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ARTICLE

The Complexity of Chemistry Mindset Beliefs: A Multiple Case Study Approach

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Mindset is a construct of interest for challenging learning environments, as science courses often are, in that it has implications for behavioral responses to academic challenges. Previous work examining mindset in science learning contexts has been primarily quantitative in nature, limiting the theoretical basis for mindset perspectives specific to science domains. A few studies in physics education research have revealed domain-specific complexities applying to the mindset construct that suggest a need to explore undergraduate perspectives on mindset within each science domain. Here we present a multiple case study examining chemistry-specific mindset beliefs of students enrolled in general and organic chemistry lecture courses. A between-case analysis is used to describe six unique perspectives on chemistry mindset beliefs. This analysis revealed that students' beliefs about their own ability to improve in chemistry intelligence or regarding chemistry-specific cognitive abilities did not consistently match their views on the potential for change for other students in chemistry. The nature of the abilities themselves (whether they were naturally occurring or developed with effort), and the presence of a natural inclination toward chemistry learning were observed to play a role in students' perspectives. The findings from this analysis are used to propose a more complex model for chemistry-specific mindset beliefs to inform future work.

Introduction

General and organic chemistry undergraduate courses present a variety of challenges to many students and thus often require persistence to achieve successful outcomes. Some students manage to overcome their challenges, while others do not. General and organic chemistry are considered gateway courses for various science, technology, engineering, and math (STEM) degrees, as well as prerequisites for many professional programs (Harris et al., 2020; Koch, 2017; Tai et al., 2005). Course failure and withdrawal rates are typically high for general and organic chemistry, not unlike other STEM gateway courses (Harris et al., 2020; Horowitz et al., 2013; McKinney et al., 2019; Popejoy and Asala, 2013). These rates of unsuccessful course completion support the claim that academic challenges are both plentiful and present substantial obstacles for many students. Institutions aim to increase STEM course retention, increase course completion success rates, and contribute to increased diversity in STEM and medical professional fields. Insight into the nature of students' decisions to persist or give up in the face of challenge is instrumental to addressing this problem.

Mindset has been identified as a relevant psychological construct to include in the investigation of persistence behaviors as it involves beliefs about the malleability of intelligence and is linked to persistence and challenge-seeking behaviors (Burnette et al., 2013; Doron et al., 2009; Karlein et al., 2019; Lou & Noels, 2016; Molden & Dweck, 2006). The term "mindset" originates from research on Implicit Theories of Intelligence, which states that individuals hold either incremental theories (beliefs that intelligence can increase) or entity theories of intelligence (beliefs that intelligence is a fixed trait). Incremental theories are linked to persistence because improvement is believed to be achievable with effort. Entity theories are linked to giving up because challenges are believed to be associated with evidence that one's intelligence is insufficient for the task (Dweck & Leggett, 1988). The terms "growth mindset" and "fixed mindset" are more commonly used in more recent studies but are still based on the original definitions of "incremental" and "entity" theories of intelligence, respectively (Luftenegger & Chen, 2017).

In recent years, there has been an increasing interest in understanding mindset in STEM contexts (Gorson and O'Rourke, 2019; Morris et al., 2020; Kalender et al., 2022; Limeri et al. 2020a; Little et al., 2019; Lytle and Shin, 2020). This increased research interest has been provoked by findings suggesting that student beliefs about specific domains vary and are more predictive of their outcomes in that domain relative to their general mindset beliefs (Scott and Guinea, 2014; Shively and Ryan, 2013; van Aalderen-Smeets et al., 2018). Gender and racial stereotypes likely influence students' beliefs about who can succeed in certain STEM fields, and thus their field-specific mindset beliefs (Aronson et al., 2002; Burkley et al., 2010; Good et al., 2003; Good et al., 2012; Ibourk et al., 2022; Leslie et al., 2015; Lytle and Shin, 2020). Several studies have found that domain-specific mindset beliefs: 1) decline over time in STEM courses, and 2) are more predictive of student outcomes

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relative to general mindset beliefs (Dai and Cromley, 2014; Scott and Ghinea, 2014; Shively and Ryan, 2013). These findings highlight the profound effects of experiences in STEM courses and the importance of understanding students' beliefs in association with these domains.

Most mindset theory development occurred through an examination of phenomena in young children to explain behavioral differences (Dweck and Leggett, 1988; Macakova and Wood, 2020). There is evidence to suggest that not only are mindset beliefs at the undergraduate level more complex relative to younger students, but also that the domain-specificity becomes more relevant as students age (Gunderson et al., 2017). Gunderson and coworkers found that students' beliefs about their peers' ability in math become less growth relative to their beliefs about their peers' ability in language with increasing age (2017). These belief gaps only increase when it comes to student beliefs about adults working in math-related fields compared to writing-related fields. Recent meta-analyses conducted over large samples of mindset studies have found inconsistent results for mindset interventions and the predictive relation of mindset with achievement for adult students (Costa and Faria, 2018; Sisk et al., 2018). The average effect sizes for the impact of mindset (with or without intervention) on achievement observed across studies decreased with students' increasing age. An improved understanding of the underlying differences in the impact of adult student mindset and associated behaviors on achievement can help to differentiate these effects from those observed in younger students.

Reports that students can endorse both growth and fixed mindset beliefs simultaneously have existed since early in the mindset research (Dweck et al., 1995). However, the notion that mindset beliefs are context-dependent has gained traction in research lately. The learning environment can activate one view over another (Little et al., 2016), which may yield various effects on student behaviors. The shift in beliefs as a function of a performance feedback loop for STEM subjects also suggests that context matters (Dai and Cromley, 2014; Limeri et al., 2020a; Scott and Guinea, 2014). Likewise, findings that instructors' mindsets about students and the messaging expressed in instruction and teacher-student communication impact student outcomes also point to the environmental influences on student beliefs (Canning et al., 2019; LaCosse et al., 2020; Muenks et al., 2019; Barger, 2019). Little and coworkers called for a shift in methodology away from survey measures that capture a small snapshot of students' views toward rich qualitative analysis to begin understanding the nature of context influences on student mindsets in physics (2016), which could be equally important in other STEM domains like chemistry.

A deeper understanding of the various aspects of undergraduate chemistry mindset perspectives is needed, along with an examination of contextual influences on the expression of these beliefs in chemistry courses. This multiple-case study examines eight students' chemistry-intelligence beliefs and experiences in general and organic chemistry to characterize chemistry-specific mindset perspectives as indicated by their expressed beliefs, behaviors, and interpretations of challenges.

Theoretical framework

Domain-general mindset theory

Mindset research began with the discovery of behavioral pattern differences in children when faced with challenges or failures (Diener and Dweck, 1978; Dweck and Leggett, 1988). Eventually, the two opposed implicit theories about the nature of intelligence (incremental and entity theories) were uncovered as an explanatory factor for these differences in behavioral responses by way of setting differential goals (mastery versus performance goals) (Bandura and Dweck, 1985; Dweck and Leggett, 1988).

The key difference between these two operating theories lies in the meaning attributed to failures or challenges (Molden and Dweck, 2006). A student who endorses incremental theory beliefs will interpret failures as challenges that have yet to be overcome because they believe their intelligence can attain the necessary level for success at a task. On the other hand, entity theorists view failures as an indicator of their insufficient ability and do not believe it is possible to affect their intelligence level. The lack of control over intelligence associated with entity beliefs yields helpless responses and negative affect when exposed to failure experiences in attempts to deflect attention from their insufficient ability. Some behaviors associated with entity theories are procrastination (Howell and Buro, 2009), reduction of effort (Burnette et al., 2013), avoiding help-seeking, evaluation, and difficult tasks (Hong et al., 1999), and minimizing the importance of the failure by changing pursuits (Molden and Dweck, 2006). In sharp contrast, the presence of a feeling of control over intelligence associated with incremental beliefs encourages efforts to improve, persistence, maintained confidence, enjoyment of challenge, and positive affect associated with minor improvements (Dweck and Leggett, 1988; Molden and Dweck, 2006).

Behavior-aligned mindset model

To align mindset theory with a process-oriented motivation theory, Burnette et al. (2013) proposed the Setting/Operating/Monitoring/Achievement (SOMA) model. The SOMA model provides a framework for operationalizing the interrelations between mindset beliefs and behaviors through a

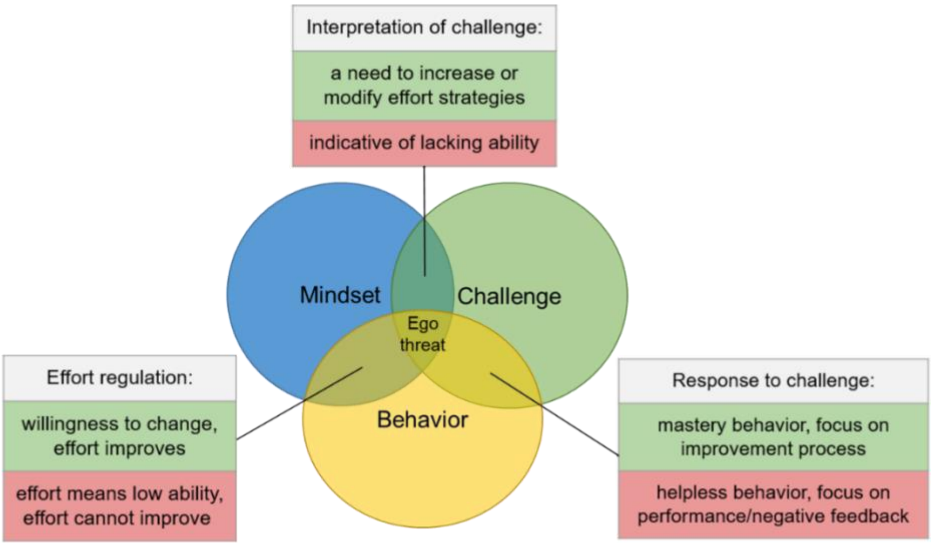

Figure 1. A three-pronged mindset meaning model for case analysis indicating the interactions between mindset, challenges, and behaviors, where green represents growth mindset interpretations (productive strategies or beliefs) and actions and red represents fixed mindset interpretations and actions (unproductive strategies or beliefs).

self-regulation motivation theory lens (Bandura, 1986; Carver & Scheier, 2001). The types of goals students set are associated with their implicit theory beliefs, such that mastery goals align with incremental beliefs and performance goals align with entity beliefs. Students then operate out of these goals by incorporating various mastery or helpless strategies as seen fit. The strategies a student utilizes can be affected by the presence of an "ego threat," or a challenge, which is incorporated into the model as a mediator between implicit theories and goal operating strategies. Students monitor their progress toward goal achievement to inform future behaviors and will likely adjust their strategies to improve their goal operation. The publication that presented this model used a meta-analysis to test the hypotheses embedded in the theoretical framework using path analysis modeling techniques. The model was supported by the study results and provides a useful conceptualization for the practical behavioral and achievement outcomes of interpreting challenges as ego threats. Through this model, the helpless operating strategy is the selected response to the interpretation of a challenge as an ego threat and was found to negatively predict goal achievement (Burnette et al., 2013).

