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ARTICLE

Student Perceptions of "Critical Thinking": Insights into Clarifying an Amorphous Construct

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"Critical thinking" has been situated as an important skill or way of thinking in chemistry education. However, despite its perceived importance, there has not been an established consensus definition for chemistry and science education with many resources operating from working definitions. The many definitions obfuscate what "critical thinking" is and entails and thus makes it an amorphous construct within education. Previous work in chemistry education has explored how different groups define "critical thinking" and found that the groups had limited agreement. The work here seeks to expand the literature base on what we know about "critical thinking" by probing perceptions of the construct further. Using semi-structured interviews and constructivist grounded theory, I explored student perceptions of "critical thinking" in the context of organic chemistry courses. From the analysis, I generated four major themes. Students perceived that "critical thinking" 1) involved the application and use of knowledge, 2) was contrasted to passive approaches to learning, particularly rote memorization, 3) was learned from previous experiences prior to organic chemistry, and 4) was motivated by a variety of intrinsic and extrinsic forces. I assert that these overarching commonalities across student perceptions align with the previous literature and the scientific practices in three-dimensional learning, thus offering a potential way forward for clarifying the construct and being more explicit about what we want students to know and do.

Introduction

Within chemistry education, it is not uncommon to see the term "critical thinking" in research articles, course assignments, and learning goals (Bernardi and Pazinato, 2022; Dixson et al., 2022; Hunter and Kovarik, 2022) or hear it mentioned in conversation about pedagogy. The prevalence of "critical thinking" implies a particular value and importance, and the term's definition is seemingly taken-for-granted and assumed to be universally understood in many contexts. However, a common definition of what the construct means to chemistry education has not been agreed upon with some advocating that we stop using the term entirely (Cooper, 2016; Stowe and Cooper, 2017). Scholars have certainly attempted to operationalize "critical thinking" (Facione, 1990), however, these efforts lacked discipline-based education research (DBER) perspectives and, in some cases, relied on other amorphous terms, such as "problem-solving" and "inquiry", which were poorly defined and did not explicitly detail what students must know and do (Rickert, 1967; Charen, 1970; Byrne and Johnstone, 1987; National Research Council, 2012b; Gupta et al., 2015; Cooper, 2016; Weaver et al., 2016; Stowe and Cooper, 2017). In previous work by my colleagues and I, we found that students often used terms like "critical thinking" to describe their learning experiences in organic chemistry courses. However, for many of these responses, it was unclear what students were actually doing when they were "thinking critically" or how they would define the construct. At this point, I began to conceptualize this study and turn to the literature to generate insights on what "critical thinking" meant in the context of learning chemistry.

Early attempts to operationalize this way of thinking have been attributed to Edward Glaser (Glaser, 1941; George, 1967; Abrami et al., 2015) where Glaser's definition leveraged the application of knowledge and necessary affective dispositions to think "critically" (Glaser, 1941). Though other sources have situated "critical thinking" as the general application of knowledge like Glaser (Dunning, 1954; Gupta et al., 2015; Barron et al., 2021), other definitions diverged by including facets such as interpretation (Dunning, 1954), synthesis and/or evaluation (Smith, 1963; George, 1967, 1968; Oliver-Hoyo, 2003; Gupta et al., 2015; Forawi, 2016), metacognition (Kuhn, 1999; Tsai, 2001), literacy (Paul and Elder, 2011; Vieira et al., 2011), being inherently "scientific" way of thinking (George, 1967), requiring consistent practice (Kogut, 1996; Oliver-Hoyo, 2003), leveraging practices such as argumentation or asking questions (Siegel, 1989; Osborne et al., 2004; Crenshaw et al., 2011; Mulnix, 2012; Hand et al., 2018), and the general approach taken when people are unsure of what to do next (Dunning, 1956; George, 1967; Vieira et al., 2011), amongst others. This lack of coherence within research on "critical thinking" in science education has been criticized with Crenshaw and colleagues noting that "there are nearly as many definitions of critical thinking as there are publications on the topic," (Bailin, 2002; Crenshaw et al., 2011).

In 1990, Facione published the "Delphi Report" which was a major attempt at operationalizing "critical thinking" using a panel of 46 experts on the construct (Facione, 1990). Within the "Delphi Report", "critical thinking" was defined as "purposeful, self-regulatory judgment which results in interpretation, analysis,

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evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based... The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit," (Facione, 1990). Though the definition from the "Delphi Report" has been leveraged in chemistry education (Danczak et al., 2017, 2020), it's important to note that past and present conceptualizations of "critical thinking" have not always aligned with this definition and that the panel did not reach a full consensus. Furthermore, the panel of experts used in the report consisted primarily of philosophers and did not include discipline-based education experts at the time.

Aside from defining "critical thinking", research has also struggled to conceptualize the construct as involving general skills that could transfer between domains (Ennis, 1962; Charen, 1970; Lau, 2011) or as discipline-specific skills that are dependent on content knowledge (Siegel, 1989; Mulnix, 2012). In 2012, the National Academies considered "critical thinking" to be part of the 21st century competencies that were necessary for "deeper learning" which entailed transferring knowledge from one situation to another. However, this report from the National Academies concluded common definitions had not been established for constructs like "critical thinking" and acknowledged that "research to date provides little guidance about how to help learners aggregate transferable competencies across disciplines" (National Research Council, 2012b).

The amorphous nature of "critical thinking" creates major problems for measuring and promoting whatever it is. Despite its nebulous nature, various instruments have been published to assess "critical thinking", all of which operate from their own conceptualization of the construct, indicating that one instrument may not be appropriate for all contexts (Ennis, 1962; Watson and Glaser, 1964; Wright and Forawi, 2000; Banning, 2006; Forawi, 2016; Danczak et al., 2020; Insight Assessment, 2020; The Critical Thinking Co., 2021; Assessment Day Ltd.). Furthermore, some have sought to explore strategies and develop frameworks to help promote and develop "thinking critically" (Abrami et al., 2015; Duncan et al., 2018). In their meta-analysis of "critical thinking" strategies, Abrami and colleagues concluded that individual practice, discussion, real-world examples, and mentoring could all be helpful for developing "critical thinking" (Abrami et al., 2015). Abrami and colleagues were careful to define "critical thinking" in their meta-analysis, but it implies that much of our research on "critical thinking" operates from conceptualizations of the construct that may be different.

Despite these divergent perspectives on a seemingly important construct, there has been some overlap amongst definitions. For example, the application and use of knowledge (Glaser, 1941; Dunning, 1954; Gupta et al., 2015; Barron et al., 2021), the contrast of "critical thinking" to rote memorization (Dunning, 1954; George, 1967, 1968; Rickert, 1967; Facione, 1990; Tsai, 2001; Mulnix, 2012; Santos, 2017), and the idea that "critical thinking" must be explicitly taught to students are notable commonalities (George, 1967, 1968; Rickert, 1967; Byrne and Johnstone, 1987; Facione, 1990; Barak et al., 2007; Vieira et al., 2011; Mulnix, 2012) have all been noted. However, commonalities across many studies and perspectives may differ from one another as well.

As noted earlier, given the divergence in what "critical thinking" is understood to be, researchers in chemistry education have advocated for abolishing the term altogether and being more explicit about what we want students to know and do with (Cooper, 2016; Stowe and Cooper, 2017). These authors have also suggested that the scientific practices in A Framework for K-12 Science Education (National Research Council, 2012a) and three-dimensional learning (3DL) (3DL4US, n.d.) could act as the component parts of "critical thinking" (Cooper, 2016; Stowe and Cooper, 2017). However, this particular stance implies that systematic curricular and pedagogical overhaul may be necessary to have longitudinal impacts on how students approach learning due to the need for consistent practice (Kogut, 1996; Oliver-Hoyo, 2003). Certainly, other scholars' definitions of "critical thinking" have relied on various scientific practices covered in the Framework such as argumentation or asking questions (Siegel, 1989; Osborne et al., 2004; Crenshaw et al., 2011; Mulnix, 2012; Hand et al., 2018).

