benefits of certain molecules in foods – which align with the ''biological impact'' theme. The responses which discussed a molecule's physiological benefits were often personal, sometimes connecting the organic molecule to significant moments in their past. Recalling how their molecule helped them adjust to a difficult situation, one student wrote:

''[Apigenin] can relieve anxiety, act as a muscle depressant, and induce sleep. I can thank my mom for looking out for my siblings and I during that hard time and I can give chamomile tea some credit for keeping my stress/anxiety levels low during that time.'' [ingredient in chamomile tea, food]

As this student also discussed how their molecule impacted their body, it aligns with the food code as well as the ''biological impact'' theme.

All molecules that did not fit the *food* or *medication* code were compiled under the *other* code (n = 59). Still, these remaining molecules demonstrate that students made a wide variety of connections between organic chemistry and their lives; the connections were often related to ''hobby'' and ''relationship'' themes. Similar to the medication- or food-based molecules, many of the molecules that were categorized as *other* were also tied to memories. For example, one student reminisced about learning to play the viola, a hobby, and wrote:

''Pimaric acid is one of the most important molecules to me because it is a component of what allows my instrument to make the sound that I fell so in love with [...]'' [found in the resin that encases violins, other]

In some instances, students described how their selected molecule affected their interactions and relationships with others. Discussing the importance of a multi-functioning hormone, one student connected it to their ability to engage socially:

''Vasopressin supports my heart and organs, it might encourage human social interaction, and it is one of the many chemicals that constructed the person I am today.'' [hormone related to student's health diagnosis, other]

Others wrote about molecules with more focus on specific relationships, like those with family members. One student discussed how their molecule, a monomer, was a large part of their father's vocation that supported their family and also encouraged them to pursue chemical engineering:

''With [styrene], my father has been able to sustain and raise a family of six children till this moment [...] If not for styrene, I probably wouldn't be in America right now studying chemical engineering.'' [monomer in polystyrene that is significant for their father's occupation, other]

This was not the only instance of a student choosing a molecule they perceived as being tied to their participation in science. Another student described how a hormone related to their food allergy led them to their current path toward studying pharmaceuticals:

''My allergies have not only made me more responsible, but have also led me to the current path [pharmaceuticals] that I am on. Who knows, without histamine I may have never made it to Organic Chemistry.'' [hormone produced during allergic reactions, other]

This molecule was described as other because it did not fit our definition for the medication-related molecules, however it did fall under the ''biological impact'' and ''hormone'' themes. Overall, there were a handful of students that chose a variety of molecules with perceived connections to their trajectory in science.

The responses that received the *other* code included a wide variety of connections. Nonetheless, we saw students express how their molecule impacted their interactions with their environments and the people in their lives, similar to how students described a medicine- or food-related molecule. Additionally, there were a few students who wrote about how their participation in studying science was influenced by their molecule. Across connections, we saw student highlighting similar themes, yet each student identified their own background and experiences and thus wrote about a unique molecule, connection, and story.

Students' descriptions of their molecule varied in level of detail. The assignment prompted students to explain why and how the molecule they selected was important to their life, thus all assignments received the *application* code. However, some students chose to include additional content on the function or underlying chemistry of their molecule. Here, we will focus on assignments that received the *function* or *chemical basis* code because they provide nuance to how students described their chosen molecule. About half of the students (n = 42) provided some background on how their molecule functions. Many of these students chose molecules that related to medicine or that have some biological impact, and thus included explanations

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for how the molecules interact with the body. Other times, descriptions included how their molecule influenced their performance during a specific task or activity. For example, one student described the effect of a supplement they take before going to the gym:

"L-Citrulline is a non-proteogenic amino acid that works by increasing Nitric Oxide levels in the blood [...] It relaxes the muscles in the blood vessels allowing for more blood to flow. This increases oxygen in the cells, resulting in an increased performance in the gym." [active ingredient in pre-workout powder, other]

Other assignments that didn't describe a molecule's impact on the body received the *function* code if they described a specific process their molecule underwent. This student described how their chosen molecule, Finasteride, is linked to their medical condition:

"What I found out was that testosterone goes through a process called 5α-reduction to form DHT (dihydrotestosterone), an androgen hormone. DHT is the hormone that is responsible for my type of hair loss, androgenic alopecia." [molecule that slows hair loss, medication]

As these biological processes are not covered within this organic chemistry course, students either relied on previous knowledge or sought out sources external to course material to research the background of their molecule.