A general mindset model synthesizing the literature on the interconnections between three major mindset themes (mindset beliefs, challenge experiences, and behaviors) was developed by the authors as a framework for analysis, inspired by the SOMA model. Figure 1 presents this general mindset model as a Venn diagram. At the center of the three interacting factors in student experiences lies ego threat. Ego threat here is conceptualized as the meaning associated with challenge as a function of the beliefs that determine behavioral responses. It should be noted that the work associated with the SOMA model was conducted across domains (domain-general) and through quantitative techniques, thus lacking the specificity to academic and STEM contexts as well as the depth of qualitative investigation.

Theoretical model interpretation

For the purposes of this study, it was necessary to create operational definitions of challenge, mindset, behavior, and ego threat. The research team created definitions to apply during analysis: a) Ego Threat - an interaction of beliefs about intelligence with challenge indicating a threat to one's sense of self, producing defensive behaviors as a response. b) Behaviors - what students do when learning, challenged, or feeling threatened (Burnette et al., 2013). c) Challenge - the nature of the challenges students face and what they perceive to be challenging. d) Mindset - students' beliefs about their ability to improve in a particular area and how they view natural abilities in the context of chemistry.

It is important to explain the hypotheses associated with each overlap between factors represented in the general mindset model from Figure 1. We can begin by considering the overlap of mindset and challenge. When a challenge is present, differences in interpretations of that challenge arise as a function of mindset. A growth mindset interprets challenge as a need to increase or modify effort strategies, and a fixed mindset interprets challenge as indicative of lacking ability. Similarly, when challenge is absent, differences in interpretation are possible as functions of mindset: a growth mindset interprets the lack of challenge as a demonstration that previous effort has allowed relevant skills to be developed, while a fixed mindset interprets the lack of challenge as indicative of high or natural ability in the relevant area.

The next relationship to consider is the interaction between challenge and behavior. The interpretation of challenge as ability-related leads to helpless responses such as avoiding demonstrating ability or evaluation, sabotaging performance by other means such as procrastination, and giving up or disengaging emotionally to deflect blame on the level of caring. This ability emphasis also leads to focusing attention on negative feedback and performance outcomes. Meanwhile, the interpretation of challenge as effort-related or "needs-development" leads to mastery responses such as seeking help from other sources, altering strategies, exerting more effort, and increasing self-regulation. The effort emphasis also leads to focusing attention on improvement and the learning process.

The final relationship depicted in the model is between mindset and behavior, such that, the behavioral responses indicate the students' mindset through practical demonstration of their beliefs. When considering students' effort beliefs, the belief that necessary effort implies low ability reveals a fixed mindset, while the belief that effort is the means to improve at any ability reveals a growth mindset. When considering students' willingness to change and improve, ignoring feedback as useful for improvement and decreasing effort reveals a fixed mindset, while attention to improving through feedback and increasing effort reveals a growth mindset.

Using this model, we can contrast theoretical criteria for identifying growth and fixed mindset individuals as opposite ends of a continuum. A student with a strong growth mindset believes that any ability can be developed or improved given the appropriate resources and will to do it, does not give up easily in the face of challenge, and focuses on understanding and mastery as a litmus test for success. Alternatively, a student with a strongly fixed mindset believes that abilities tend to be naturally derived and explain the differences between people in achievement and intelligence. This student will also more readily give up in the face of challenge, especially if it is the first serious challenge encountered in life and focuses on achievement and competitive measures of success. This theoretical model will be used in the data analysis of this study as a lens to recognize behavioral indicators of growth or fixed mindset beliefs.

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Science domain-specific mindset theory

Recently, two studies presented a new framework for mindset in undergraduate physics contexts (Kalender et al., 2022; Malespina et al., 2022). Although chemistry and physics are different domains, both fall under the STEM field umbrella, are physical sciences, are known to have difficult courses, involve substantial mathematical and spatial reasoning abilities, and are likely to present challenges. Two dimensions were described as relevant to students' physics mindsets, resulting in a four-component model of physics mindset: "my ability" beliefs, "others ability" beliefs, "my growth" beliefs, and "others growth" beliefs (Kalender et al., 2022; Malespina et al., 2022). This perspective allows students to endorse each belief to some degree, acknowledging that they can believe in the improvability of intelligence while simultaneously believing there are limitations to it based on natural capacities. These views of the self can match views of others or be misaligned due to high or low self-confidence in physics ability. Multidimensional modeling was used to resolve the mindset subfactors associated with a set of items developed for physics mindset with students enrolled in introductory calculus-based physics courses, revealing the four components of physics mindset. Additionally, MANOVA tests were used to uncover gender differences in mindset beliefs. Male students had significantly higher mindset scores and female students were found more likely to believe that ability is needed to be successful in physics. They also found that "my ability" (fixed physics ability about self, reverse coded) beliefs positively predicted course grade and "others growth" (improvability of physics intelligence for others) beliefs negatively predicted course grade (Kalender et al., 2022). The results do not completely align with general domain mindset findings and were also generated through quantitative methods. However, this framework provides insights and motivation for conceptualizing the nuances of mindset in a STEM domain.

Study goals and design

The overarching purpose of this study is to examine chemistry mindset as a phenomenon within the context of general and organic undergraduate chemistry courses. Understanding this phenomenon requires qualitative theoretical development, which makes a multiple case study approach very valuable as a starting point. Each case will be briefly examined to consider how individual students can be classified with respect to their expressed chemistry mindset beliefs and behaviors. Comparisons will be made across cases to make distinctions between different chemistry mindset perspectives and to uncover relevant themes. Specifically, the research questions driving the study of each case and subsequent analyses are:

1. How can differences in chemistry mindset be characterized considering students' beliefs on the nature of chemistry-related abilities, interpretations of challenge, and behavioral responses?
2. What degree of alignment is observed between interview themes and extant general intelligence mindset theory to provide insight into chemistry mindset as a distinct construct?

To address these research questions, interview content will be analyzed inductively for chemistry-specific mindset content using broader themes from the general mindset model (Figure 1).

Methods

Multiple case study design

This study serves as a qualitative component within a larger study on chemistry-specific mindset of students in general and organic chemistry courses. The study was conducted through a multiple-case study methodology. The purpose of this case study analysis was two-fold: instrumental and descriptive. An instrument case study serves to gain insight into a phenomenon through examination of each case (Stake, 1995). In this study, the phenomenon we aim to better understand is the relationship of undergraduate chemistry mindset beliefs with challenges and behaviors. The second purpose was to provide a full description of this phenomenon within context, aligning with a descriptive case study design (Yin, 2003). For this reason, the unique background of each student must be considered, along with their experiences in the course and the context in which they discussed mindset topics. In a multiple case study, the unit of analysis should be clearly defined. In this study, the unit is defined as a single student over at least two semesters. A total of 8 individual units were examined to understand the complex nature of chemistry mindset through consideration of each individual's interrelated mindset, challenge, and behaviors, and through comparison between cases to identify patterns in this science domain-specific context.

Participant recruitment and case selection

The overall study was approved by the Institutional Review Board before any data collection. Participants were recruited from general or organic chemistry lecture courses via participation in a chemistry mindset survey (a focal point of the larger study, see Data sources below) at the beginning of the Fall 2020 semester ("pre-semester survey"). Students indicated at the end of the survey whether they were willing to be interviewed. Selecting students for interviews was based on their answers to survey questions, with a goal of including equal numbers of students who self-reported fixed mindset beliefs, growth mindset beliefs, and those who reported average mindset values between growth and fixed regions of the distribution. Likewise, their open-ended definitions of chemistry intelligence were considered in the selection process because many students included mindset-related statements about chemistry intelligence along with their definitions. This was used as a secondary source of evidence for their beliefs beyond their self-report on survey mindset items. A total of 14 individuals were interviewed during Fall 2020 and 5 additional students were interviewed in Spring 2021, following similar recruitment procedures. These students received $10 for their participation in the interview.

During Fall 2021, only selected case study participants were invited to participate in a follow-up interview to gain additional insight into their views. For this second interview, a $20 incentive was offered to ensure high participation and reduce attrition.

To select individuals for a multiple case study from the larger interview participant pool, students who had completed both pre- and post-semester surveys in Fall 2020 and Spring 2021 (a total of 4 survey time points) were identified. This criterion was used because it indicates full data existed for each of the participants selected for the case study, leading to an inclusion of eight individuals. Seven were initially interviewed in Fall 2020 and one, Camille, was interviewed in Spring 2021. The case study participant characteristics are described in Figure 2. Two students were first-year (freshmen) undergraduates during the first interview semester, three were second-year students (sophomores), two were third-year (juniors), and one was a post-baccalaureate student completing course prerequisites for medical school admission. Three students initially participated during general chemistry I, two during general chemistry II, and three during organic chemistry I. Students who initially participated in organic chemistry II courses were not included since they were no longer enrolled in introductory courses by Spring 2021. This reason also applied to fourth-year seniors; they could not participate once they had graduated. Students in this study had a range of demographic backgrounds and previous educational experiences.