In our previous research on student perceptions of transformational intent and classroom cultures in organic chemistry, my colleagues and I noted that many students would use the term "critical thinking" to describe their experiences. However, these responses were often vague and unclear as to what students were doing when they engaged in this way of thinking, highlighting that the term had a taken-for-granted meaning amongst students (Bowen et al., 2022). In a related study on student perceptions of "critical thinking", Danczak and colleagues found that there was limited agreement amongst undergraduates, teaching assistants, teaching faculty, and chemical industry employers' definitions of "critical thinking" (Danczak et al., 2017), further highlighting the amorphous nature of the construct amongst different groups in chemistry.

With this in mind, I became more interested in what students perceived "critical thinking" to be and what it might entail. My aim for this study was to extend the literature base on student perceptions of this amorphous, yet pervasive, construct in science education (such as the work done by Danczak et al., 2017). I wanted to go beyond how students defined "critical thinking" and probe the experiences and factors that informed their understanding and use of this way of thinking. To assist in this endeavor, I employed a constructivist grounded theory approach and used semi-structured interviews with students across three different organic chemistry courses at a large, research-intensive Midwestern university in the United States. My rationale for choosing students in organic chemistry was to align with our previous work in these courses where students often used the term to describe their experiences (Bowen et al., 2022). My research questions for this study were as follows:

1. What are the commonalities across student perceptions of "critical thinking"?

2. What insights do student perceptions of "critical thinking" offer to help clarify the construct in instruction?

Theoretical Framework

Caution has been advised when using theoretical frameworks with grounded theory studies since they may interfere with the development of theory (Corbin and Strauss, 2015). However, other scholars have asserted that researchers are not "blank slates" and thus influenced (and informed) by previous work and training (Charmaz, 2006; Timonen et al., 2018). As will be described in more detail later, I am adopting a constructivist grounded theory approach which acknowledges the importance of theoretical frameworks in the context of the study (Charmaz, 2006). From the constructivist grounded theory perspective, the theoretical framework provides a lens through which to understand how the researcher interpreted and situated the data, and for this study I was informed by sociocultural perspectives (Vygotsky, 1978a; Rogoff, 1990; John-Steiner and Mahn, 1996; Lemke, 2001; Mantero, 2002; Zotos et al., 2020; Bowen et al., 2022).

Sociocultural perspectives have been recently employed in chemistry education research to explore graduate teaching assistants' teaching identity (Zotos et al., 2020), how students identify the significance of course material they are learning through writing (Petterson et al., 2022), and how students perceive their courses' learning cultures (Bowen et al., 2022). These perspectives situate the significance of social interactions and contextual factors on how people think, talk, and act. Within the context of this study, I work from the assumption that student conceptualizations of "critical thinking" have largely been informed by their sociocultural experiences. That is, students come to understand "critical thinking" via social interactions with instructors, peers, and family and the ways of thinking and doing supported by their learning environments (Vygotsky, 1978b; Rogoff, 1990). Therefore, students' understanding of "critical thinking" may be the product of socialization where their understanding has been heavily shaped and informed by others who have purported a certain way of conceptualizing "critical thinking" (Rogoff, 1990; Miller and Goodnow, 1995; Lemke, 2001; Gutiérrez and Rogoff, 2003; Nasir and Hand, 2006; Calabrese Barton et al., 2008).

With the adoption of this sociocultural view, I believe "critical thinking" is informed by expectations and norms of that space (Becker et al., 2013; Chang and Song, 2016; Bowen et al., 2022). My aim was to use this theoretical perspective in conjunction with my methodological approach to identify emergent themes that not only provide insight into what students think "critical thinking" is but where they source this understanding, how they see it developing, and what factors are influential for encouraging them to engage in it.

Methodology

Course Contexts

I focused on organic chemistry students in this study for three reasons: 1) previous work related to this study was conducted alongside the same students (Bowen et al., 2022; Flaherty, 2020b), 2) the students were more accessible to me, and 3) organic chemistry has been situated as providing students with generalizable "critical thinking skills" (Dixson et al., 2022). Two types of organic chemistry courses were used in this study: one that had been transformed using three-dimensional learning (OCLUE) (National Research Council, 2012a; 3DL4US, n.d.) and a more traditional organic chemistry experience. These courses were taught during the Fall 2021 semester at a large, research-intensive, midwestern university in the United States. Both courses involve a lecture and recitation component. The recitations meet once a week for 50 minutes and are a chance for groups of 30 students to meet in a smaller class environment to work on practice problems for the course under the guidance of a graduate teaching assistant in the department. Both courses were considered large lecture classes with 200-300 students. Due to the COVID-19 pandemic, both courses were offered online via Zoom.

I invited students in organic chemistry taught by three different professors. Two of the professors were teaching the transformed curriculum, Organic Chemistry, Life, the Universe, and Everything (OCLUE) which has been previously discussed elsewhere, and the third professor taught a more traditional organic chemistry course (Cooper et al., 2019; Bowen et al., 2022). OCLUE is informed by A Framework for K-12 Science Education (National Research Council, 2012a) and leverages three-dimensional learning (3DL4US, n.d.). In the context of this transformed curriculum, students are often asked to engage in scientific practices in the context of fundamental, core ideas in chemistry (Cooper et al., 2017). Students in OCLUE are frequently encouraged to engage in causal mechanistic reasoning (Crandell et al., 2019, 2020) and construct explanations (Houchlei et al., 2021), among other practices outlined in the Framework. On the other hand, the traditional course is typically organized via functional group rather than core ideas, and students are not often required to provide reasoning or engage in scientific practices. In a previous analysis of assessments between these two courses, it was found that the traditional course had more questions that could be answered via recall (Stowe and Cooper, 2017). Previous research from my colleagues and I in these two types of organic chemistry courses also found that more students in OCLUE perceived they were expected to use their knowledge throughout the course while more students in the traditional course perceived they were expected to rely on rote memorization and knowledge (Bowen et al., 2022). However, in both types of courses, students used terms like "critical thinking" to describe their experience which influenced me to initiate this study.

Participants

There were 14 interview participants and all were informed of their rights as research participants in accordance with the IRB at my institution. Participants signed a consent form to explicitly communicate their acknowledgement of the study and consent to being audio recorded. All students were given the option to choose their own pseudonym or have one generated for them randomly. Participants ranged from freshmen to returning students who had previously completed degrees at the same institution, and the students were majoring in a variety of disciplines with most participants being interested in health-related professions. Four of the participants were enrolled in the traditional organic chemistry course while the remaining students were enrolled in the transformed course (OCLUE) previously described above. Participant information is included below in Table 1. In order to collect a range of perspectives, I opted to recruit participants from OCLUE and traditional organic chemistry courses considering these courses had differing approaches to instruction. Furthermore, this project was motivated by a previous comparative analysis between these two courses **(Bowen *et al.*, 2022)**, thus I found it important to incorporate perspectives from both learning environments here.

Table 1. Participant Information

Participant	Year	Major	Professor	Course
Damien	Senior	Earth and Environmental Science	Professor 1	Traditional
Clara	Sophomore	Human Biology		
Whitefox	Freshman	Physiology (Pre-Med)		
Milo	Senior	Kinesiology (Pre-PA)		
Reina	Freshman	Human Biology and Psychology (Pre-Med)	Professor 2	OCLUE
Amanda	Sophomore	Human Biology (Pre-Med)		
Noelle	Sophomore	Human Biology (Pre-Med)		
Virginia	Sophomore	Biochemistry and Molecular Biology (Pre-Dental)		
Ember	Sophomore	Biochemistry (Pre-Med)		
Rebeka	Sophomore	Microbiology and Molecular Genomics	Professor 3	OCLUE
Arisha	Junior	Interdisciplinary Studies of Social Science (Pre-Med)		
Adelynn	Sophomore	Physiology		
Hailee	Returning Student	Pre-PA (previously graduated with Kinesiology degree)		
Ella	Sophomore	Secondary Education – Chemistry		

Interview Question Development

To align with my methodological approach, my interview protocol structure was informed by Charmaz (Charmaz, 2006). The interview questions were designed to be open-ended, elucidate how students define “critical thinking”, highlight how and why they define “critical thinking” in that way, and generate insights into how students use (or don’t use) “critical thinking”. Early questions in the interview were influenced by my previous work on student perceptions of organic chemistry classroom cultures (Bowen et al., 2022). The full interview protocol, including the questions asked during the semi-structured interviews are included as supplementary material. Upon drafting the questions, I had discussions about the initial protocol and refined it with my colleagues. To ensure my questions would be understood by my target population (undergraduate students), I conducted three pilot interviews with undergraduates who had previously passed organic chemistry at the institution of my study. The undergraduates were encouraged to provide feedback on the questions which was used to refine the protocol further.