Students' use of external resources was also demonstrated by a subset of students who researched and explored the chemical background of their molecule by providing information about the chemistry related to the relevant aspects of the molecule (*e.g.*, chemical properties or reactions mechanisms the molecules undergo). The additional effort students took to research this material was evident by the citation of external resources within their assignments.

As with the *function* code, the assignments given the *chemical basis* (n = 33) code ranged in the depth of their discussion of the chemistry. Chemical basis codes were seen for many different types of molecules. Some students provided detail on molecular features, like the molecule's pK_a or functional groups. Others provided more detail on the function the molecule plays in a relevant chemical reaction, like this student who detailed galactose's role in how they digest dairy:

"It was only recently that I began to take Lactaid, a supplement containing lactase, the enzyme that initiates the hydrolysis of lactose into its two byproducts, one of which is galactose. This hydrolysis reaction is so important to someone like me because my body does a horrible job at digesting lactose by itself." [byproduct from the breakdown of lactose, other]

Across assignments we found diversity in the types of molecules students selected and the level of detail they included in their descriptions. There was a tendency for students to draw on personal experiences that related to the individual relevance level as nearly all connections were centered around molecules that played a major role in memories, relationships, and health and well-being. This focus on personal experiences may be attributed to the assignment description which encouraged a focus on the individual relevance as students were asked to describe a molecule with a personal connection.

Interviews

The interviews provided insight into student's approaches to selecting their molecule. As indicated in the writing assignments, most students focused on personal connections that aligned with the individual level of relevance shown in Fig. 1. Among students' individually relevant connections, there was variety along the intrinsic and extrinsic dimensions as well as between the past, present, and future dimensions. We first detail results aligning with the individual level of relevance, starting with the intrinsic dimension and then moving to the extrinsic dimension. Finally, we end on the few connections made in alignment with the societal and vocational levels. Information about each interviewed student, the molecule they chose, the connections they made, and the relevance codes that were applied to them are detailed in Fig. 3.

Individual-intrinsic – all student described how their chosen molecule was relevant to them personally. Within all the interviews, students described their molecule as being significant to their lives at not only a single moment but in a distributed fashion from the past to the future. However, Angela and Chris specifically mentioned a stronger connection to the past. Angela describes their past experience with running in high school:

"But most specifically, I had a connection to [adenosine diphosphate] in my past because of running cross-country and track. It was something that your body naturally produces [...] And so it'll always be there, but it was most important around this time."

Similarly, Chris described how their molecule, methylene blue, was important to their experience in their high school chemistry class. Chris stood out in their discussion in how they chose their molecule; they expressed that they had their molecule in mind during the beginning stages of responding to the assignment. Holly and Angela also had a molecule in mind prior to thinking of a connection. Notably, Angela discussed having to search for a new molecule as their first choice had already been claimed by another student. Regardless of their approach of determining a connection prior to or after choosing a molecule, all interviewed students claimed they had a connection to their molecule in their past.

Student	Molecule	Relevance Codes				Connection Codes
		Individual *Intrinsic*	Individual *Extrinsic*	Societal	Vocational	
Angela	adenosine diphosphate	x				Other
Cecilia	cuminaldehyde	x	x			Food
Chris	methylene blue	x	x		x	Other
Clara	topiramate	x				Medication
Gene	testosterone enanthate	x				Medication
Holly	melatonin	x		x		Other
Jane	butane	x	x			Other
Joseph	allicin	x	x			Food
Leonard	abietic acid	x				Other
Noel	geraniol	x				Medication
Sheldon	chlorhexidine	x	x			Other

Fig. 3 Interview participants and their respective molecule, relevance codes, and connection codes.