Data sources and collection

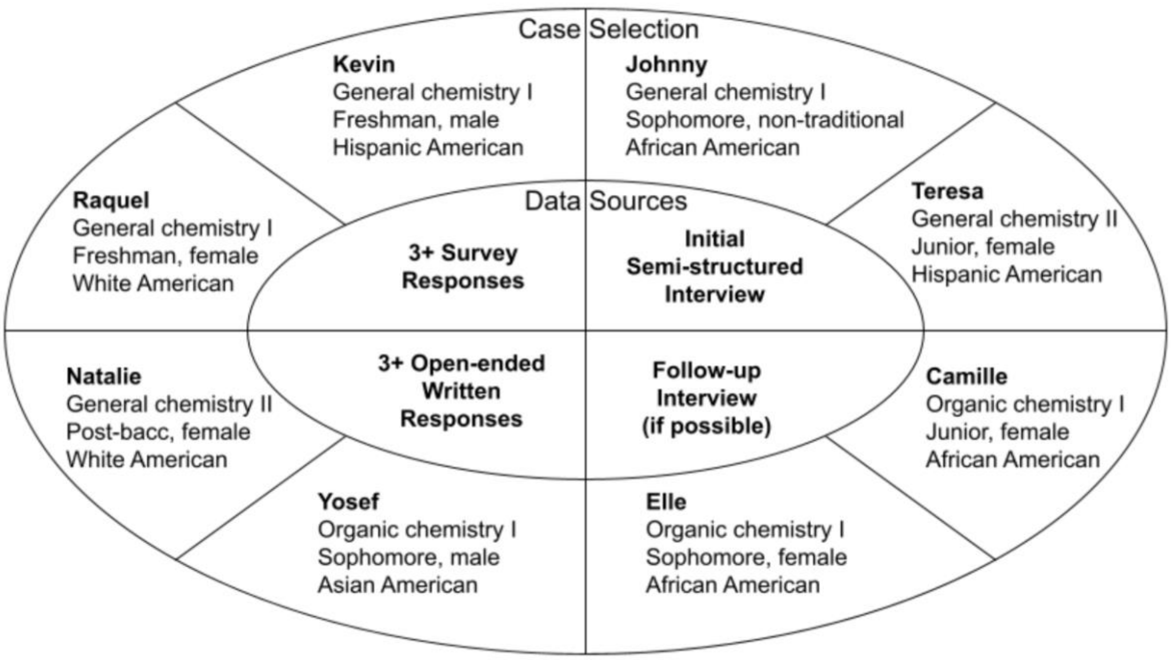

Figure 2. Multiple case study participant selection with student characteristics at the time of first interview and the data sources utilized within each case.

Data from each case participant were collected through a combination of survey measures, open-ended responses to survey questions, an initial interview, and a follow-up interview if they were willing to do so. Surveys were administered using online Qualtrics® survey software during the first three weeks and last three weeks of each semester, Fall 2020 and Spring 2021. Instructors provided survey access to students by posting an announcement containing a link within their course management pages. During this time, the Chemistry Mindset Instrument (CheMI) (Santos et al., 2022) was under development and each survey supported the development process through the inclusion of open-ended questions and various iterations of the instrument. Measures related to achievement goals and self-efficacy were included for purposes of the larger study.

In addition to survey response data, case study participants provided in-depth interview content for analysis. The first interviews were conducted during Fall 2020 and were semi-structured. Interviews took less than one hour and incorporated questions as well as several tasks to prompt deeper discussion of mindset topics. Interviews were conducted online using a virtual meeting platform and students were sent a PowerPoint © file containing the tasks before beginning. The full interview protocol and the tasks students completed during these interviews are available in the Appendices A and B. Interviews were screen-captured and audio-recorded for later analysis. After initial questions, students were prompted to share their screens and present the slides associated with a particular task. Students were instructed on how to complete the task and told to use a think-aloud method as they completed each task. Probing questions about the reasons behind task decisions and beliefs indicated in the task were then used to elicit a deeper discussion of each student's views. At the end of the interviews, students were asked to clearly state their mindset beliefs and explain why they hold such beliefs ("Do you think that people can change their intelligence in chemistry? How did you come to believe this?").

A follow-up interview was requested during Fall 2021 from each of the case study participants. The interview protocol is provided in the Supplementary Information. Questions in this interview focused more on students' experiences in chemistry classes, backgrounds, challenges, responses to challenges, and perceptions of others' views about chemistry as a subject. Towards the end of the follow-up interview, each case study participant was directed to comment on one of their previously completed tasks. This involved sharing whether they still held the views they did at the time of task completion, explaining why they think they completed it that way, and providing what (if any) changes they would make.

Qualitative analysis

All interviews were transcribed verbatim using audio recordings. The resulting text files were then imported into Nvivo® to conduct inductive coding. The coding scheme was developed using the interviews of non-case study participants from the Fall 2020 data pool. Two researchers simultaneously coded the same interview file separately and then met to discuss and negotiate codes. Interviews were analyzed for content related to mindset, challenge, and behavior and these served as the three lenses for coding rounds. The coding occurred via a three-pass method where each coder considered one lens of analysis at a time (mindset, challenge, or behavior), then repeated with each of the other two analysis lenses. Over time, new codes were identified and were merged to represent similar concepts. Additionally, the names of inductive codes were altered to align with literature mindset language. In establishing the final codebook, the two researchers repeated the simultaneous coding and discussion sessions through 6 total interviews until data saturation was reached. The definition applied to establish data saturation was taken from the method described by Guest and coworkers (2020) and considered the proportion of new codes appearing during each consecutive round of inductive content analysis. When codebook changes had slowed significantly to the point that no further changes were made when considering another data set, data saturation had been reached. Additionally, interrater reliability was examined after each interview and an acceptable Cohen's Kappa value (κ = .705) was obtained in the final codebook development round with analysis of Isabel's interview.

One final coder meeting was conducted to refine codes further and align the names of each theme more closely with terminology from the mindset literature. Additional details of the final codebook are available as supplementary material accompanying the online article (Table S1). Once the codebook and interrater reliability were inductively developed and established using other transcripts from the larger interview pool, all case study interviews were coded according to the three-pass method previously described. This coding scheme was applied to both initial interviews and follow-up interviews deductively.

After coding all interviews, coding frequencies were compared across cases. The transcripts were examined for relevant quotes to represent their expressed views on each aspect (mindset, behavior, and challenge), and summaries for each case were drafted. These summaries were sent to each participant for member-checking, or verification that the summaries accurately represented their views. Most participants replied that it was a correct representation or submitted minor corrections to explain in more detail.

Limitations

In qualitative analysis, bias is difficult to minimize due to personal interpretations and communication styles. To address this, member-checking was employed with students after their follow-up interview was completed. Only 6 of the 8 case participants agreed to follow-up interviews and one of these did not submit their review of the member-checking summary provided. Additionally, eliciting responses that reveal students' views required multiple interview activities and revised questioning in the second round. It is possible that some students did not fully express their beliefs within the constraints of the interview structure. To further obscure student views, their comments about chemistry mindset beliefs were intertwined with their beliefs about STEM and general mindset. Students' views about chemistry mindset were complex and difficult to disentangle from their general mindset views and the views discussed often depended on the context of the interview topic. Finally, with the limited nature of a multiple-case study approach, generalizations cannot be made about the particular views expressed by each individual. They provide some evidence that other mindset views exist but cannot speak to the prevalence of each view in the population. Likewise, data saturation of mindset perspectives cannot be confirmed from a small sample size resulting from this methodological approach. Further studies can shed light on mindset category generalizability through analysis of larger samples. Although student identities were not thoroughly explored based on the data collected in this study, future studies should investigate how student identities affect their domain-specific mindset beliefs.

Results and discussion

Case descriptions and mindset perspectives

Six distinct chemistry mindset perspectives were uncovered as themes in the case interviews. These six perspectives were labeled: 1) "Interest," 2) "Confidence," 3) "Natural Baseline," 4) "Some Abilities," 5) "Most Abilities," and 6) "All or Nothing Ability." These are outlined in Table 1. Table 2 presents a more detailed description of each case organized by the three lenses of mindset beliefs, behaviors, and challenges. The mindset perspectives used below were developed as themes for each case with respect to their beliefs about chemistry specifically. This analysis was conducted to address the first research question: How can differences in chemistry mindset be characterized considering students' beliefs on the nature of chemistry-related abilities, interpretations of challenge, and behavioral responses?

Table 1. Chemistry mindset perspectives uncovered as themes for each case.

Chemistry Mindset Perspective	Description	Case
Interest	• Anyone can improve or develop chemistry intelligence in areas they naturally lack. • Interest is a key motivator for the effort required to improve.	Yosef
Confidence	• Anyone can improve any aspect of chemistry intelligence, but confidence is a key ingredient to realize that change is possible. • Chemistry intelligence develops over time and naturally weak areas can be improved with effort and experience.	Natalie Teresa
Natural Baseline	• Despite acknowledging that aspects of chemistry intelligence are naturally set at certain levels, they aren't fixed and can improve to any level with the necessary effort. • The effort required for different people to reach the same level will vary depending on natural strengths and weaknesses.	Johnny Kevin
Some Abilities	• Some abilities are naturally weak and stable or naturally strong and can be improved with effort. • Belief in the ability to improve is a significant factor in whether or not it is possible.	Camille
Most Abilities	• If someone is naturally *intelligent* in chemistry, they are able to improve to a greater extent than someone who is not naturally intelligent in chemistry. • Both types of students are able to apply effort to improve their *ability* and achieve some level of success.	Raquel
All or Nothing Ability	• Tends to view chemistry intelligence as a single ability that is either naturally present or not. • Someone who does not have this natural ability can apply effort to get by well enough but they won't become more intelligent in that area.	Elle

Table 2. Case descriptions with mindset, challenge, and behavior themes from interview content.

Case	Background	Mindset Beliefs	Challenges	Behaviors
Yosef	• Biochemistry major • Lifelong interest in science • Family support for education and high grades	• Interest is a driving force for change. • Interest and talent can be natural or developed. • External influences can spark interest. • Anything lacking naturally can be developed. • Failure experiences drive improvement.	• Creativity is an ability in chemistry that Yosef feels he lacks naturally and must develop. • Earned a low grade on an exam in organic chemistry and used the experience to change habits.	• Learns from mistakes rather than avoiding them. • Desires improvement and welcomes feedback. • Focuses on small intrinsic rewards and avoids comparison with others. • Seeks help from the instructor.
Natalie	• Post- baccalaureate • Threatening academic environment discouraged medical pursuit • Wrestled with imposter syndrome • Renewed intention to pursue medicine • Fear of chemistry has turned to enjoyment	• Shifted beliefs about improvability of chemistry-specific abilities to include all aspects after seeing significant self- improvement in weak areas. • Defines intelligence as a willingness to learn from mistakes. • Intelligence develops over time and can be improved by anyone in any area.	• Challenges managing time with external pressures. • Remote learning presented challenges during complex theoretical content segments. • Feelings of challenge are a good indicator that ability needs to improve in an area.	• Grades have come to signify alignment of understanding with expectations rather than a measure of ability and are used for self-evaluation. • Often seeks help. • Mistakes are valuable if they are overcome and produce change.
Teresa	• Premedical • First-STEM major in family • Initially intimidated by reputation of organic chemistry • Grown to enjoy chemistry	• Anything can be improved with effort. • Chemistry intelligence develops with experience. • Natural abilities are not genetic but developed early on.	• Perception of challenges has shifted with confidence levels and now leads to increased effort and help seeking. • Previously, challenges confirmed beliefs that chemistry intelligence was not natural for her.	• Changes to her confidence in chemistry dramatically affected behaviors. • Low grades used to imply low ability, but now motivate effort. • Previously allowed negative self-perceptions based on comparisons. • Now regularly seeks help.
Johnny	• Premedical non-traditional student • Family history in science and medicine • Always learned quickly • Doesn't view math and science as his natural abilities • Negative feelings toward chemistry in high school that have	• Willingness to put forth effort is key to improving chemistry intelligence. • Any aspect of chemistry intelligence can be improved. • Accumulation and application of knowledge are the definitions of intelligence he used to explain his own improvement in chemistry. • Has improved his mathematical thinking in chemistry over time.	• It is challenging to read chemistry problems and not know how to begin solving them. • Another challenge is not knowing how to check the work done to solve a problem. • New content can be overwhelming, but repeated practice can help problems feel more natural.	• Understanding is more important than the grade, but the grade measures understanding. • He boosts his confidence in chemistry by developing creative explanations and helping others. • Comparison with others isn't helpful and mistakes are useful for learning.