Data Collection

Students were contacted toward the end of the Fall 2021 semester to determine if they were interested in participating in interviews for extra credit in their courses which is common practice in my department. I received many requests for interviews, and as students volunteered, their name and information were added to an Excel spreadsheet. Given that I had access to course performance data for professors 2 and 3 (the OCLUE professors), I stratified students according to their course performance based on whether they had a 4.0, 3.5, 3.0, 2.5, or 1.5-2.0 in the course at the time of data collection. Then, one student was randomly selected from each stratification. Since course performance data was not available from students in the traditional course (with professor 1), I opted to randomly select from the list of volunteers. Students who were not chosen were given the option of completing another assignment for extra credit alongside students who did not volunteer to be fair.

Students were notified of being selected, and an interview time was scheduled. Students were e-mailed a welcome document which included some of the major questions covered in the interview (this document is included as supplementary information). Interviews were semi-structured and conducted online via Zoom with each interview lasting between 30-75 minutes. Interviews were recorded using the Zoom recording feature with live transcriptions to assist with the transcription process later on. At the end of each interview, participants were given the option to choose a pseudonym, e-mail one, or have one generated for them.

After each interview, I reflected and took notes, detailing any questions or ideas that came up during the conversation. Most interviews were transcribed immediately after conducting them. Each interview underwent two rounds of transcription. First, I listened to each interview with the Zoom transcriptions and corrected them. Then, I listened to the audio once again with the transcript in hand, checking it for accuracy, and making edits when necessary. Once a master transcript of each interview was made, the transcripts were further deidentified by redacting instances where they referred to their specific professor or themselves by name.

In grounded theory, the use of theoretical sampling is considered an important component of the method (Charmaz, 2006; Corbin and Strauss, 2015; Timonen et al., 2018), however, grounded theory articles have been published without the use of theoretical sampling across education more broadly, including in this journal (Randles and Overton, 2015; Dunn et al., 2019; Barron et al., 2021; Flaherty, 2020b). Given the timeframe of the study, the online nature of the course, and logistical issues, I was unable to engage in theoretical sampling as traditionally defined, and instead I relied more on convenience and random sampling.

Constructivist Grounded Theory

Grounded theory was co-developed by Barney Glaser and Anselm Strauss (Glaser and Strauss, 1967), and it has been further extended and developed into various schools of thought (Glaser, 1978; Charmaz, 2006; Corbin and Strauss, 2015); that is, there is not one approach to grounded theory. Though there are some commonalities between these different types of grounded theory (Timonen et al., 2018), I opted to use Charmaz's constructivist grounded theory (CGT) for the purposes of this study (Charmaz, 2006). CGT was chosen as the methodology because it offered an approach to explore open-ended data while minimizing biases and assumptions, and it acknowledged the role of the researcher in the research process. That is, CGT acknowledges that the themes and subsequent theory or framework developed by the researcher is co-constructed alongside the participants. Furthermore, there was a precedent for using Charmaz's CGT to explore student perceptions in the context of the transformed organic chemistry course used in this study (Flaherty, 2020b).

At its core, CGT can be viewed as principles and practices for engaging in qualitative work (Charmaz, 2006). The methodology is a highly inductive approach, meaning that all concepts and ideas described emerge directly out of the data (Charmaz, 2006; Corbin and Strauss, 2015; Creswell and Poth, 2017). Like some other types of qualitative methods, constructivist grounded theory acknowledges that "objectivity" is largely unobtainable, and instead researchers can rely on their personal experiences to help make sense of the ideas emerging from the study (Charmaz, 2006; Corbin and Strauss, 2015). Although it is often said themes "emerge" from qualitative data (language that I use here), to me this means that themes were derived via inductive methods and thus not meant to imply the themes were independent of my perspectives and thoughts. That is, the themes I interpreted were generated by me in an inductive manner. Though some may argue that grounded theory must lead to a strong, well-supported theory, recent conceptualizations have instead argued that sometimes CGT leads to a conceptual, or analytical, framework which may be less comprehensive than a theory but still productive for making sense of the data (Timonen et al., 2018).

Data Analysis

All data was analyzed within the MAXQDA 2022 software (VERBI GmbH, 2022), and I underwent multiple stages of coding in accordance with constructivist grounded theory (Charmaz, 2006; Corbin and Strauss, 2015; Creswell and Poth, 2017). Like other types of grounded theory, Charmaz relies on use of the constant comparison method and memo-writing throughout coding (Glaser and Strauss, 1967; Charmaz, 2006; Corbin and Strauss, 2015). I began by engaging in a process of open coding where I went line-by-line through interview transcripts. During this stage I wrote down thoughts, notes, identified assumptions, questions, and potential initial categories. During this stage, many memos and notes were made to guide analysis. Next, I engaged in initial coding which involved line-by-line reading once again, but this time I used my notes from the open coding stage to further analyze for meaning. During the initial coding stage, I began to assign initial categories to coded data. These initial codes were largely descriptive with initial attempts at locating meaning within the data.

Once all available interview transcripts had undergone open and initial coding, I engaged in a focused and axial coding stage. Here, I identified codes that were relevant to the research questions (though I kept note of the other codes in case anything changed). These relevant codes were then analyzed further to develop larger and more encompassing emergent themes. At this point, the initial codes were combined, modified, or re-coded, if necessary. The final stage of coding is known as theoretical coding and is the stage that develops the theory or analytical framework of the study. This stage involves analyzing and establishing relationships between the themes and categories captured in earlier stages of coding (Timonen et al., 2018), and is often referred to as the core category (Charmaz, 2006; Corbin and Strauss, 2015; Flaherty, 2020b). Once relationships were identified, a final write-up of the categories, themes, and subsequent relationships between them was completed to establish the analytical framework that arose inductively from the data in this study on how students perceive "critical thinking". As I will show later, this core category is explained narratively and woven into the previous literature on what "critical thinking" means and entails with a remarks on how to move forward with "critical thinking" in chemistry education.

Reliability and Validity

While addressing reliability and validity in any study is important, it is more-so here given that I am the sole author of this qualitative work (Merriam and Tisdell, 2016; Creswell and Poth, 2017). The underpinnings of constructivist grounded theory as a method are clear that the research process involves a co-construction of findings (i.e., interpretations) between the participants and the researcher. That is, the findings here are unique to the participants and myself considering that our perspectives and assumptions were interacting throughout the research process and represented within this final write-up (Charmaz, 2006; Flaherty, 2020b). To offer some credibility to my interpretations, however, the findings presented here have also been noted in the literature previously discussed, offering a sort of theoretical triangulation (Merriam and Tisdell, 2016). To assist with this, I have opted to give a detailed methodological section to clarify my approach. However, just like with all qualitative work, the goal here was not to generate generalizable findings (in the statistical sense). Instead, the findings and subsequent discussion are meant to be transferable. That is, components (and in some cases, all of the findings) of my interpretations may transfer to different contexts and participants and should be seen as potential perspectives that may be operating in other spaces.

Reflexivity is an important part of qualitative work, and I engaged with it through the use of memo writing, which is also an important procedure in the grounded theory methodology. In the spirit of transparency, upon initial generation of the themes presented here, my thought was that I had essentially re-affirmed pieces of what was already known or theorized about the construct of "critical thinking" (as evidenced in the literature review). However, after discussions with other scholars and additional reflection, I concluded that not only had I extended the empirical evidence base of what people perceive about "critical thinking" but had established additional evidence that supports a way forward for such a nebulous construct.

I have attempted to include thick descriptions of my methodological approach and as many quotes from the interviews as possible to allow readers to better understand my interpretations (Merriam and Tisdell, 2016). Finally, the peer review process offers a powerful way of supporting this work. Although I conducted this study by myself, it has been assessed by the expertise of my colleagues in accordance with the inclusion in this journal.