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Considering impacts on their present life, all interviewed students received the *present/intrinsic* code. Several of them discussed their molecule as directly affecting their body or health; this aligned with the fact that for most of the interviewed students the molecule they selected was from a medication or substance that was directly introduced to the body, aligning with the "biological impact" theme discussed among many of the writing assignments. Only Leonard and Jane chose a molecule with little to no effect on their physical body, choosing a molecule found in a musical instrument and a kitchen tool, respectively.

Most of the interviewed students, aside from Angela, Holly, and Sheldon, discussed that their molecule will likely be important to their future lives. For example, Noel discussed their use of a molecule, geraniol, found in a skin care product:

"I still use this compound currently and probably – I'm assuming will continue to use it. I think that's what kind of drew me [to] it because it was something that is very relevant in my life still and not just something that I'm thinking of in the past."

Additionally, Clara and Chris also felt their molecule affected their future, Clara choosing an ingredient in a medication she predicts she will continue to use and Chris choosing a molecule that got them interested in chemistry and inspired their future career goal of teaching high school chemistry.

Individual-extrinsic – many students selected molecules that were important to their close relationships. While some students made connections exclusively to their personal lives, other students described how their molecule also had an impact on people they had close relationships with, such as friends and family members. Connections made to people that they had close relationships with were considered as extrinsically relevant at the individual level. For some, students expressed that their choice of molecule was explicitly due to their relationship to an individual who was close to them. Only five students—Cecilia, Chris, Jane, Joseph, and Sheldon—discussed an extrinsic connection, but they all verbalized having an intrinsic connection as well.

Like interviews that displayed individual/intrinsic connections, students chose extrinsically relevant molecules that played a part in various combinations of their past, present, and future lives. But all of these students stressed their molecule's connection to the past. Cecilia, Sheldon, and Jane described how their selected molecules were directly or indirectly related to a family member and tied to past memories. Having similar types of connections, Jane and Cecilia both chose a molecule related to time spent in the kitchen with their parents. Jane stated:

"Obviously myself and my parents come in a little bit because they gave [butane] to me. And then my mom because I started baking with my mom when I was like five or helping her, right? Helping her in the kitchen [...]"

A more explicit representation of extrinsic relevance was seen in Sheldon's discussion of their molecule. They spoke about the molecule that plays a part in their brother's health conditions. Sheldon mentioned:

"I chose it because my brother has a genetic disease, and it's one of the compounds that my mom uses when she gives him the infusions he needs [...] it's something that will probably be used for most of my brother's life."

Aside from Sheldon, Joseph was the only other student that expressed having an extrinsic connection with their molecule that extends from their past. Joseph felt that their molecule, a compound responsible for the scent of garlic, plays an important role in their relationship with their significant other:

"[Allicin] has been in my current relationship since the beginning [...] and will continue to be in my relationship just because it's just a chemical that we commonly use for cooking and stuff, which is something I enjoy doing a lot."

While only some students expressed extrinsic connections, we saw that these connections impacted their relationships in various ways. In Jane and Cecilia's cases, the molecules played a role in activities that they did with family members. For Chris, their focus was with a molecule that connected them to their high school chemistry teacher. In Sheldon's case, the molecule had a significant impact on the health of the family member and no direct impact on Sheldon themself.

The results of the interviews described above suggest the prevalence of individual relevance with a tendency toward intrinsic relevance but spanning the scale of temporal relevance. For example, some stated they have cooked ingredients containing their molecule since they were young, and they now think about it as they continue to use it when cooking. And those who chose a medication see themselves as taking it for the rest of their lives. The connections students made also appeared to be personally meaningful as some would keep the same connection and search for a new molecule even when their first choice of molecule was taken. Overall, students recognized that their selected molecules were important to a great portion, if not most, of their life and not just during a snapshot of their life.