	become positive in college			
Kevin	• Neuroscience major • Lifelong passion for science • Experiences of success in school from childhood • Self- perception as smart • Failure experiences applying to college • Re-evaluated beliefs about the necessity of effort	• Different aspects of chemistry intelligence are more (or less) easily changed, but no ability is static. • Individuals begin with various ability levels as a "baseline" but can improve to any level desired with effort. • The rate of change can vary drastically between people.	• Does not experience challenges with grades in chemistry. • Described challenges with distinctions in complex applications of chiral synthesis. • The stress of feeling lost with the content was something he used to motivate seeking understanding.	• Holds self to high standards and uses grades as a measure of understanding. • Would ask for help if challenged, but more often helps others. • Views learning chemistry as a collaborative activity.
Camille	• Pursuing a career in neurosurgery • Interest in medicine since childhood • Gifted education • Family emphasis on grades • Previously disliked chemistry • Now enjoys explaining chemistry to others	• Some abilities in chemistry can be changed more easily than others. • "Mindset" affects a person's ability to succeed in chemistry, but also the natural abilities that person has. • If some abilities are naturally weak, they are stable. • Some abilities can only be developed.	• Has challenges with the language aspect of chemistry (applying correct terminology). • Describes having challenges with believing she can improve in certain areas and it fluctuates on different days.	• Grades are important for the evaluation of your abilities by others. • Tends to procrastinate when her grades are high. • Mistakes allow her to see that she is improving and can be motivating to try harder. • Willing to ask for help and enjoys helping others.
Raquel	• Medical career aspirations • Values chemistry and finds it interesting • Family is supportive of education • Self-perception as smart • Tends to earn A grades in chemistry	• Makes a distinction between *chemistry ability* and *chemistry intelligence* and believes that chemistry ability is more changeable through effort. • Natural abilities can improve if a person has them. • Someone who doesn't have a natural ability can't do much to improve it. • Values effort over "direct intelligence."	• Faced visualization challenges when learning about crystal structures. • Overcame this challenge by examining various representations until she was able to visualize better.	• Doesn't avoid challenging problems and uses them to learn and improve. • Compares her grades with others to feel better about her own grades. • Describes competing with herself in performance expectations. • Will listen to constructive feedback but tends to avoid negative feedback and mistakes.
Elle	• Nutrition science major • Pursuing a career in endocrinology • Experience with a diabetic parent • Parents work in and value education	• Makes a distinction between *chemistry ability* and *chemistry intelligence* and believes that chemistry ability is more changeable through effort and memorization. • Natural abilities are the key determinant in whether someone will be good at chemistry.	• Study and learning strategies to be successful in chemistry have been the greatest challenge. • Motivation is also a major challenge. • Describes only doing enough to get by in chemistry, which is not something she does in other classes.	• Uses grades as a primary gauge of success. • Believes she should learn from mistakes and shouldn't avoid paying attention to feedback. • Has worked with a tutor to improve in chemistry.

• Naturally good at math and science (not chemistry) • Does not like chemistry	• Doesn't make distinctions between overall chemistry intelligence and aspects of it that could come naturally to different people.	• The tutor and changes to study strategies have helped to overcome some of these challenges.	• Tends to skip challenging problems and doesn't feel like trying when she can't solve a problem. • Competes with others in her mind, but often this makes her feel inadequate.

Chemistry Mindset Perspectives as a Continuum

Comparing across cases, it is apparent that students discuss very different factors as a rationale for their mindset beliefs in chemistry. Likewise, the implications of their beliefs on their behaviors seem to be dependent on their perceived competence beliefs about themselves as well as their interpretations of challenges. Multiple perspectives were uncovered by considering each case individually. Three students expressed views that fall on the growth end of a mindset continuum (Yosef, Natalie, and Teresa), while two expressed more fixed views (Raquel and Elle). Much of Dweck's work described and treated general mindset as a binary construct (despite measuring it with an ordinal scale): either students have growth mindsets or they have fixed mindsets and the students in the middle of these two cutoffs were simply left out of analyses (Dweck et al., 1995a; Dweck et al., 1995b; Dweck & Leggett, 1988). This description of chemistry mindset perspectives contrasts this approach by placing each participant at different locations between full growth and fixed mindset ends of a spectrum.

Elle and Yosef expressed views that represent the far ends of the mindset spectrum from one another, Elle being the most fixed in mindset and Yosef holding the strongest growth beliefs. A possible explanation for the strength of Yosef's growth convictions is his high ability in chemistry, which he doesn't attribute to natural ability, but rather effort and interest. He believes he developed chemistry intelligence through combined effort and interest, so he must think that to be true for anyone. Yosef shares his beliefs about people's ability to improve with the following statement, "I know for a fact, based off of experience that if you put in effort for any small thing – if you really want to put in effort, you can definitely change that. There's like nothing that's impossible to change -- unless you're like, not biologically capable of doing it, I think an average person has the ability to change no matter what it is."

Elle has had the opposite experience of Yosef's. She has low interest and low perceived ability. She thinks the ability portion is natural and thus does not have an interest in chemistry because it's not easy or relatable. She does believe effort makes a difference in her performance, but not as much in her chemistry intelligence, which she doesn't care as much about regardless. Elle expresses her frustration with learning chemistry in the following:

> "Sometimes chemistry will just push me to a point where I just do not want to even try because it just tests me so much and I just don't know what else to do. And challenging problems are...I'm not saying I don't do them at all, but I definitely don't do as many as I should -- because I think if I did, I would really be trying to, like, get A's on tests and I really don't do that. I really just try to get a B. And that's just so weird to even say, 'cause that is really not who I am, to try to get a B, but that's who I am in chemistry…I don't want to be burned when I don't get an A. Because I don't expect it because I know I'm not putting in the effort that is required of an A in chemistry. And just all the different factors -- Not naturally being good at it, not really wanting to work at it, wanting to do the bare minimum just to try to get good enough. -- It's like an internal issue."

None of the students' perspectives completely overlapped, but a few students had sufficient similarities in their views to be categorized within the same mindset theme. First, both Kevin and Johnny seemed convinced that natural abilities are important to how easily you can understand chemistry, but both also expressed that any ability can be developed and equated that to increasing chemistry intelligence. For example, Johnny says,

> "I would contrast it as, the natural ability would be like the clay and developed with effort is when you take that clay and mold it into something with edges and, like, corners and, you know, so it becomes something more defined, as opposed to just this big blob of material or matter…I feel like you can have these natural abilities but you still need to do something to shape them and hone them…if you don't, then you could have all the natural ability in the world -- It's almost like raw potential. Somebody could have potential, but never meet that potential or meet that promise."

Second, both Teresa and Natalie expressed confidence that chemistry intelligence is improvable through effort but required performance feedback to create a sense of confidence that growth is possible for themselves as well. To provide evidence for this belief, Natalie shared her experience with improving in visualization skills in organic chemistry: "The ability to rotate models in my head, I've gotten a lot better at that...It feels like a silly small thing, but it's been really rewarding…I used to not be able to do this at all or understand what it is. And now I feel like I kind of know what's happening."

Another similarity was the strength of emphasis placed on natural abilities by both Camille and Raquel. Nevertheless, they

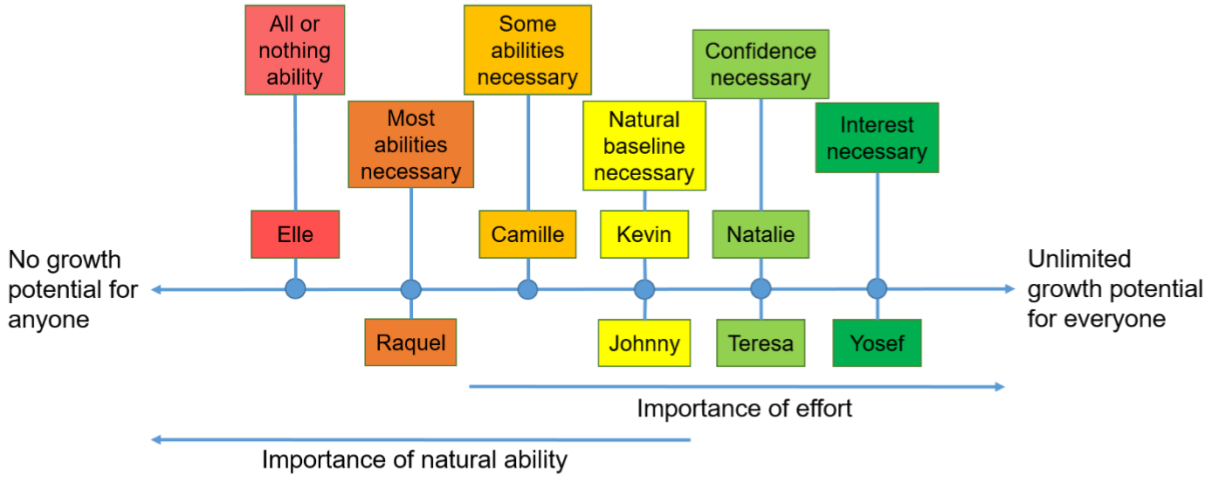

Figure 3. Case participants' mindset perspectives organized along a continuum from most fixed to most growth mindset. The colors along the continuum represent the degree of growth or fixedness of a given mindset perspective theme.

were able to believe themselves capable of growth in chemistry due to their own natural abilities for STEM subjects. Despite this similarity, Camille expressed that increasing chemistry intelligence is possible through effort focused on developing relevant abilities, though she felt that not all abilities were changeable. Her belief about stable abilities is apparent in the following quote: "I think it's just differences that we all have as humans. There are people that are always going to be able to have a better memory than most. Like, I have a terrible memory. No matter what I do I can't necessarily change it. The only thing I can do is improve on how I try to relate the information that I'm trying to remember to things that I've -- Things that I know, things that just come naturally to me." Raquel expressed a higher number of abilities as difficult to change, showing a belief that natural abilities are mostly stable.