Results and Discussion

My colleagues have previously highlighted how "critical thinking" has been defined in various ways. The amorphous nature of this construct was also noted in this study with half of the participants (seven out of fourteen) stating that there was not one definition of "critical thinking" while others struggled to formally define it. Though previous work has explored student conceptualizations of "critical thinking" (Danczak et al., 2017), the goal of this study was to extend the literature base on student perceptions of the construct via qualitative methods that sought to go beyond how students defined the construct (though important and necessary to know) and ultimately generate insights on how students arrived at this understanding of "critical thinking", and how students motivated themselves to engage in it. As previously mentioned, this work was influenced by our previously published work (Bowen et al., 2022).

Given the nebulous nature of "critical thinking", my methodological approach (which focused on looking for common themes), and my initial interpretations at the start of data analysis, I found it more productive to focus on the commonalities of "critical thinking" shared amongst students in the sample. However, it's important to note, student perceptions of "critical thinking" in this study were not identical, but the commonalities between them may offer an analytical and practical handle that can be leveraged to better understand how students conceptualize similar constructs and how we can support student learning.

From my analysis, I synthesized findings into four major themes which sought to detail student perceptions of what "critical thinking" is (theme #1), what it is not (theme #2), the perceived origin of their conceptualization and how it develops (theme #3), and the motivational factors that encourage students to engage in it (theme #4). All four themes and associated subcategories are included in Table 2. In accordance with constructivist grounded theory, it is imperative to acknowledge that these themes were developed by me, and that someone else could have developed different themes from the same set of data (hence the influence of sociocultural factors). My approach was inductive and my findings were based on how pervasive these themes were across student perspectives. That is, I wanted to highlight what I interpreted as the most salient factors. Prior to discussing these themes, I believe it important to mention some minor findings that highlight commonalities across students that were not explored in substantial detail to warrant incorporation into a theme. I refer to these findings as minor findings.

Table 2. Themes and subcategories

Themes and Subcategories	**Number of Participants With Responses in Theme or Subcategory**
Theme #1: "Critical thinking" involves the application and use of knowledge	14 (all participants)
• Applying and using knowledge	11
• Building up and connecting knowledge	10
• Reasoning and understanding why	8
• Synthesizing knowledge and noting patterns	1
• Analyzing questions	2
Theme #2: "Critical thinking" is contrasted against more passive approaches to learning	14 (all participants)
• Using rote memorization	14 (all participants
• Knowing the answer prior to practicing	2
• Reading over notes	2
Theme #3: Prior experiences inform "critical thinking" which is further developed through practice	14 (all participants)

Theme #3.1: Students' conceptualization of "critical thinking" is primarily based on prior experiences	14 (all participants)
• Previous academics	14 (all participants)
• Family and friends	3
• Work	1
• Social experiences	2
Theme #3.2: Practice is necessary for developing "critical thinking"	14 (all participants)
• Practicing in general	12
• Reflecting and learning from mistakes	7
Theme #4: Intrinsic and extrinsic factors motivate "critical thinking"	14 (all participants)
Theme #4.1: Intrinsic factors motivate "critical thinking"	12
• Having interest and curiosity	6
• Being challenged and disciplined	6
• Wanting to work with and help others	2
• Relating content to self	3
• Setting goals	1
• Helping with learning	5
Theme #4.2: Extrinsic factors motivate "critical thinking"	11
• Prompting from learning tasks	5
• Grading	10
• Experiencing social pressures	1
NOTE: Students could have had multiple responses in a single theme, coded as different subcategories; hence why subcategory numbers do not total up to 14.	

Minor Findings

In my analysis, I dubbed these findings as minor because students often did not provide additional information or spoke generally about their experience. However, given my focus on common themes across student perceptions, I found them to be informative and related to the study. All (that is, all fourteen participants) students in this study perceived that "critical thinking" was significant and important for their learning and life, that they enjoyed engaging in "critical thinking" with some situating it as a love-hate relationship, and that it was applicable across all courses (including those outside of science). This final minor finding was interesting given that historically some have situated "critical thinking" as inherently "scientific" (George, 1967). Furthermore, in a more recent study, Flaherty found that undergraduate students in OCLUE perceived that science students would be more curious and questioning than history students regarding argumentative claims (Flaherty, 2020b), potentially indicating that these students might perceive science majors as being more "critical" than students in non-science degree paths.

Furthermore, despite the different curricular and pedagogical approaches in the organic chemistry courses in this study, all students perceived that they were using "critical thinking" in their organic chemistry courses at the time of the interview. Unsurprisingly, all students were familiar with the term "critical thinking" despite its nebulous nature. This related to the fact that most participants (eleven out of fourteen) mentioned that "critical thinking" had been mentioned (and even expected of them) but had not been made explicit to them in the past. These minor findings provide additional context to the themes and further support my decision to explore commonalities across student responses.

Theme #1: "Critical thinking" involves the application and use of knowledge

Theme #1 focused on capturing commonalities across student conceptualizations of "critical thinking". Though students discussed "critical thinking" in various ways, a point of convergence was that all students situated "critical thinking" as applying and using knowledge in some way, a perspective that was also noted in the literature (Glaser, 1941; Dunning, 1954; Barron et al., 2021). This theme included several subcategories: 1) applying and using knowledge (in general); 2) reasoning and understanding why; 3) building up and connecting knowledge; 4) synthesizing knowledge and noting patterns; and 5) analyzing questions. The subcategories and number of participants that had a response coded as the subcategory is shown in Table 2. It's important to note that the subcategories were not mutually exclusive; that is, a student's conceptualization of "critical thinking" could have multiple subcategories depending on how they discussed the construct.

Applying and Using Knowledge (In General). The subcategory of "applying and using knowledge" captured responses that discussed "critical thinking" as involving the general application of material. In some cases, this entailed applying previously learned knowledge to unfamiliar problems or new situations as noted by quotes from Amanda and Virginia below.

"…you're presented pieces of information or like concepts like being able to absorb that and apply it in a new given situation and being able to like work through like a problem with what you already know I guess, is how I would, specifically like applying it. I think that's how I would define [critical thinking]…" (Amanda 85; OCLUE)

"…I said in my opinion [critical thinking is] learning something new and using that knowledge to apply to future concepts and ideas" (Virginia 21; OCLUE)

For both Amanda and Virginia, the application of concepts and ideas to "future" problems was important for their understanding of "critical thinking". The perspectives of these students was also noted in previously mentioned literature (Glaser, 1941; Dunning, 1954, 1956; George, 1967; Vieira et al., 2011; Gupta et al., 2015; Barron et al., 2021). In total, eleven out of fourteen students discussed "critical thinking" as applying and using knowledge in general.

Building Up and Connecting Knowledge. The "building up and connecting" knowledge subcategory captured responses that detailed how students used their knowledge to build up or draw relationships between concepts. Initially, the "building up and connecting knowledge" subcategory was a category all to itself. I opted to incorporate this subcategory into the theme because 1) in order to relate concepts together one must use their knowledge, and 2) the subcategory consistently co-occurred with "applying and using knowledge (in general)" or other subcategories already subsumed in the theme. Hailee and Damien provide examples of how students talked about this subcategory.

"…with organic chemistry there, we have different principles and theories that, um, we build upon, and that's like our foundational understanding of certain concepts like… um, in recitation it was like Le Chatelier's principle so there's always like facts and scientific evidence and theories that are, build upon what we learned in class and those kind of tie back into what we, the reactions we do" (Hailee 51; OCLUE)

"…so critical thinking, and in my opinion, is just utilizing all these building blocks that intro classes and intermediate classes prepare you for, to be able to get to these more advanced classes…" (Damien 47; traditional)

Both quotes above highlight how previous information learned, sometimes in another course (i.e., introductory courses) would need to be used for new problems in organic chemistry or upper-level courses. Therefore, to these students, connecting concepts together and building off of previous knowledge was important for engaging in "critical thinking" and was how they situated it. In total, ten out of fourteen participants had responses in this subcategory.

Reasoning and Understanding Why. Some participants were more specific in what they meant by applying and using knowledge. That is, they not only conceptualized "critical thinking" as involving application and use of knowledge, but they saw it as involving reasoning and being used to understand why something happens. Arisha and Milo offered exemplar responses for this subcategory.