Societal and vocational – two students described their chosen molecule as societally or vocationally relevant. Although the assignment description was designed to elicit mainly individual relevance, Holly and Chris recognized the relevance of their selected molecule more broadly, in addition to making connections to their individual lives. Holly expanded their connection to apply to a population of college students when they discussed the use of melatonin:

"[...] to solve the sleep deprivation for the college student. And it is like a kind of medicine for solving these kinds of problems. And I myself take the medicine as well."

We consider Holly relating their molecule to a larger community of students as being aligned with the societal dimension of relevance. On the other hand, Chris described how their molecule impacted their experience of learning chemistry when they said:

"This was a very broad overview of sort of why I ended up enjoying chemistry, why I'm planning on teaching chemistry. And so specifically that honors chem teacher is someone who really figured into that sort of decision."

As Chris discussed their molecule, they also talked about their consideration of pursuing a career in teaching chemistry. This connection to a future career directly relates to the vocational dimension of relevance. Both Holly and Chris, though, did not go in depth as they made connections to societal and vocational relevance, therefore their discussions were not

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nuanced enough to distinguish between implicit and explicit or past, present, and future varieties.

Demonstrated by interviews with students, we saw that despite the focus of the assignment on eliciting individual connections with student's lives, some were successful in making connections to a wider scope outside of their personal lives.

Discussion

What types of connections are students making between their lives and organic molecules?

Students chose a wide variety of molecules when making connections to their lives. The students' written responses detailed a variety of both molecules and levels of description, while the interviews revealed how students made decisions when completing the assignment. Both the interviews and student responses detailed the connections to various organic molecules, which were predominantly characterized as relevant at the individual level. This focus on the individual level of relevance aligns with Stuckey *et al.*'s (2013) claim that novice students tend to recognize individual relevance.

There were also instances in the writing assignments and two of the interviews where students indicated connections aligning with the vocational and societal dimensions of relevance. Students who wrote about their molecule being tied to their desire to pursue or study a science field demonstrated their consideration of a future vocation. Other students chose molecules related to food and wrote about how their choice was related to their connection and participation within their culture; these connections to cultural communities align with the societal dimension of relevance. Further support for connections between chemistry and society are needed considering the research report published by Royal Society of Chemistry in 2015 that found the public felt chemistry lacked concrete examples of its applications (TNS BMRB, 2015). Some studies have also emphasized the need for the public to recognize chemistry's relevance (Anderson *et al.*, 2021; Howell *et al.*, 2021; Raaijmakers *et al.*, 2021). Although students in this study primarily demonstrated their ability to recognize individualized relevance, they could be further guided to consider connections to society and vocations through the assignment design.

While making connections to their lives, students mentioned periods of their life where the molecule was most impactful, which related directly to the temporal aspects of the relevance in science education framework. In students' responses to the assignment, many of them described having an extended relationship with their molecule. Similarly, in interviews most students described their molecule as being connected to more than just one portion or event in their lives. Connections to variations of the past, present, and future may be due to students' tendency to focus on important memories or individuals as many assignments detailed how important these connections were to them. Collectively, the connections that students described are meaningful and temporally long lasting.

How do students approach selecting and describing their connection to their organic molecule?

Regardless of connection type, students' writing assignments included varying levels of descriptions of their molecules. Some students were invested enough in their molecule that they researched additional information about it. Additional information included discussion of a molecule's function, commonly seen with medicine-related molecules, or details of a molecule's chemical features, primarily regarding the molecule's structure. Much of this added content was not covered in the course, therefore students must have drawn on prior knowledge or retrieved this information from external resources.

In the interviews, students provided insight as to how they approached completing the assignment. Most students identified a connection to their life first and then went on to choose a molecule related to the connection, rather than starting with a molecule in mind. Angela, Holly, and Chris were the only students who described knowing what molecule they wanted to write about prior to thinking about a connection. Of these three, Holly and Chris were the only interviewed students who made societal- and vocational-type connections. The approach of students making a connection first mirrored the structure of many of the written assignments. Students commonly began their writing assignments by describing a memory, relationship, or health-related event. When students described a memory first, they would often follow with a connection to an individual that was part of the memory. In other cases, students began with their relationship with an individual and then described memories associated with them. In either case, students commonly ended their assignment with a description of how their molecules fit into those aspects of their life.