Based on the similarities and differences discussed above, different categories of mindset perspectives can be defined. These mindset perspectives are presented in Figure 3 along a hypothetical continuum. Elle carries the traditional implications of fixed beliefs, in that, if a person doesn't have natural ability for chemistry, then there is not much that can be done other than to protect one's ego through avoidant behaviors. Raquel is a bit more open to the idea of improving chemistry intelligence but much more for those who have the natural ability to begin with. Camille has a slightly more flexible view on overall chemistry intelligence but emphasized specific abilities as unchangeable and the need to leverage the natural abilities you do have to improve. Kevin and Johnny both believe that development of any ability is possible, yet state that natural ability plays a role in how easily one can learn. They were placed at the same point on the continuum in Figure 3 because their views are similar, yet Kevin has more confidence because he views himself as having natural ability for chemistry and Johnny does not. Johnny instead has a natural interest (or curiosity) and thus is willing to develop his weak areas. Teresa and Natalie both believe that anything can be developed yet were hesitant to believe this about their own chemistry intelligence without evidence supporting that they could improve. Teresa's shift from lack of confidence in general chemistry to complete enjoyment of the success she found in organic chemistry is more substantial than the changes Natalie experienced. This could suggest that Natalie's mindset beliefs are more deeply ingrained and drive her effort to improve, while Teresa has exerted effort out of a desire to succeed and her mindset beliefs followed her improvement. Finally, Yosef expressed very optimistic views regarding anyone developing abilities if they have interest in that domain. He did acknowledge that some people have a "God-given talent" for certain subjects, but also said that everyone must work hard to be good at chemistry. His main comparison between students who do well in chemistry and those who do not was based on the amount of effort they apply as driven by their personal interests. He also stated that educators play a significant role in how personally interesting a course is through their own enthusiasm for the content.

Chemistry Mindset Perspectives in Two-Dimensions

Another way to consider the contrasts in students' views discussed in the interviews is to consider the dimension of chemistry mindset beliefs about others as a separate continuum from beliefs about self. Studies investigating physics-specific beliefs have described a similar phenomenon (Kalender et al., 2022; Malespina et al., 2022). Students' beliefs about their own intelligence may relate to their beliefs about others; however, it is entirely possible that their views about self may be substantially more or less optimistic than their views about other people. Figure 4 presents a two-dimensional translation from the single-dimension continuum in Figure 3 as an alternative theoretical placement of each case based on their individual revealed perspectives. The top right quadrant represents a growth mindset regarding both self and others, resembling the traditional view of a growth mindset most closely. For this reason, Yosef belongs in this quadrant as he was positive that anyone can grow, including himself. Kevin and Johnny might also be placed in this region slightly closer to the axes as they both expressed optimistic views about self and others. The bottom right considers others more capable of growth than the self, characteristic of the two students who tended to doubt themselves in the absence of positive

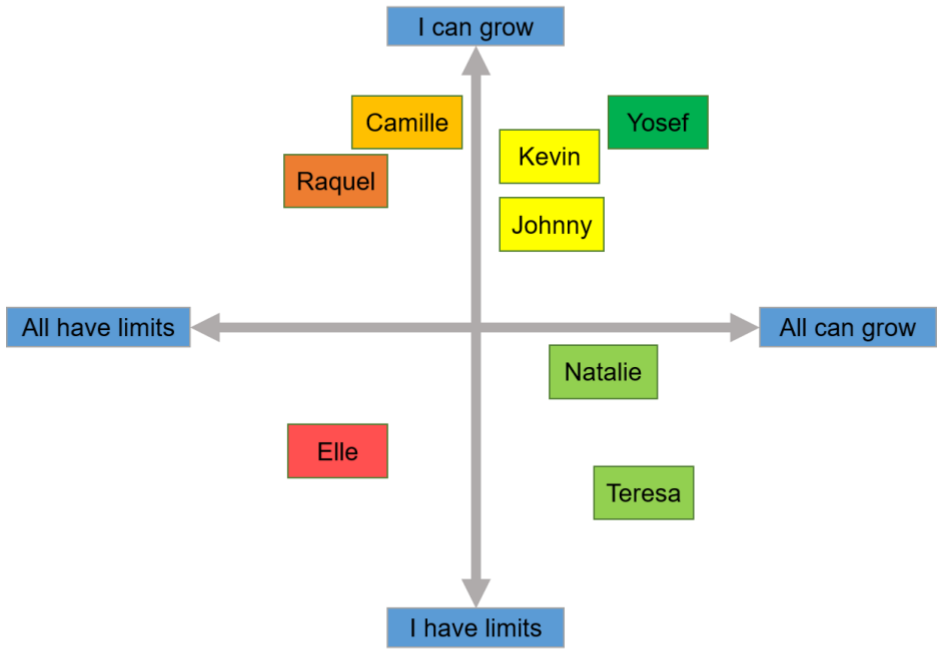

Figure 4. Qualitative placement of each case along two dimensions of mindset: myself and others. The same colors for each case are used from Figure 3 to indicate the degree of growth or fixedness of each mindset perspective uncovered when considering a single mindset dimension.

performance feedback, yet firmly believed in development over time (Natalie and Teresa). The top left quadrant represents the view that growth is more possible for "me" relative to others, a possibility when a student holds high self-efficacy beliefs and views their own relevant abilities as naturally occurring. Two students seem to fit well in this region, namely, Camille and Raquel, with Camille slightly more optimistic about both others and self. Finally, the bottom left quadrant is the most analogous to the traditional view of a fixed mindset. Beliefs that natural ability in a specific area dictates one's intelligence for that subject. Elle most clearly expressed this view toward chemistry for herself and others and has thus been placed in the corresponding region of the plot.

Results from the survey measures indicate that the case study participants tended to have more fixed mindsets about others' chemistry intelligence compared to their own. Aligning with the interview findings, Yosef was shown to have the highest growth mindset about his own chemistry intelligence as well as that of other students. Raquel and Elle both scored the lowest on their chemistry mindset beliefs as well as their beliefs about others, with Raquel reporting the most fixed chemistry mindset about others. Johnny and Teresa both reported a more growth mindset about others compared to themselves, aligning with the expressions of self-doubt and lack of natural ability in the area of chemistry described in their interviews. All participants reported a chemistry mindset on the growth end of the scale, but the degree of growth chemistry mindset about self and others aligned well with the interview findings.

The other important result from the survey measures included in the case study was the relationship between chemistry mindset about self and the participants' self-report of mindset-related behaviors. Behaviors were consistently slightly less growth mindset compared to the measured chemistry mindset belief. This meant that the students with the highest reported mindset-related behaviors were those who also held the most growth beliefs about their own chemistry intelligence. Combined with the observation that mindset beliefs about self and others do not always align, this finding suggests that chemistry mindset beliefs about the self most strongly predict a student's mindset-related behaviors (i.e. avoidance, persistence, reception of critique, etc.). It should be noted that only qualitative observations can be made about these survey results with a sample size of 8 participants and generalizations cannot be made based on this evidence alone.

To address the second research question, rather than considering three categories of mindset (growth, middle, and fixed) as the traditional mindset literature suggests (Dweck et al., 1995a; Hong et al., 1999), we can consider the four quadrants of the two-dimensional conception of mindset (Kalender et al., 2022; Malespina et al., 2022). The upper right and bottom left quadrant represent the growth and fixed labels as previously defined; however, with a richer measurement distinction as a combination of two dimensions. In contrast, the bottom right and upper left quadrants may shed additional light on the messy middle described in the mindset literature (Hong et al., 1999).

Alignment of Chemistry Mindset with General Mindset

In considering the distinctiveness of chemistry mindset as a construct, these cases can be compared to theoretical mindset perspectives in a general context. This analysis addresses the second research question: What degree of alignment is observed between interview themes and extant general intelligence mindset theory to provide insight into chemistry mindset as a distinct construct?

Mindset determines how a challenge is interpreted. The difference between general-domain growth and fixed interpretations of challenge lies in whether the presence of a challenge indicates a need for effort or lack of ability. An absence of challenge theoretically leads a fixed mindset student to believe they have naturally sufficient high ability to succeed and a growth mindset student to believe that their prior effort has improved their ability sufficiently to be successful. Most cases examined here apply effort attributions more often for both situations regarding themselves and others yet suggest that some of their peers simply have natural ability allowing them to be unchallenged or successful without effort. Only Elle expressed the ego threat reaction to challenge as an interpretation that she lacked ability. Teresa expressed discouragement and doubt associated with challenges in her first interview, although when she began overcoming her challenge by performing well, her attribution shifted from ability to effort. Raquel, Camille, and Kevin all attributed any lack of challenge to their innate chemistry intelligence, but when they were challenged, they suggested a need for effort and stated that this motivated them to try harder. For the most part, this theoretical implication of general mindset beliefs aligned with the interpretations of challenge as a result of their chemistry mindset beliefs, yet students whose views were less on the extreme ends of the chemistry mindset continuum were more likely to display a mixture of interpretations depending on perceived competence in chemistry. This description of chemistry mindset yields more nuance in interpretations of challenge than the description of general mindset.

How challenge is interpreted determines the response to it. The general mindset interpretation of challenge as ability-related should lead to helpless responses and increased focus on negative performance feedback. Alternatively, the interpretation that the presence of challenge is associated with effort or "needs development" should lead to mastery responses and a focus on improvement. The only case examined in this study that continually reflects the helpless response to challenge was Elle. She described engaging in avoidant behaviors such as giving up on challenging problems, being extremely bothered by mistakes, trying to care less about her grades to cope with the disappointment, and comparison with peers. It does seem that Teresa formerly focused on the negative performance feedback and later focused on the positive performance feedback she received to drive her desire to continue improving. The other students tended to interpret challenge as an indication that they needed to apply effort to understand or to develop ability in that aspect. These students discussed more often approaching their instructor for help, persisting in attempts to understand concepts or solve problems, and working with peers to support each other's learning. These students desire improvement and tend to use their grades as an indicator of their improvement in understanding rather than as a comparison point with others. Because several of the students' chemistry mindset beliefs about self were not aligned with their beliefs about others, mastery responses were often observed even when a student's overall chemistry mindset was a bit more fixed. Camille and Raquel presented this contradiction to the theoretical response to challenge for general mindset views. Because they both had a perception of high self-competence in chemistry, they hold beliefs that their natural strong suits could be improved to overcome challenge. This created another distinction between the theoretical general mindset and chemistry mindset for students with less polar perspectives.