"…You can really like apply what's going on to like a situation like you're not just doing it, like you're actually… like, like, get what's going on, versus just like going with the flow like what someone's telling you is happening. Like you can see why it's happening" (Arisha 55-57; OCLUE)

"So, just in general, critical thinking to me is… instead of asking, like, answering what something is, it's how something is, why something is" (Milo 39; traditional)

I argue here that in order for students to engage in reasoning and parse out why a phenomenon happens, students must apply concepts and use their knowledge in some way. In fact, in many cases (Arisha's response being one example), responses in this subcategory mentioned "application" and "reasoning" or "understanding why" together. In our previous work we noted a similar co-occurrence in student perceptions of what they were expected to do, with many responses associating the application of knowledge to understanding why (Bowen et al., 2022). In total, eight out of fourteen students had responses in this subcategory.

Synthesizing Knowledge and Noting Patterns and Analyzing Questions. The vast majority of responses related to theme #1 were contained in the other subcategories. However, there were other perspectives that we posit are related to seeing "critical thinking" as the application and use of knowledge. For Adelynn, they discussed how they often synthesized knowledge together across multiple assignments and learning tasks, a process which involved applying knowledge and using it to note patterns between related concepts.

"I think of it as like, okay, from all the lectures, and all the notes, and even like, the beSocratic homeworks, and recitations like, there's just like, a bunch of information, and I just tried to see like, what, you know, I try to like, put it all together and really see patterns amongst that and, um, like, the general overarching like, takeaways I can think of..." (Adelynn 11; OCLUE)

On the other hand, a couple of students also discussed the process of analyzing questions with the ultimate goal of figuring out which information needed to be applied, as Noelle notes:

"…I guess just like, um, like you're given a problem, you need to analyze it, you know, so I guess, analyzing it first, and then thinking

back on what you know that can be applied in order to find a solution for it." (Noelle 43; OCLUE)

Although the number of responses in these two subcategories was much smaller than the others, with only three students across both subcategories having coded segments assigned to them, I find them to be important for inclusion considering they represent the ways students conceptualized "critical thinking" and how it involved the application and use of knowledge.

Theme #2: "Critical thinking" is contrasted against more passive approaches to learning

Theme #2 focused on capturing commonalities in student perceptions of what "critical thinking" is not. Within the interview protocol, I explicitly encouraged participants to contrast "critical thinking" to other ways of doing to further clarify their perspective. The rationale for this was based on previous interview experiences that found some participants had an easier time navigating what was not representative of an abstract construct, rather than what it was. With this group of students, all of the participants contrasted "critical thinking" against passive approaches to learning, particularly rote memorization, an idea also noted in the literature (Dunning, 1954; George, 1967, 1968; Rickert, 1967; Tsai, 2001; Santos, 2017). Similar to theme #1, theme #2 includes multiple subcategories: 1) using rote memorization; 2) knowing the answer prior to practicing; and 3) rereading over notes. However, it is worth noting that in the case of this theme, the "rote memorization" subcategory was far larger and more prevalent than the others. A breakdown of the number of participants with responses in each subcategory is included in Table 2.

Using Rote Memorization. As the name suggests, responses that contrasted the use of rote memorization to "critical thinking" were included in this subcategory. Examples from Clara and Rebeka are included below:

"Just the ones where you kind of like copy notes from a board and the next day or a week later, you're tested on exactly what you, you know, word by word from what you copied. I think that doesn't allow for critical thinking to happen" (Clara 49; traditional)

"…not critical thinking is straight memorization without asking like the who, what, why, when, like, um, not exploring like the ideas that came before just like taking the baseline facts…" (Rebeka 29; OCLUE)

As can be seen, Clara, a student in the traditional organic chemistry course, mentions situations where students are testedover how well they can regurgitate copied information as being the opposite of what "critical thinking" is. Similarly, Rebeka contrasts "critical thinking" to memorization and further expands on this by stating that "critical thinking" involves the "who, what, why, when…". All fourteen participants contrasted their conceptualization of "critical thinking" with rote memorization, and it was, by far, the dominant subcategory in this theme, indicating strong commonalities across student conceptualizations. However, it's worth noting that some participants were quick to say that this did not mean memorization was entirely "bad", a perception which I plan to explore in a different study.

Knowing the Answer Prior to Practicing. The "knowing the answer prior to practicing" subcategory captured the few responses that illustrated situations where the answer was already known prior to starting practice problems. The students who had responses in this subcategory talked about how knowing the answer prior to engaging in a problem may instill false confidence into students and that it "tricked" students' brains into thinking they understood the material. Adelynn and Hailee provide examples below:

"…like trying to do the problem but just for like, you kind of expect the answer or you know it already, and I think there's like, not a true test of what you actually know" (Adelynn 47; OCLUE)

"…I think it's in those moments like if we were to just kind of sit there and guess, and think, oh, I think I've seen that answer before where I just, you know, a really vague, um, principle, you know something and then you just click the answer and you just keep going and you don't really understand why you chose it but you get it right and you just kind of move on and not knowing the deeper meanings for the answers or why the processes work the way they do and the foundational level" (Hailee 31; OCLUE)

From the perspective of these students, knowing or recognizing an answer to a problem can hinder a student from looking beyond the answer into understanding why the answer is correct. Only Adelynn and Hailee had responses allocated to this subcategory, therefore it is a small but important part of their perception into what is not "critical thinking".

Reading Over Notes. Passively reading over notes was identified as another direct contrast to "critical thinking" by a couple of students. Although the students who mentioned this identified that reading over notes could be helpful for studying, they saw that passively reading the notes by itself was not efficient for learning. Whitefox and Adelynn provide examples below:

"…reading things it has like, it has neither the, you're not like, spending enough time in it, and also like, you're not even like, I guess, mentally challenging yourself, and there's no critical thinking involved in it whatsoever." (Whitefox 43; traditional)

"Another example that might apply is like, reading over your notes. Like, you might think that like that information is getting into your brain more because you're like, reading over it, but I just don't think that's like, very critical thinking because it's not like, taking stuff you know and trying like, to apply it to something that you don't know the answer to yet." (Adelynn 47; OCLUE)

Earlier in the interview, Whitefox noted that *"…I find rereading notes is one of the most like, inefficient in terms of like, yield for studying,"* (Whitefox 27). This perspective coupled with their quote above highlight how Whitefox contrasts this passive approach to "critical thinking". Similarly, Adelynn also noted that rereading notes was not effective and connected it back to how it does not encourage one to apply knowledge. Similar to the previous subcategory, only two students (Whitefox and Adelynn) had responses in this subcategory.

Theme #3: Prior experiences inform "critical thinking" which is further developed through practice

Theme #3 captured how students came to understand what "critical thinking" meant and how they got "better" at it. This theme sought to extend the insights generated from previous themes by exploring how students perceived they arrived at their conceptualizations of "critical thinking" captured by themes #1 and #2. Given my theoretical framework, I found this to be an important inclusion in this study since students' past sociocultural experiences with academics, work, family, and friends impacted how students conceptualized "critical thinking".

Theme #3.1: Students' conceptualizations of "critical thinking" are based on their prior experiences. A breakdown of responses in this subtheme are included in Table 2. Students in this study relied on previous academic experiences, family, friends, work, and social experiences to conceptualize "critical thinking". That is, there was little to no evidence amongst these students to suggest that their organic chemistry experience informed their "critical thinking". For example, Damien relied on their hydrogeology course as helping them develop "critical thinking" while Reina provided a broader explanation and stated that different environments "[play] a role into how you think":

"…I would say that one, one of the classes that really allowed me to see how things kind of pieced together, um, and from a variety of disciplines was actually my hydrogeology course, um, of Fall 2019, and that was really cool to see how chemistry, physics, geology biology, all combined to impact, you know, subsurface movement of water, and, and, and different pollutants that could travel to various areas and how it impacts, you know, agriculture or forest land or, or your drinking water…" (Damien 155; traditional)

"…everyone grows up in a different environment, the way in the way like, parents teach you, the way that you, um, interact with your friends when you're younger too, it all just plays a role into how you think, and I think that it can be very different for people…" (Reina 67; OCLUE)

All students in the study relied on their prior experiences in the context of "critical thinking". I only show two examples above due to space limitations but students also mentioned their families (i.e., mirroring approaches of family members), social pressures (i.e., engaging in "critical thinking" in order to compete in a class), and work (i.e., working in a hospital) as informing their understanding of "critical thinking". I found it interesting that students did not discuss their organic chemistry course in the context of developing their "critical thinking" given that scholars and instructors assert that organic chemistry develops these generalized "critical thinking" skills (Dixson et al., 2022). According to the students in this sample, they arrived at organic chemistry already having some conceptualization of what "critical thinking" was and how to do it; that is, they were engaging in a practice they had been using and learned previously.