Notably, Angela, Noel, and Sheldon all began with an event or individual and then formed a connection to chemistry but had to reconsider their molecule as their first choice had already been claimed by another student. In each case, these students described how they moved on from their first molecule and looked for a different one in the same context. This indicates that the personal connections made to specific individuals or events were strong enough that students persisted with that connection and identified a different molecule despite their first molecule being unavailable to write about.

In general, Stuckey *et al.* (2013) claimed that novice students tend to see the importance of individual connections most prevalently. Our study along with previous studies support this claim and demonstrate how students make personal connections to science. However, in the present study a few students did consider societal and vocational levels of relevance. In response to this assignment, students frequently focused on health-related moments in their lives and therefore commonly chose medicinally relevant compounds. In alignment with students' tendency to focus on relationships or memories, these medications were commonly tied to the students' health or that of an individual close to them. Connections to various health-related events demonstrate students' abilities to find aspects of chemistry with varying degrees of impact. Considering the perspective of younger students, Hartwell and Kaplan (2018)

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found that students in a 9th grade biology class connected the class content to hobbies, events, activities, and other self-relevant areas in their life throughout a series of writing assignments. For students in an upper secondary chemistry course, Broman *et al.* (2022) found that students made similar types of health-based connections. In this case though, students were presented with several context based problems relating to five different topics (medical drugs, soaps and detergents, fuels, energy drinks, and fat); these topics were also presented in three different contextualized settings (personal, societal, and professional context). Although this assignment had a much more narrowed lens for interpretation, the students were able to determine the relevance of the problems, while also finding the applications interesting (Broman *et al.*, 2022). Overall, our results align with previous studies because they showed that students can successfully determine the relevance of course content regardless of educational level.

Conclusions and implications

This study used a qualitative approach to investigate the ways in which students identified organic chemistry as relevant to their lives through choosing an organic molecule and writing about it. In responding to the assignment, students primarily considered the individual level of relevance; correspondingly, we saw most students describing molecules as having a personal connection to their lives. The majority of chosen molecules included those found in medications, foods, and other common items. Students connected their chosen molecule to memories, relationships, and hobbies relevant across their lifetimes.

Our findings demonstrate that students could identify a range of meaningful connections that organic molecules had to their lives, which students may not have been able to explore with traditional chemistry assignments. The open-ended nature of this assignment may have allowed students to take a more active role in how they engaged with course material, thus leading them to make molecule selections specific to their experiences. Instructors could consider using a similar open-ended assignment to allow their students to explore a chemistry topic of their choice. Alternatively, the assignment could be implemented into other STEM classes in which students could make connections to other course material (*e.g.*, students could be prompted to make connections to a specific biological molecule in a biochemistry course).

We also found that some students made connections to their culture, which has implications for practitioners to explore how similar assignments could support culturally relevant education. Moreover, similar assignments could also be used to encourage students to consider making connections between chemistry and society or future vocations. Responses to such assignments could help instructors recognize when to highlight other course material that may relate to their students' lives, which may in turn support their students' affective learn experiences.

Overall, this assignment's design and objectives should be further adapted to thoroughly explore how students connect chemistry content to their lives, and how this connection could foster their motivation to learn chemistry. Future investigations should be conducted on similar assignments to determine the various ways students view chemistry as relevant, aside from their connection to organic molecules. For example, this assignment could be adapted to include language that explicitly prompts students to consider the vocational and societal relevance of chemistry topics. Lastly, studies should also explicitly investigate the relationship that exists between relevance and motivation.