Growth mindset. A domain-general growth mindset has been described as someone who meets the following criteria: a) believes that any ability can be developed or improved given the resources and will to do it, b) does not give up easily in the face of challenge, and c) focuses on understanding and mastery as a litmus test for success. Considering these statements, several students from this case sample can be classified as having a growth mindset. Most notably, Yosef, Kevin, Johnny, and Natalie exhibit these beliefs, behaviors, and emphasis on mastery. Camille and Teresa also describe these to some degree, with some limitations. Camille is limited in her belief that any ability can be developed, and Teresa is limited in her focus on mastery and rather describes her measure of success as performance based.

It must be acknowledged that the academic environment in which all students in this study were enrolled places a general emphasis on performance above mastery and the primary tool provided for diagnosing one's mastery is performance scores. If academic environments aim to promote mastery and growth beliefs, the performance focus may need to be reconsidered due to its impact on students' interpretations of their own success.

Based on the criteria described for a growth mindset, Yosef, Kevin, Johnny, and Natalie would all be considered to have a growth mindset. In the case analyses described here, Yosef, Teresa, and Natalie were all considered to have chemistry mindsets aligning with growth beliefs and Johnny and Kevin were considered to lie on the growth end of the spectrum. Some caveats to this classification process were misalignment of beliefs about oneself relative to others and some emphasis on natural abilities or an innate interest in chemistry. Thus, a growth chemistry mindset appears to be more complex in nature than a theoretical general growth mindset.

Fixed mindset. A domain-general fixed mindset has been described as someone who meets the following criteria: a) believes that abilities tend to be naturally derived and explain the differences between people in achievement/intelligence, b) more readily gives up in the face of challenge, especially if it is the first serious challenge encountered in life, and c) focuses on achievement and competitive measures of success. Elle meets all these criteria and was classified from the analysis as having a fixed chemistry mindset. She is prone to giving up in chemistry when she's challenged. It may even be the first science or math subject that she has encountered such level of challenge, based on her identity beliefs that she is a smart STEM student. She is also one of the only students who openly admits to competitive behaviors when it comes to performance in chemistry. She describes grades as an indication of one's intelligence in that subject and bases much of her feelings of worth on her performance. Lastly, she describes abilities like chemistry intelligence or math intelligence as being genetically inherited and uses this to understand the differences in chemistry achievement between herself and her peers.

Raquel meets two of these fixed mindset criteria. She explains the differences between people's achievement in chemistry by way of their natural abilities. She also admits to using some degree of competitive behavior in comparing her grades to others to boost her self-esteem. However, she does not give up in the face of challenges and rather becomes more motivated when challenges arise because she believes herself capable of overcoming them due to her high natural ability. Camille meets the first criterion (natural abilities) to some degree, but is a bit more flexible in that view, and does not meet any of the others. Teresa met the third criterion to some degree in her first interview (performance and competition) but attempts to minimize these comparisons to maintain her confidence and does not meet the others. Classifying a chemistry fixed mindset, as indicated by these cases, is complex. Some of the criteria from a theoretical fixed general mindset aligned with students whose views approached a growth chemistry mindset. This is due to misalignment of beliefs about the self and others in chemistry because of perceived self-competence.

Conclusion

Within-case analysis using the mindset meaning model revealed some nuances in chemistry mindset that have not been previously described for general mindset. First, it appears that multiple types of growth mindset may exist, some more deeply ingrained than others and regarding oneself as well as others. Likewise, some variation in middle mindset beliefs was observed in that two students were closer to having growth mindset beliefs while the third student had more mixed beliefs depending on which abilities were natural and stable and which were changeable with effort. Finally, two kinds of fixed mindset categories were uncovered as a function of ability perceptions. One student viewed herself as having high chemistry ability and experienced less challenge and therefore exhibited a very different profile from the student with low chemistry ability perceptions and a high degree of challenge. This analysis resulted in the ability to expand the traditional mindset continuum to include each perspective sequentially. These findings suggest that inclusion of challenge interpretations and behavior in quantitative measures is important to more accurately identify an individual's chemistry mindset perspective (RQ1).

Furthermore, evidence for multiple dimensions of chemistry mindset beliefs was uncovered in this case study as a function of who is being considered (self versus others). Similar dimensions have been uncovered for undergraduate students' physics mindset beliefs (Kalender et al., 2022; Malespina et al., 2022). Moreover, the degree of ingrained beliefs about oneself was found to correspond to interpretations of challenge and behavioral responses to challenge. This suggests that although there is substantial alignment of chemistry mindset, behaviors, and challenges observed in these case participants with extant literature findings, the object of mindset items (me or someone else) are critical to predictive measures of an individual's behaviors (RQ2).

Implications for Research and Teaching

Mindset has long been conceptualized as a meaning system that individuals operate out of (Hong et al., 1999). It has also previously been reported that the referent (me versus others) impacts the predictive relation between mindset measures and outcomes (De Castella and Byrne, 2015). Although these layers have been considered previously in the measurement of mindset, little attention has been given to the possibility that they can be combined to provide a richer description of students' mindset views for categorical comparisons. A comprehensive measure addressing all these aspects has not been developed for undergraduate students and particularly not for domain-specific contexts. This case study revealed that chemistry mindset does not align perfectly with general mindset models, suggesting these to be separate constructs. Likewise, mindset may have unique characteristics and perspectives within other science disciplines.

The multiple aspects involved in a rich description of a students' chemistry mindset could be considered for better triangulation of their true beliefs and the depth to which they hold such beliefs. The more accurate our description of a student's mindset, the more appropriate predictions could be made regarding their success in chemistry courses. One method to resolve this concern for large-scale mindset classification would be to create a multidimensional mindset instrument, specific to chemistry, that addresses each construct as a subfactor: 1) chemistry mindset about self, 2) chemistry mindset about everyone, 3) interpretation of challenge in chemistry, and 4) behavioral response to challenge in chemistry. These additional factors can allow for the creation of many mindset categories that could each be evaluated for their relative contribution to the predictive relationship of mindset with student success outcomes.

In chemistry classrooms, a variety of student affective profiles are present. Feedback carries different meaning to each student as a function of their mindset beliefs and self-perceptions of chemistry ability. Chemistry instructors should be aware of this when providing feedback to students and emphasize the ways in which it is beneficial to their improvement rather than evaluative of their ability. Also, students may place different degrees of emphasis on the effects of effort toward impacting their *intelligence* or just their "ability." Noticeable improvements in mastery or skills can be emphasized by instructors over simple grade improvements or "native abilities." Because students were more likely to exhibit mastery behaviors when they had high ability self-perceptions, instructors can impact students' mindset beliefs about the self by placing emphasis on improvements over the scores themselves, which is likely to increase ability perceptions and thus foster growth beliefs about the self.

Another avenue for impacting students was suggested by one of the case participants, Yosef. He perceived his instructors as impacting his interest through their enthusiasm and passion for the subject of chemistry. It is important for instructors to remember that they serve as role models for students. Instructors can share how they improved their own intelligence in chemistry through effort and that they believe this to be possible for any student who is willing to engage in it. This can be specifically targeted as individual skills, such as visualization, mathematical thinking, and disciplinary language usage. Instructors can also share topics of personal interest related to course content and provide opportunities for students to see how the concepts being covered are relevant to them.

Conflicts of interest

There are no conflicts to declare.

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Appendices

Appendix A. Initial in-depth semi-structured interview protocol with tasks developed based on general mindset literature.
Fall 2020 Semi-Structured Interview Protocol

Description of phases and questions students will be asked to respond to using think aloud:

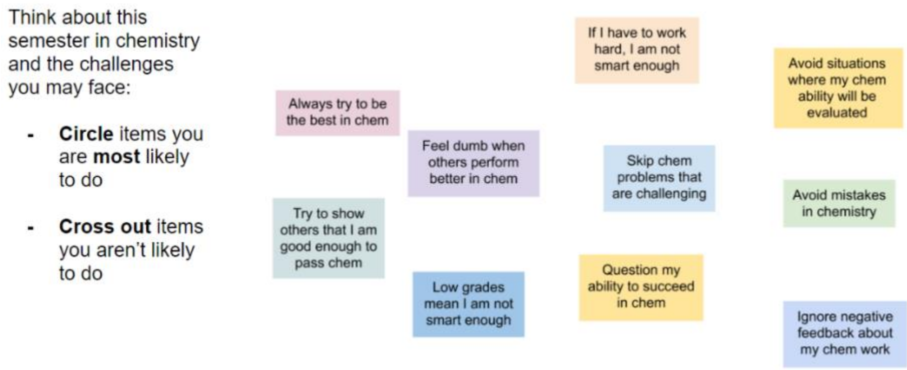
Phase 1: Beginning questions to practice talking:

- How is the current semester of chemistry going?
- What course are you in, how are your grades, do you feel challenged currently in chemistry?
- What do you notice about someone in chemistry class that makes you think they are smart/intelligent?
- Do you recall family members praising you more for your ability or for your effort in school?
- Do you think your chemistry intelligence is the main factor determining your chemistry performance?
- Why or why not? (How would you define it?)
- Can you tell me about a time when you faced a challenge in chemistry? What happened, how did you respond, and what was the end result?

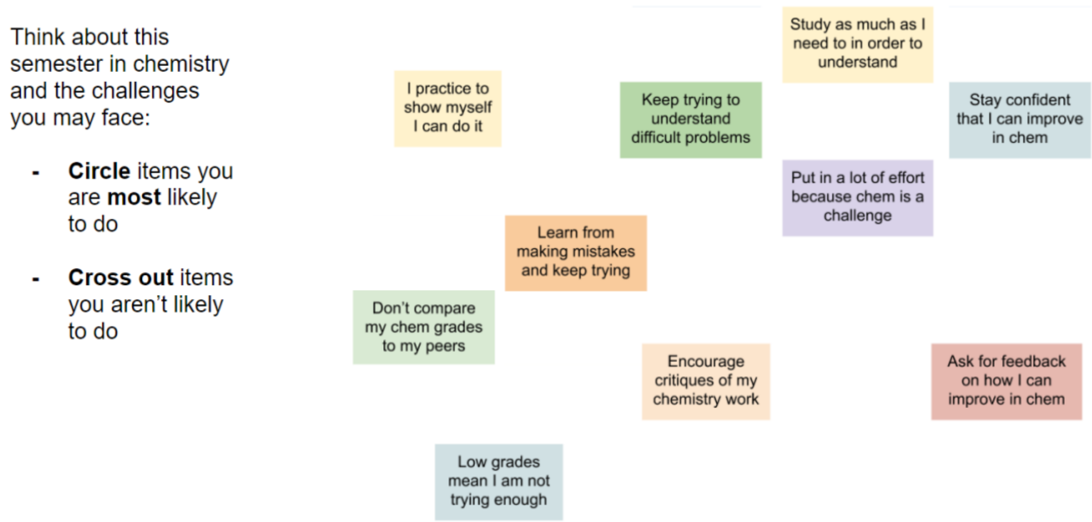
Phase 2: Behaviors in challenging chemistry scenarios selection activity (Appendix A Figures 1 and 2)

- Which of these items can you see yourself doing this semester when you experience challenges in chemistry? Circle the ones you think are relevant to you and cross out those that you don't think you would do.