Theme #3.2: Practice is necessary for developing "critical thinking". A breakdown of responses in this subtheme is shown in Table 2. This subtheme contained responses that describe how "critical thinking" develops. All students had at least one coded segment that discussed how "critical thinking" developed through consistent practice, as noted in the quotes below by Clara and Whitefox:

"I would say the more that you really, and like, authentically immerse yourself in the content and the material. And the more that you kind of want to be in the classroom setting. And the more effort, like I said, that you put in, I think practicing and putting in the effort is a really big thing. I think the more that you do that, the more that you'll be rewarded and that reward comes from critical thinking" (Clara 95; traditional)

"I think you have to like be in that field and keep applying that critical thinking for that field over and over again that helps you make, become quicker, forming connections between concepts and also simply because the more concepts you have the easier it is to form connections between them. So I think the more exposure, you have to that field, you're going to be able to form, be able to, be able to critically think in that field" (Whitefox 79; traditional)

The idea of practicing being necessary for the development of "critical thinking" was noted in the literature (Kogut, 1996; Oliver-Hoyo, 2003; Abrami et al., 2015). In some cases, students' perceptions went further, such as when they discussed reflecting on responses and learning from their mistakes in the context of practicing. This highlights that students do perceive one must consistently practice to get better at something, a theme which could be pedagogically useful.

Theme #4: Intrinsic and extrinsic factors motivate "critical thinking"

Up until this point, the themes have covered how students conceptualized "critical thinking", where students source their understanding of the construct, and how they perceive it develops. However, I also wanted to generate some insights on what motivates students to engage in this way of thinking. Theme #4 captured a variety of motivating factors that students thought encouraged them to think "critically".

Theme #4.1: Intrinsic factors motivate "critical thinking". A breakdown of responses in this theme is shown in Table 2. Intrinsic factors were those that students internally leveraged to get themselves to engage in "critical thinking" (according to their definition). As one can imagine, there were many different factors mentioned by students including: 1) having interest and curiosity, 2) being challenged, 3) being disciplined, 4) wanting to work with and help others, 5) relating the content to their major and life, 6) setting goals, and 7) helping with learning. For example:

"…I think when I critical think in my classes I learn more, and I understand things more. And so, I think if we want students to succeed, or you yourself as a student, you want to succeed, pushing yourself to critically think about that is something that's going to help…" (Ella 75; OCLUE)

In Ella's quote, they note that by engaging in "critical thinking" they ultimately learn more, highlighting how engaging in that way of thinking helps with their learning. On the other hand, Clara (below) notes that when they are working with a problem at the appropriate challenge level, they find this fun and engaging, and this is what helps them think "critically" about the content.

"So, a question where I feel like I have some of the pieces, but I need to find the, the other ones, those types of questions I really like to critically think about because I feel like I have all the tools needed and I just have to kind of set it up. So that, that becomes fun. I, I want to say like when it's a question that is the right amount of difficulty…" (Clara 119-121; traditional)

In total, twelve out of fourteen participants leveraged intrinsic factors to motivate themselves to think critically.

Theme #4.2: Extrinsic factors motivate "critical thinking". A breakdown of responses in this is shown in Table 2. Intrinsic factors were not the only way that students encouraged themselves to think "critically". In fact, some students were vocal about not enjoying chemistry, yet they still perceived they could engage in "critical thinking" with the material. In some of these cases, students relied more on extrinsic factors to motivate themselves. Similar to theme #4.1, there were a variety of factors mentioned by students including: 1) prompting, 2) grading, and 3) experiencing social pressures. In the case of prompting, Noelle offers a great example:

"…So, like on the [homework] how she has is like okay, like each slide is like one step for the problem. So it's like okay let's do like when it's like the multiple step reactions and she's like okay like what's, what's step one and then you click next and like okay now based on that, what's step two, and you do that, draw it out whatever, so I like that because then I like gets me thinking about every step focuses on every step, versus like, there have been like some problems versus like okay here's this, here's a giant box like draw the whole reaction, it's like four steps, but it just like gets all mixed up, so I like it how she actually breaks it up sometimes, that helps me so" (Noelle 131; OCLUE)

In Noelle's experience, the homework questions that were broken up and scaffolded encouraged them to "critically think". This was largely due to the prompting in the task which encouraged students to think about each facet individually before bringing all of the information together. Aside from prompting, some students were motivated by their grades and performing well in the course:

"…so I guess, to be motivated to think critically means you need to be motivated to be a high achiever in the class, and think that there's that kind of motivation come from both like past experiences, especially if you have like a tracker record of like it's doing good you want to keep the track record going, um, and also, I also know people who are like who have a track record of doing average, they have no incentive they're like, oh, I'm just aiming for a B or I'm just aiming for a C, I hear that quite a lot, people are like, not, I guess, uh, they're not aiming for an A" (Whitefox 101; traditional)

From Whitefox's perspective, one must be "motivated to be a high achiever" in order to "critically think". However, Whitefox was not alone in this perspective, and various students talked about the role of grades as a motivating factor. For example:

"So, I mean, I think it is possible to, like, critically think even though you don't have like an interest in it, if you want, if there's like a different motivation behind it, I guess… Which I think for most people would be like being successful and like getting good grades," (Amanda, 129-131; OCLUE)

Amanda also notes the role that grades can have for motivating students to engage in certain ways of doing, in this case "critical thinking". Other students talked about how grades hinder them from engaging in "critical thinking" with some situating grades as inaccurate of a student's "actual" learning. Regardless, for a handful of students, grades were a motivating source. In total, eleven out of fourteen students discussed extrinsic factors and their role with "critical thinking".

Differences Between OCLUE and Traditional Organic Chemistry

Much of the previous research between these two types of courses have been comparative and have found differences across student approaches to learning tasks and perceptions (Crandell et al., 2019, 2020; Houchlei et al., 2021; Bowen et al., 2022). In the case of this study, I noted that all students in this study perceived they were engaging in “critical thinking” in their organic chemistry courses. Despite the differences in course design and enactments between OCLUE and the traditional course, there were strong commonalities amongst students when discussing “critical thinking”. As illustrated in theme #4, students may draw on a variety of ways to motivate themselves to think “critically”; that is, even if a course does not encourage it, students may motivate themselves to think in a certain way. Though student conceptualizations of “critical thinking” showed overlap, there were some differences in the when and where students perceived they were thinking “critically” in their organic courses.

In OCLUE, students primarily saw themselves “critically thinking” on their weekly homework assignments (as long as they took them seriously), recitations, and course assessments. For example, Arisha, Hailee, and Ember describe how OCLUE encouraged them to think “critically” on homework, recitations, and exams, respectively:

“I think we definitely are expected to use like the term critical thinking like we're supposed to take the knowledge we learned in lectures and be able to like, apply it to our homework and exams.” (Arisha 9; OCLUE)

“…I know one that we did in recitation was kind of like describe, like it was like explain this reaction, so you have to draw out the reaction, and then you have to explain why it happened like that. And sometimes its flipped where she'll ask a question like, um, why does why, like why is carbon… what am I thinking of? Why are fats not soluble in like, why is oil not soluble in water, something like that, she'll tell you to explain it, and then she'll tell you to like, draw a picture that also aids the explanation…” (Ember 21; OCLUE)

“…you have to really know what you're doing to do well on the test because it's not a multiple choice test and it's not just facts or, you know, like s-simple concepts, it's really broad concepts that all build off of each other so I think you would, you wouldn't be able to get by at all with just memorizing…” (Hailee 35; OCLUE)

On the other hand, students in the traditional course perceived that they were primarily asked to engage in “critical thinking” on in-class activities (of which there were two for the semester), recitations, and homework (though for different reasons), and not as much on their course assessments. For example:

“…I would say that the critical thinking, parts have been present throughout the whole semester, but most, mostly in, um, the you know the activity, like I mentioned… and I feel that critical thinking part comes out in recitation more than it does in lecture.” (Damien 93; traditional)

“…I would say not as much critical thinking on the quizzes and exams because it’s multiple choice. I would say critical thinking is used much more on the homework since there's, uh, a good bit of questions that require like, you to draw the molecule or to type out the name, so.” (Milo 101; traditional)

Here, Milo talks about how the multiple-choice assessments do not encourage “critical thinking” but discusses how “critical thinking” on the homework involves more open-ended responses. Though Damien perceived that “critical thinking” was taking place throughout organic chemistry, they primarily discussed it in the context of the activities (and recitations) which students perceived had them relate multiple concepts together.