Author contributions

Safron L. Milne: conceptualization, formal analysis, investigation, methodology, visualization, writing – original draft. Solaire A. Finkenstaedt-Quinn: conceptualization, formal analysis, methodology, validation, writing – review and editing. Nicholas F. Garza: investigation, methodology, formal analysis. Steven C. Zimmerman: conceptualization, investigation, resources. Ginger V. Shultz: funding acquisition, project administration, supervision, writing – review and editing.

Conflicts of interest

There are no conflicts to declare.

Appendices

Writing assignment description

In course X, you will engage in multiple forms of writing, including MWrite assignments, case comparison assignments, and experimental notebook pages. These assignments focus on important skills, concepts, and reactions in organic chemistry, and are based on different ways scientists write in their careers. Scientific writing tends to be clear, concise, and objective, which does not always give as much room for personal expression. So for this assignment, you will 'choose your own adventure,' and relate organic chemistry directly to your own life.

For this assignment, select an organic compound/molecule that relates to your life. Please avoid obvious choices like ethanol/caffeine/*etc.* You should explain why the compound you chose is important in detail, both to you personally and to society as a whole. Your response should tell a story that describes why the compound is important to you. You are not required to include any 'chemistry' content about your compound beyond its IUPAC name and a common name if there is one; your focus should be on telling the story of how the chemical compound relates to your life.

Your response should be approximately 350–750 words in length. You must include a drawing of your compound that is hand-drawn or produced in either ChemDraw or ChemDoodle (no google images or screenshots from online). For all figures that you include in your response, you must cite the source (using either ACS or APA format) or indicate if they were drawn by you (*e.g.*, in ChemDraw or on paper). You must additionally cite any other outside sources used in writing your response (Tables 1–3).

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Writing assignment coding scheme

Table 1 Writing assignment coding scheme

Connection code	Description level code	Definition	Exemplar
Medication	Application	Describes what medication or medicine-related substance the molecule is present in and what they use the medication for.	*Years later, I took my uncle to a doctor's visit as an interpreter and found out he was taking Diazepam to help his anxiety. Diazepam is mainly used as an anxiety medication [. . .]*
	Function	Explains how the molecule is affecting the body, often a specific bodily process is described. No chemical mechanisms or reactions are mentioned.	*Isotretinoin is a vitamin A derivative that reduces sebum production and shrinks the size of the sebaceous glands.*
	Chemical basis	Provides in-depth description of how the medication works within the body's chemical processes or gives chemical background on the molecule (*e.g.* structure, properties, functional groups, *etc.*)	*Structurally, [Carbamazepine] is made from two benzene rings connected by an unsaturated seven-member ring with a nitrogen replacing a carbon, commonly called an azepine ring. Connected to the nitrogen in this ring is a carbon that has a double bond to an oxygen and a single bond to a nitrogen.*
Food	Application	States what food item contains the molecule. May also state that the molecule is responsible for the food item's taste/smell.	*There is a reason for adding garlic into almost every recipe; it is because of garlic's taste and smell. 1,3-Dithiane contributes to the alliaceous and roasted tasting component of the garlic.*
	Function	Characterizes the molecule contained in a food item as affecting the body in some way (*e.g.* performance, mood) when consumed.	*I did some digging and learned that in chamomile tea there is a molecule Apigenin [. . .] this molecule can relieve anxiety, act as a muscle depressant, and induce sleep.*
	Chemical basis	Details any chemical description of the molecule (*e.g.* structure, properties, functional groups, *etc.*)	*[Glycopyrrolate] contains a nitrogen atom with a formal charge of +1 in one of its cyclopentane groups, this charge being balanced by a Br-ion in solution.*
Other	Application	Labels the molecule as being contained in a substance or a simple description is given for what the molecule is used for.	*Lithium stearate is used within the creation of lithium grease which is utilized within suspension components, bearings, and any other moveable object [in a car].*
	Function	Defines a function of the molecule, more specific than what the substance is used for but less descriptive than the chemical background of the molecule.	*Salicylic acid is successful in acne targeted skin care products because it dissolves the moisture that is holding the dead skin cells together, allowing them to shed from the surface of the skin.*
	Chemical basis	Provides any chemical description (*e.g.* structure, properties, functional groups, *etc.*) is given with where the molecule is found/how it is used.	*3-(8Z-Pentadecenyl)-catechol, nicknamed urushiol II with the chemical formula $C_{21}H_{34}O_2$ [. . .] has a very long hydrocarbon chain sprouting from the benzenediol. Like some people are with peanuts, a poison ivy rash is actually an allergic reaction that people get from making contact with this compound.*