- For some of the circled responses: Can you give an example of a time you did that in a class?
- For some of the crossed out responses: Why did you cross that out (social desirability?)? Why don't you think you would do that?



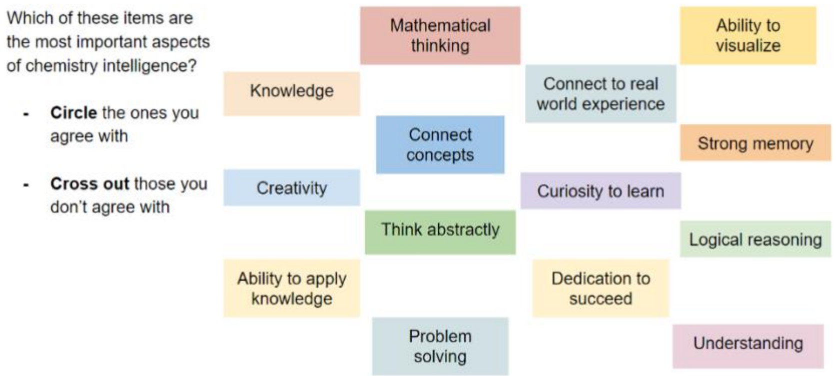
Appendix A Figure 1. Entity behavior item task



Appendix A Figure 2. Incremental behavior item task

Phase 3a: Beliefs about cognitive abilities important to chemistry intelligence selection activity (Appendix A Figure 3)

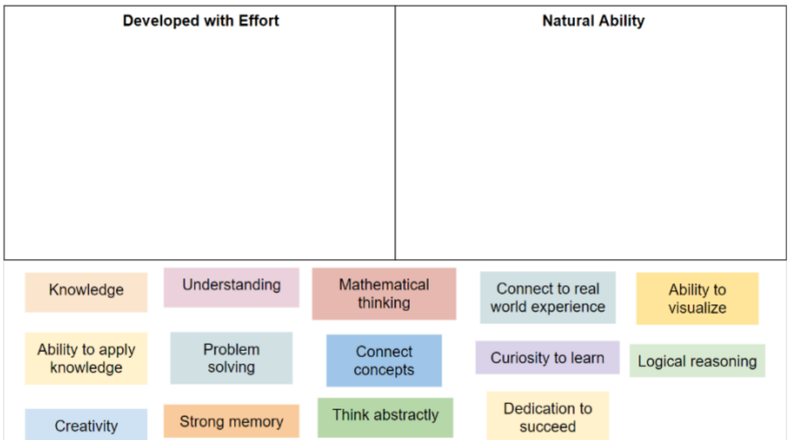
- Which of these items are the most important aspects of chemistry intelligence? Circle the ones you agree with and cross out those you don't agree with.
- Are there any other aspects you would like to add to this list?
- Which of these are aspects you feel like you are good at vs not good at? Why?



Appendix A Figure 3. Chemistry intelligence aspects task

Phase 3b: Beliefs about chemistry intelligence cognitive abilities origins sorting activity (Appendix A Figure 4)

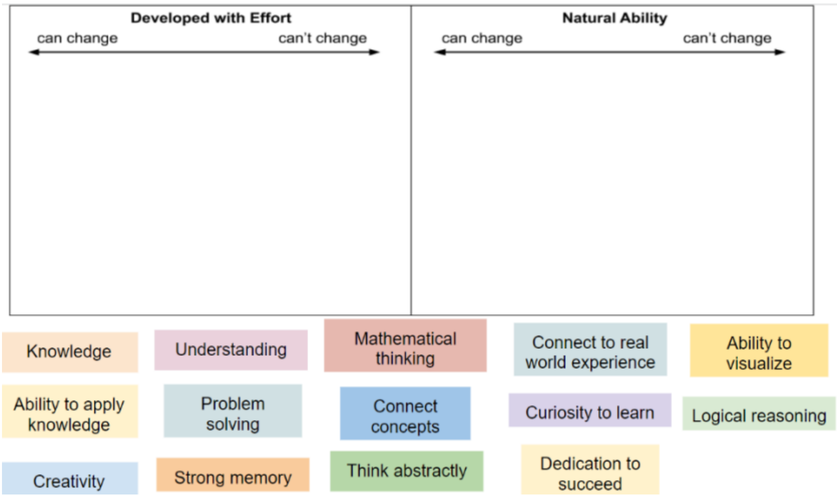
- Out of the items you circled, how do you think you get those abilities? Are they developed or natural abilities?
- What do you think "natural ability" means?
- Why do you think these are developed? Can you give an example?
- Why do you think these are natural abilities? Can you give an example?



Appendix A Figure 4. Natural and developed chemistry intelligence aspects sorting task

Phase 3c: Beliefs about chemistry intelligence cognitive abilities malleability within origin sorting activity (Appendix A Figure 5)

- Can you sort each of these into those that you can change versus those that you cannot change?
- How would you define "change" in this case?
- What evidence of change would you look at to verify that it had happened?
- Why do you think these can change?
- Why do you think these cannot change?



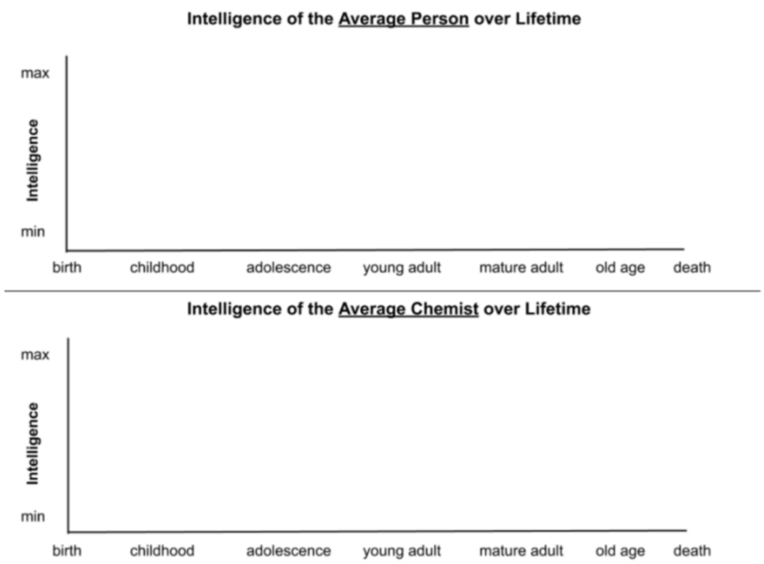
Appendix A Figure 5. Malleability of chemistry intelligence aspects sorting task

Phase 4: Discussion of survey response reasons and discrepancies with currently stated beliefs

- Here are the responses you selected from the survey earlier this semester.
- Why did you choose this answer before? What were you thinking when you read the question? (social desirability?)
- Today, you said this behavior/answer, but/and on the survey you said this. Why do you think they were different/the same?
-

Phase 5: Graphing of intelligence over lifetime activity (Appendix A Figure 6)

- How do you define intelligence as a whole?
- What do you think a graph of intelligence vs. time looks from birth, through childhood, adolescence, adulthood, and elderly stages until death for the average person?
- How should the graph look for the average chemist?
- Can you explain why you drew each graph the way you did?
- Why is the graph for the average person the same/different from the average chemist?
- Can you compare the max intelligence you drew and the shape of each graph?



Appendix B Figure 6. Intelligence level over lifetime graphing task

Phase 6: Final questions

- Do you think that people can change their intelligence in chemistry? How did you come to believe this?
- Throughout your chemistry courses, has your confidence in your chemistry ability changed? How and why?
- Have you ever dropped, withdrawn, or failed a chemistry course? If so, what factors influenced that decision/event?
- Do you often doubt your ability to succeed in chemistry? If so, what causes you to think that way?
- Have you ever said (or believed) that you aren't good at chemistry? Why?

Appendix B. Follow-up semi-structured interview protocol**.**

Fall 2021 Follow-up Interview Protocol: Multiple Case Study

Description of phases and questions students will be asked to respond to using think aloud:

Phase 1: Beginning questions to practice talking and reflecting on past experiences and what brought them to this point.

- What class are you currently in and what is your major/reason for taking chemistry?
- What led you to select your major? What are your career goals?
- Can you tell me a bit about your background? What were some influences on your academic/career goals?
- What were some influences on what you value as demonstrating intelligence?
- Can you discuss your experiences with chemistry before college? What is your history with chemistry?

Phase 2: How does the student view their identity with regards to science and/or chemistry?

- How well do you feel that you fit in as a science major? What about in a chemistry class? Why do you see yourself that way?
- What kind of person do you think becomes a chemist?

Phase 3: What are external factors affecting the student's beliefs about chemistry?

- How do your family and friends talk about chemistry and/or your major? Do they seem to think it requires natural ability or very smart people?
- How do you think your chemistry instructors view your intelligence in chemistry? Do they seem to think it can change?
- How does society/our culture/everyday person view chemistry in terms of difficulty/ability?
- Do you agree with these different perspectives about chemistry? Why or why not?

Phase 4: What are the student's internal beliefs about chemistry and challenge experiences?

- How challenging do you believe chemistry is? Is it more or less challenging to you compared to your peers? Why do you think this is? Were there differences between organic and general chemistry in terms of difficulty?
- What is the most challenging aspect of chemistry to you?
- What are some specific challenges you have faced in chemistry classes? How big of a challenge was it? When did it happen and how did you feel? What did you do?
- What does encountering a challenge in chemistry mean to you (low ability or more effort)? How does that make you feel? What do you do when there's a challenge?

Phase 5: What are some behaviors the student acknowledges being important to their success?

- What is something you achieved in chemistry that you are very proud of?
- What is something you did in chemistry that you are not so proud of?

Phase 6: Previous interview activity results

- Show either the categorization of chemistry abilities, the natural ability vs developed abilities, or the plot for intelligence and ask further questions to clarify perspective and gauge changes in beliefs.