Upon further digging into these activities in the traditional course, I found something quite interesting. As readers may recall, OCLUE is informed by three-dimensional learning which incorporates three-dimensional items on homework, recitations, and assessments, all of which students perceived involved “critical thinking” while the traditional course is *not* transformed. In an effort to enhance and expand transformation efforts at my institution, there is a fellowship program for faculty members that acts as professional development to help interested faculty engage with and utilize three-dimensional learning in their courses. The faculty member who taught the traditional organic chemistry course in this study was part of this fellowship program in the past. Though their course looks largely traditional, they have attempted to incorporate more three-dimensional items into their instruction and assessments. One way they have done this is through the two activities in their course. That is, the two activities, which most of the students in the traditional course mentioned as getting them to use “critical thinking” were developed in a professional development program that sought to instruct faculty on how to incorporate three-dimensional learning into their learning tasks. Though the degree to which the courses incorporate three-dimensional learning is quite different, it is interesting to see students mention “critical thinking” in the context of three-dimensional activities in both courses.

The Core Category

The core category in grounded theory is developed in the theoretical coding stage and represents the theory that is generated based on interpretations in the data. The theory is based on the inductive categories and themes that have emerged and been interpreted in the data; that is, the theory is grounded in the data, hence the name (Glaser and Strauss, 1967; Charmaz, 2006; Corbin and Strauss, 2015). As I noted in the methods section, I have opted to use constructivist grounded theory which further describes the core category as an analytical handle by which to interpret and situate the findings (Charmaz, 2006); however, the analysis was still informed by other schools of thought on grounded theory, such as the use of axial coding (Corbin and Strauss, 2015).

Within this methodological approach, Charmaz stresses that researchers "should focus on meaning, action, and process" (Charmaz, 2006; Hallberg, 2006) which I have sought to do. In my experience, grounded theory approaches within the framing of Corbin and Strauss (Corbin and Strauss, 2015) encourage the generation and communication of a more formalistic theory with the core category; however, those within constructivist grounded theory may have a core category that's more "narratively" explained due to its inescapable connection to its context and sociocultural factors (Hallberg, 2006) which is an approach I take here.

Since the core category should describe what the study was about, taken together, all four major themes inform my core category of conceptualizing "critical thinking". With the focus on how students perceived what "critical thinking" is (themes #1 and #2), what experiences influenced their perception and how "critical thinking" develops (theme #3), and what motivates them to do it (theme #4), my aim was to provide an analytical and practical handle on what students believe "critical thinking" to be, despite its amorphous nature noted by students in this study and throughout the literature. These themes therefore address my first research question of what commonalities exist across student perceptions. In a similar study by Danczak and colleagues, they noted similar themes across student responses, including the application of knowledge. They concluded that students primarily defined "critical thinking" as "to analyse and critique objectively when solving a problem" (Danczak et al., 2017). Although some students mentioned the idea of "objectivity", it was not a major point of convergence. However, the focus on analyzing and solving problems was also noted in student responses in this study.

Although the themes can be useful in their own right, my overarching goal has to clarify what students meant when they mentioned "critical thinking". I argue all four themes represent student perspectives in this sample, and I believe can extend the literature base on our understanding of how students conceptualize "critical thinking". To address my second research question of what insights student perceptions can provide to help clarify the construct, I posit that students seemingly do not conceptualize "critical thinking" as thoroughly as some definitions, such as in the "Delphi Report" (Facione, 1990), nor do their definitions align across all facets. That is, students also recognize the amorphous nature of the construct. Previously I mentioned that others have advocated for abolishing the term "critical thinking" and instead situating the scientific practices in three-dimensional learning as component parts of the construct to make it explicit what we want students to know and do (Cooper, 2016; Stowe and Cooper, 2017). Using the themes from this study, I add credence to this assertion, and I will discuss the core category and subsequent themes in the context of two facets: 1) the amorphous nature of "critical thinking" and 2) the alignment of student perceptions with the scientific practices in 3DL

The Amorphous Nature of "Critical Thinking". Research related to "critical thinking" has been going on for decades and disciplines are still struggling with developing a consensus definition. The amorphous nature of the construct was also recognized by students in this sample. For example, Adelynn described "critical thinking" as merely a "buzzword" while Reina and Clara saw the definition of "critical thinking" changing based on the person defining it. Although both Reina and Clara were able to provide a definition for "critical thinking", they were quick to recognize its nebulous nature. Some students, such as Milo, Amanda, and Whitefox had a more difficult time defining "critical thinking" despite receiving the interview questions ahead of time. For example, in response to the question "how would you describe what "critical thinking" is (like if you had to give a definition)?", all three participants hesitated. Therefore, if students also recognize the amorphous nature of the construct or are confused by its meaning, its mention in instruction is not a useful practice.

Despite having previous experience with "critical thinking" and stating they had come across the term before, students confirmed its amorphous nature in various ways throughout the interview. The different conceptualizations noted are likely rooted in the ways that students have been trained in their previous experiences. From theme #3, students were drawing on a variety of experiences to conceptualize "critical thinking", and the diversity across these experiences make it even more difficult for a consensus definition to be established.

Within CER, Stowe and Cooper have suggested that we completely avoid the term "critical thinking" and instead be more specific about what we want students to know and do (Cooper, 2016; Stowe and Cooper, 2017). Throughout the literature and this study, it is clear that "critical thinking" is something more than having declarative knowledge. Themes #1 and #2 highlight that students perceived that this knowledge must be put into practice and that rote memorization is not "thinking critically". In the literature I noted there was overlap amongst definitions that described "critical thinking" as the application of knowledge (Glaser, 1941; Dunning, 1954; Gupta et al., 2015; Barron et al., 2021), contrasting the construct against rote memorization (Dunning, 1954; George, 1967, 1968; Rickert, 1967; Facione, 1990; Tsai, 2001; Mulnix, 2012; Santos, 2017), and that practice is important for its development (Oliver-Hoyo, 2003; Abrami et al., 2015). All three commonalities were also noted in student perceptions of the construct and are represented in the major themes identified, indicating potential points of nucleation for clarifying the construct and what we want students to do when we say "critical thinking". That is, these general overarching commonalities may act as foundations of what "critical thinking" is and entails but will require more explicit and detailed descriptions of what students are expected to know and do, an idea I will discuss next.

The Alignment of the Commonalities of "Critical Thinking" with the 3DL Scientific Practices. While the commonalities may offer a foundational scaffold for "critical thinking" in science education, I posit that these commonalities must be situated within the literature and theories of learning and have more explicit and detailed learning targets. Others have previously asserted that the 3DL scientific practices act as component parts of "critical thinking"

(Cooper, 2016; Stowe and Cooper, 2017) and over time other scholars have also situated "critical thinking" as involving certain scientific practices (Siegel, 1989; Osborne et al., 2004; Crenshaw et al., 2011; Mulnix, 2012; Osborne, 2014; Hand et al., 2018). The scientific practices in 3DL define concrete and specific ways of doing that mirror the ways of thinking expert scientists employ (National Research Council, 2012a; 3DL4US, n.d.). Engagement in a scientific practice requires the use of scientific knowledge where the knowledge is applied to come up with a solution. In some cases, multiple practices are needed, but they all require application of relevant knowledge.