Interview coding scheme

Table 2 Interview coding scheme

Dimension	Time/motivation	Definition	Exemplar
Individual	Past/intrinsic	A connection is made to students' personal interests or lives in the past	*I picked this because it is something that I've used on my skin kind of a lot in the past years [. . .]* (Noel)
	Past/extrinsic	A connection is made to something that affected students by association in the past (*i.e.*, to a family member)	*I guess my past is using the kitchen torch and same as my present and the future. Yeah. I don't know. I don't plan to stop baking anytime soon.* (Jane)
	Present/intrinsic	A connection is made to students' personal interests or lives in the present	*So let's see, because this is medication, so I take it daily. I take it every morning and every night and it affects how I live.* (Clara)
	Present/extrinsic	A connection is made to something that affects students by association in the present (*i.e.*, to a family member)	*The molecule has been in my current relationship since the beginning of the relationship. It's presently in my relationship and will continue to be [. . .]* (Sheldon)
	Future/intrinsic	A connection is made to students' personal interests or lives in the future	*I have to take supplemental testosterone. I've been taking it for a number of years now, and I will most likely have to continue for the rest of my life probably.* (Gene)
	Future/extrinsic	A connection is made to something that will affect students by association in the future (*i.e.*, to a family member)	*[. . .] because it's something that will probably be used for most of my brother's life* (Sheldon)
Societal		Students make a connection to society (health, the environment, *etc.*) and/or global issues	*How to solve the sleep deprivation for the college student. And it is like a kind of medicine for solving these kinds of problems.* (Holly)
Vocational		Students make a connection to vocations, planned vocations, or vocations of others	*[. . .] Because I'm hoping to be a secondary, so high school, chemistry teacher.* (Chris)

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Interview participant codes

Table 3 Interview participant codes

Student	Molecule	Connection code	Description of connection	Relevance codes
Angela	Adenosine diphosphate	Other	Related to their running career that they had in the past, but they recognize the molecule's importance for every day function in the body	Past/intrinsic
Cecilia	Cuminaldehyde	Food	Ingredient in the spice cumin that they use for cooking a lot in their culture with their dad	Past + present + future/intrinsic, past/extrinsic
Chris	Methylene blue	Other	First molecule that interested them in chemistry, they learned about it in their chemistry class and relate the memory to their future career goal of becoming a chemistry teacher	Past + future/intrinsic, past/extrinsic; vocational
Clara	Topiramate	Medication	Medication they take to combat migraines	Past + present + future/intrinsic
Gene	Testosterone enanthate	Medication	Medication they began taking in their teens and continue to take weekly	Past + present + future/intrinsic
Holly	Melatonin	Medication	Medication they and other people take to combat insomnia	Past + present/intrinsic; societal
Jane	Butane	Other	Fuel for a torch they have used to cook and bake with, linked to memories of cooking with their parents	Past + present + future/intrinsic, past/extrinsic
Joseph	Allicin	Food	Molecule responsible for garlic's scent, they use to cook with often with their significant other	Past + present + future/intrinsic, past + present + future/extrinsic
Leonard	Abietic acid	Other	Molecule found in resin that coats a violin, tied to memory of learning to play	Past + present + future/intrinsic
Noel	Geraniol	Medication	Ingredient in acne medication they take	Past + present + future/intrinsic
Sheldon	Chlorhexidine	Other	Ingredient in a disinfectant used to clean kits for their bother's medical condition	Past + present/intrinsic, past + present + future/extrinsic

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