Phase 7: Final questions (What is the student's mindset toward chemistry and has it changed?)

- Is your ability to do chemistry something that you could improve in? How would that happen? What are some aspects that could be improved?
- Has the way you feel about your ability to do chemistry changed over time? How and why?
- Do your feelings about your ability to do chemistry change in certain scenarios? Can you give examples?
- Is chemistry something that you could see a career in? Why or why not?

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Supplementary Information

Table S1. Survey measures completed by case study participants.

Survey Measures/Scale	**Items**	**Scale Mean**	**SD**	**Terciles**
Chemistry Mindset (self)/10-point semantic differential ("I can't change at all" (1) to "I can change a lot" (10))	1. My problem-solving ability in chemistry is something... 2. My ability to understand concepts in chemistry is something... 3. My ability to apply chemistry knowledge is something... 4. My ability to master chemistry content is something... 5. My ability to visualize chemical structures and processes is something… 6. My ability to use mathematical and logical reasoning in chemistry is something... 7. My overall chemistry intelligence is something…	6.93	1.68	>7.57 7.57-6.29 <6.29
Nature of Chemistry Intelligence (others)/6-point Likert ("Strongly Agree" (1) to "Strongly Disagree" (6))	1. Some people naturally understand chemistry more easily. 2. Some people are just smarter in chemistry and can do well without much effort. 3. If you have to work harder than others in chemistry, it doesn't come naturally to you. 4. Students who pick up on chemistry concepts faster are gifted.	4.15	0.91	>4.50 4.50-3.75 <3.75

Incremental Behaviors/6-point Likert (“Strongly Disagree” (1) to “Strongly Agree” (6))	1. I prefer challenging chemistry work that I'll learn from, even if I make a lot of mistakes. 2. When something in chemistry is hard, it just makes me want to work more on it, not less. 3. When I encounter challenges in chemistry, I don’t question my ability to overcome them. 4. I feel motivated to understand a chemistry problem when I get the wrong answer.	4.03	0.92	>4.50 4.50-3.75 <3.75
Entity Behaviors/6-point Likert (“Strongly Agree” (1) to “Strongly Disagree” (6))	1. I prefer chemistry homework that I can do perfectly without any mistakes. 2. When I have to work hard in chemistry, it makes me feel as though I'm not very smart. 3. I often question whether I can actually improve my ability in chemistry. 4. When I experience failure at a learning task in chemistry, such as getting homework problems wrong, I feel less motivated to continue trying.	3.53	1.11	>4.00 4.00-3.00 <3.00
Open-ended Questions	1. How do you define chemistry intelligence? What experiences or observations have led you to this belief? Please write at least 3-4 sentences. 2. Please describe these experiences with challenge during this semester of chemistry briefly and what specifically you did to overcome them.			

Table S2. Interview analysis codebook descriptions and examples.

Lens	Code	Description	Example Quote
Behavior	Avoidance	self-reliance, ignoring problems, avoiding help or evaluation	Raquel: “I think, because if I know that I messed up, I'll get sensitive and I will already know that I messed up. So I don't need other people to point it out to me.”
	Comparison	positive or negative comparison of performance or understanding	Teresa: “Well, for the one, where it says feel dumb when others perform better in Chem, I would say like, in a class setting, that's more of what I felt.”
	Decrease Effort	procrastination, laziness, less effort than others, lack of effort, try less	Camille: “I would say from the interactions that I've had in the past, they can tell that I... if I were to apply myself more, I would do a lot better in the class.”
	Performance	career goals or GPA as reason for effort, going through the motions for the grade, desire to showcase ability to others through grades, show others i can be successful here, perfectionism with mistakes, maintain self-esteem, ignoring challenges, demonstrating ability	Elle: “I wanted to because I already had a B in chem 1211. And then going down from getting a B to B minus felt like very -- I might as well have failed the class. Because my GPA for science matters a lot, because I definitely want to get into medical school.”
	Helplessness	self-doubt, low confidence, negative thoughts about ability to improve, questioning ability, blaming the topic for struggles	Teresa: “Then I really start questioning like, can I actually, even if I feel confident with the way that I think I can apply what I know to the questions like, can I actually do them when I'm taking a test or a quiz?”
	Mastery	utility value (usefulness of the content), interest in learning chemistry, relevant to life, process oriented, effort celebrated during process rather than focusing on grades as measurement of intelligence, sometimes the process isn't well tuned and could impact the outcome, for the love	Kevin: “But in college, I really appreciate it a lot more. You know, I really like a math now. Like before I was getting the grade to get the grade, but I'm taking the time now to understand the meaning behind it and it turned out to be something that I could at least enjoy

		of chemistry, for understanding and mastering content	spending my time, putting music on the background and working through the problems, understanding it.”
	Increase Effort	necessary, put forth a lot of effort, comes with effort, praised effort (positive attention), studying, practicing, applying effort	Kevin: “Versus nowadays, I see I actually have to apply a lot more effort and use what have in order to sort of rank higher or get the results I want.”
	Persistence	don't doubt self, don't give up, learn through challenge, ignore negative feedback, confront challenges, goal commitment, dedication to success, willingness to improve, to learn from mistakes, understand deficiencies or weak areas, self-improvement	Natalie: “ I mean, I-- there's grades that I've gotten that I'm not so proud of, but I feel like I always put in a good effort. And while it may have taken a fair number of tears and a lot of external resources I usually got there eventually.”
	Responsible	control over own learning, work ethic, student responsibility, time management, organization, monitoring progress, self-awareness	Johnny: “And what I did was I was like, okay, now, have the materials that I know I'm going to need next semester. I can go ahead and basically, treat myself, like, I'm still in the class and like focus on internalizing all of that stuff now so that when I get to it, I'll be ready for, like, organic chem 2, but still be doing organic chem 1. And it will be more like, you know, ingrained in me. So I won't feel pressures.”
	Help-Seeking	asking instructor or tutor, studying with others, using external resources, recognizing need for help	Yosef: “Ask for feedback on how I can improve in chem. I go to office hours, talk to my professor, and she really just says stuff. Like, do these problems, do you understand what's going on, and whatnot.“
Challenge	Difficult	chemistry is hard, it's right or wrong, the content is complex or challenging to understand, not getting it	Elle: “How challenging I feel chemistry is? Very challenging and I mean...well, yeah, very challenging and it also changes on, like, the level of chemistry -- like the chemistry class that you're taking. I feel like it's very difficult.”
	Learning Environment	classroom context, online learning, peer interaction, teaching styles, adjusting to college, instructor interactions, learning style doesn't match teaching, not engaged with presented content method, assessment style, easier ability for a person (such as problem-solving or creativity)	Raquel: “The fact that in class, if I don't understand something, you know, I can raise my hand and ask. Instead of having to watch the entire lecture, and then there's this thing in the middle that I didn't understand and then I have to go and figure it out using the textbook or whatever. And then I have to go back and rewatch it, now that it actually makes sense. Just take so much longer that way, instead of just being able to raise my hand and ask.”
	Low Dedication	not interested, amount of motivation prevents success, self challenges, laziness, procrastination, low dedication to success, low commitment, poor time management	Elle: “I kinda just gave up and I ended up with a B minus in that class in the spring. And that was honestly that wasn't good at all.”
	Subject Ability	chemistry ability relative to other subjects, science and math ability, depends on the subject for a particular cognitive strength/weakness, challenges in past inform current beliefs about ability, mental block about changing	Camille: “My ability to visualize chemical structures and processes, I would say, like a 4 or 5 for that. Visualization is not my strongest suit, And so, yeah.”
	Tedious, Dense	simple recall, too much information, retention, too many tasks, have to memorize	Elle: “Memorizing mechanisms and...Yeah, that was really difficult. Memorizing different mechanisms for particular reactions. That was probably the most difficult for me.”

Mindset	Confidence	don't question, self talk, confidence and belief, high self-esteem, ignoring comparisons, positive attitude, good self-concept	Natalie: "I think, in chemistry, evidence that they had improved would be sort of question types that call upon that skill, like, more consistently feeling confident and getting those questions, right."
	Context-dependence	aware of ability to change mindset or how mindset has changed with maturity, mindset can fluctuate based on performance, setting intentions, or feelings	Camille: "And as of right now, I feel like my mindset is set on, I can Change it, depending on how I'm feeling that day, or, like, how key factors that are around me are influencing and affecting my ability at that moment and so it could, if you asked me this tomorrow, it could have been a strongly disagree, yesterday could've been a somewhat disagree, but yeah."
	Foundation	cultural background, types of intelligence depend on culture, previous experiences, educational background, preparation, outside influence, family educational encouragement, peer support in learning, resources to develop intelligence	Elle: " I would say, I don't think my high school gave me a very good chemistry...um, foundation for going into, um college. Limited, I didn't really do anything with chemistry outside of school. So, yeah, just basic and limited."
	Willingness to Learn	behavior driven toward improvement, wanting to improve enough to do something about it, tying effort to improvement	Yosef: "Definitely, yeah, because you can't, you know, you can't do something if you don't like it. Or you can't make someone do something they personally don't even want to do. Yeah, it's just gonna not really end well."
	Malleable	can change, can be developed, developable deficiency, learning grows intelligence, growth experience, improvement	Kevin: "I think just being a firm believer that nothing is set in stone. I don't like the concept of destiny or fate. I feel like everything for the most part is in one's control. If you want them to change, then see to it and it will change."
	Maturation	maturity, common sense, development over time, growing up, natural development	Teresa: "Well, it could be either tutors or teachers. They've seen more of chemistry than I have, and they've like how I said they've gone through the more advanced classes, so they've attained more of the chemical knowledge by learning new concepts, new equations, new mathematical concepts as well, so I mean, obviously the more, you know, the-- I guess that you could say more intelligent you are."
	Natural	brain-sidedness, learning style, types of input that click, types of tasks that come easily	Elle: "Probably in early childhood. And also being just born with the good genetics, also."
	Stable	can't change, unchanged, not developing	Raquel: "Because if you're not a naturally like creative person or a person who can't naturally see images of what you're learning about in your head, I feel like that is extremely, extremely difficult to be taught how to do that. You either are good at it or you're not. And you can improve it to a certain extent, but it's, that's very difficult."
	Intelligence Comparison	strengths and weaknesses, depends on the person and the subject, different levels of understanding content between people	Camille: "I think it's something that shines stronger in certain students than others, but as a whole it's in every student, it's just a matter of whether that student is able to or willing to apply themselves to the topic."

Data Availability Statement

The data supporting this article have been included as part of the Appendix and Supplementary Information.