As evidenced by the first theme, the students ultimately perceived that "critical thinking" involves the application and use of knowledge. This, in conjunction with the fact that students perceived passive approaches to learning (theme #2), especially rote memorization, was contradictory to "critical thinking", illustrates that students do see the construct as being something more than regurgitation of declarative knowledge and facts. With regard to theme #3, the scientific practices offer explicit ways to engage students in the act of doing science. That is, in a three-dimensional environment leveraging the scientific practices, students have many opportunities and access points to engage in scientific thinking and practice (Bang et al., 2017). Although the findings from theme #3 imply that students are not relying on organic chemistry to inform their perception of "critical thinking", there is more to consider. At the time of the interview, it may have been too early for students to reflect on their experiences in organic chemistry to recognize how the course had impacted their perception and understanding. Regardless, the data demonstrate that current student perceptions align well with the intended purposes of the scientific practices in three-dimensional learning. Other perspectives and studies have also found ideas like "application", "use of knowledge", and contrasts to rote memorization as being important for "critical thinking", indicating that previous work in conjunction with this study pinpoint a convergence point for the construct that aligns with the scientific practices. While we have no control over intrinsic factors that motivate students, we can, however, leverage the extrinsic factors many students relied upon, such as prompting. For example, my colleagues have conducted research into the role of prompting on learning tasks that impact how students respond (Crandell et al., 2019; Noyes and Cooper, 2019; Noyes et al., 2022). That is, through the lens of three-dimensional learning, they have found effective ways for prompting students to engage in causal mechanistic reasoning and recognize its influence on student thinking. Though grades were mentioned as an extrinsic motivating factor, I have opted to explore this perception in more detail in another publication.

I have noted alignment between what students perceive is "critical thinking" and the scientific practices since the practices would clarify the meaning of "critical thinking" and explicitly communicate what students need to do. The use of three-dimensional learning does necessitate a curricular overhaul, however, and would not be accomplished with a simple intervention. Regardless, I posit that the use of three-dimensional learning and the scientific practices offer a potential way forward for engaging students in the work of "critical thinking" that not only aligns with the evidence presented in this study, but to the perspectives that have been noted in the literature.

In relation to the alignment between student perceptions and the scientific practices, it is likely this work may require consistent instruction. All students in the study relied on past and present experiences outside of organic chemistry as influential for their understanding for "critical thinking". That is, organic chemistry was not the source of "critical thinking" skills for any of these students, as some may imply. Regardless, within theme #3, I noted that students perceived they would need to consistently practice to get better at "critical thinking". In some cases, this practice was described as "immersion" and involved reflection and learning from mistakes. As I have noted, the idea of consistent practice has also been suggested in the literature, including a meta-analysis of strategies related to developing "critical thinking" (Oliver-Hoyo, 2003; Abrami et al., 2015). That is, though "critical thinking" has historically assumed many definitions, it has consistently been suggested that it requires practice. This may suggest that one-off interventions are not as effective at providing students enough opportunities to practice and develop their thinking (Noyes et al., 2022). This point aligns with the use of three-dimensional learning scientific practices in that the underlying goal of this curricular approach is to provide consistent opportunities throughout the course, often in the form of formative assessments, so that students can receive feedback on their thinking. Such an approach can further support the use of the three-dimensional scientific practices in instruction.

By adopting a systematic and systemic approach rather than an intervention-based approach, instructors can better communicate that consistent practice and ways of doing (such as the application of knowledge) are valued. In previous research on student reasoning in chemistry courses, it was found that students in OCLUE were more likely to retain their reasoning ability over time (Crandell et al., 2020). Considering that OCLUE engages students in the scientific practices throughout the entire semester on homework, recitations, and assessments, I argue that students are given plenty of opportunities to engage in the practices, ultimately contributing to their ability to use them later. That is, OCLUE is a whole course overhaul with intentional decisions to engage students, consistently, in the scientific practices of three-dimensional learning. Similarly, theme #3 also illustrated that students are drawing on a variety of previous experiences to inform their view of "critical thinking". Given the previous discussion on the amorphous and nebulous nature of the construct, it's difficult to imagine that a single intervention would shift how students conceptualize "critical thinking".

Limitations

The first limitation I acknowledge is that the analysis was conducted solely by me. With this said, the findings not only represent interpretations of student responses, but primarily my own interpretations. As mentioned earlier, my choice of method was intentional, and in the context of constructivist grounded theory, it is acknowledged that someone else could have analyzed the same data and developed different themes (i.e., perhaps they would not have focused on commonalities); however, this is a point that Charmaz makes clear (Charmaz, 2006). Therefore, I acknowledge that I am influenced by the use of three-dimensional learning and how it may have influenced the discussion of the findings. However, I have attempted to make the connections clear and still argue that three-dimensional learning offers a way forward on this decades-long conversation on "critical thinking".

A second limitation is that this study included a small number of students (fourteen). These students were offered extra credit to participate in the interview (though other students not randomly selected for interview received a separate extra credit activity), and though I tried to ensure I was randomly selecting from a range of experience, these students may have been self-selecting and not representative of the student population at the university. Furthermore, all students were from the same large, research-intensive university and may not represent perspectives across different institutional contexts. In conjunction with this, a third limitation is that students were aware of my position as a chemistry education researcher and overall intentions of transforming curricula and pedagogy. Thus, it is possible students may have catered their responses to my interests or to "protect" their professors. For example, I noted earlier that students in the traditional course largely did not see themselves using "critical thinking" on exams, when I asked Milo why this was, they prefaced their response by saying that they really enjoyed the professor and course and did not want their response to cause any changes in the course.

Implications for Research

As I mentioned earlier, one implication is that smaller, invention-based studies may not be effective to encourage students to engage in certain ways of doing or thinking. Students noted that their understanding of "critical thinking" comes from a variety of experiences, and in order to get better at "critical thinking" that they needed to practice. Therefore, to help socialize students into particular ways of doing and thinking, it is likely better to engage students in certain practices systematically over the course of one or more courses rather than one intervention. I have situated three-dimensional learning and its practices as one way to define the component parts of "critical thinking"; however, I also see three-dimensional learning as a framework to designing environments and assessments that systematically engage students in the practices around core ideas. That is, it has value beyond clarifying "critical thinking".

To reiterate, student conceptualizations were not identical, though my themes highlight the major commonalities across student responses that could be leveraged. For example, studies could explore how students perceive certain scientific practices as being related to "critical thinking". There may be practices that students already use due to their previous academic experiences, however, there may be other practices that are important but that students are less familiar with and have a more difficult time using. Furthermore, additional work is needed to understand why organic chemistry is situated as important for developing "critical thinking" even though students in this study had already conceptualized the construct before getting to this course. The future study(ies) could comment on whether students need time to digest their experience before recognizing the impact it has on their perception, or if their prior experiences are fully dominating over their organic chemistry experience.

Implications for Teaching

To begin, I assert that instructors consider the nature of the term "critical thinking". Its amorphous nature does not lend itself to designing effective learning tasks or goals. Though there are commonalities between student perceptions of what "critical thinking" is, this should not be taken to mean that students agreed on what "critical thinking" was entirely. Instead, I propose that 100% agreement may be an implausible task. However, by focusing on the commonalities, we can seek out ways that student perceptions align with potential pedagogical approaches. In this case, I suggest that the commonalities can be addressed through the use of the scientific practices in three-dimensional learning.

Regardless of whether an instructor chooses to learn more about three-dimensional learning, I recommend that instructors think about the things they want students to know and do and spend some time defining these aspects of their instruction, especially if they are using terms like "critical thinking". Furthermore, instructors should make these definitions and learning goals very explicit to students. Constructs such as "critical thinking" and "problem solving" are often used in lectures, yet students may not be entirely clear on what is expected of them or what exactly they need to do. In some cases, students may assume they know, but their definition or understanding may be quite different than what the instructor intends. I recommend instructors concretely define what they want students to know and do instead of shrouding expectations in terms with many different definitions (without ever defining what they mean). Given the nebulous nature of the term, Stowe and Cooper have taken the position that the term "critical thinking" should not be used at all (Stowe & Cooper, 2017); however, the ubiquitous nature of "critical thinking" throughout education and society makes this difficult. Therefore, my position is that if instructors use terms like "critical thinking", or other amorphous terms like "problem solving", they should be explicit and specific about what students must know and do with regard to these terms. In terms of moving forward, I have posited that the scientific practices and three-dimensional learning offer a route to clarifying the seemingly important construct of "critical thinking". In this study, I noted how, despite the differences in how "critical thinking" was conceptualized, there were some commonalities that seemed to align with the scientific practices. This offers a potential access point to getting students to do something "more" than just memorize and go deeper into how and why chemical phenomena occur.

Conflicts of interest

There are no conflicts to declare.

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