Defining and Describing the Complex Nature of Undergraduates’ Chemistry-Specific Mindset Beliefs

Deborah L. Santos
Georgia State University

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Defining and Describing the Complex Nature of Undergraduates’ Chemistry-Specific Mindset Beliefs

by

Deborah L. Santos

Under the Direction of Suazette R. Mooring, PhD

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the College of Arts and Sciences Georgia State University 2022
ABSTRACT

In challenging learning contexts like general and organic chemistry, students’ determining factors for persistence or helplessness become more salient in their likelihood of success in the course. Incremental beliefs (or growth mindset) are theorized to result in a series of behaviors that positively influence outcomes. Because of the difficult nature of chemistry as an academic subject, we investigate the role of chemistry mindset as an influencing factor on student outcomes. We propose that chemistry-specific mindset represents a separate construct from intelligence beliefs students hold about other STEM domains for undergraduates and thus should be measured independently. We show that the term “intelligence,” used in typical mindset instruments is broadly defined by undergraduate chemistry students and largely distinct from “chemistry intelligence.” Student definitions of chemistry intelligence were used to create an instrument for measuring chemistry-specific mindset. The normality of response distributions is greatly improved in the final version and confirmatory factor analysis supports a one-factor mindset model with high factor loadings across all items. The instrument has been used to show external validity through correlations of chemistry mindset with chemistry course grades, self-efficacy, and achievement goals. Student experiences with challenge were characterized, as they interact with mindset, to gather validity evidence of claims relating mindset to persistence. A multiple-case analysis was conducted to produce a qualitative description for the domain and context-specific characteristics of the various mindset perspectives of undergraduate students toward chemistry. Evidence for multiple growth, fixed, and middle mindsets were uncovered through examining a combination of data sources collected from a small group of students enrolled in general or organic chemistry. These findings serve as evidence for the impact these beliefs have on achievement behaviors and emphasize the utility of our chemistry-specific
mindset instrument for improved fixed mindset detection and student support. This seven-item instrument provides an efficient measurement tool for instructors and researchers to use in determining affective relationships or effects of interventions in undergraduate chemistry courses.

INDEX WORDS: Chemistry education research, Mindset, Implicit theories of intelligence, Affect, Chemistry mindset, Chemistry intelligence
Defining and Describing the Complex Nature of Undergraduates’ Chemistry-Specific Mindset Beliefs

by

Deborah L. Santos

Committee Chair: Suazette Mooring

Committee: Jack Barbera
            Samer Gozem
            Hongli Li

Electronic Version Approved:

Office of Graduate Services
College of Arts and Sciences
Georgia State University
August 2022
DEDICATION

I would like to dedicate this work to the three men in my life who have influenced my decision to pursue a terminal degree and encouraged my intellectual development. First, to my husband, David, for supporting me emotionally and financially throughout this season of life. He helped to reveal the desire I had to pursue a career in higher education and has celebrated my accomplishments in each step of the process. Second, to my father, Derek Leman, for generally supporting my path in life as his child, but also consistently being proud of me in the work I have done. He has always pushed me to pursue knowledge and to think for myself, while providing an example of intellect through lifelong learning and the study of theology and related topics. Lastly, to my late grandfather, Wesley Perschbacher, who was the first and only PhD in my family and also a teacher of both scripture and Greek language. He has always been a respected figure in my life for the dignity and persistence he displayed as a pastor and, after completing his doctoral work late in life, as a professor. I have reached this point only because I have been given the necessary belief in my own capacity by these family members.
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1 INTRODUCTION

Within the field of chemistry education research, a major focus in recent years has been affective influences on student experiences in chemistry courses (Flaherty, 2020). Affect in educational contexts refers to the wide range of emotion-related components of learning, such as motivation, self-efficacy, interest, attitudes, and mindset beliefs (Flaherty, 2020). Certainly, cognitive aspects of learning are crucial to student success, yet emotional aspects determine behavioral and cognitive engagement in the learning process (Galloway and Bretz, 2015; Xu and Lewis, 2011). As a relatively young research field compared to other science discipline-based education research, chemistry education research needs appropriate frameworks and tools to define and measure affective constructs for many research efforts. For example, a useful tool known as the Attitudes toward the Subject of Chemistry (ASCI) has been developed for measuring attitudes in chemistry (Bauer, 2008). Now that an appropriate measurement device has been created, chemistry education researchers can use it to detect attitude differences across student demographic groups, to examine the effectiveness of learning interventions, to evaluate its predictive ability on achievement measures, and to model its theoretical role along with other affective factors in a framework through statistical equation modeling techniques (Flaherty, 2020). Beliefs fall under the affective research domain, and specifically, mindset beliefs are a particularly sparse topic in existing chemistry education research.

Psychological and educational research on mindset, or implicit theories of intelligence, has been popular since its inception approximately 40 years ago. The many implications of the implicit theories theoretical framework have interested educators for decades as a way to impact student outcomes and understand differential behavioral patterns. A wealth of studies has been published with a focus on young children, displaying strong evidence for the existence of two
very different mindsets: growth and fixed. These mindsets determine the willingness of a student to engage in challenging tasks, how well a student receives feedback, how they respond to feedback, the degree of effort applied when a task is challenging, and the willingness to continue after encountering failure (Blackwell et al., 2007; Dweck and Leggett, 1988; Hong et al., 1999). Fewer studies have comprehensively examined this framework with older students, such as undergraduates (Macakova and Wood, 2020; Robins and Pals, 2002). As students have little exposure to chemistry as a separate subject prior to high school, it is important that the mindset framework be understood from an adult student perspective before attempting to measure the mindset construct in chemistry courses. To date, few studies have reported measuring mindset in chemistry learning environments (Bedford, 2017; Limeri et al., 2020a/b), and even fewer that have considered the possibility that the framework might apply differently to a college-age population.

Since implicit theories of intelligence provides a framework for understanding predictors of student persistence or avoidance in the presence of challenge, it may be useful for examining student course experiences in introductory undergraduate chemistry. Both general and organic chemistry are known to be challenging college-level courses, and across institutions, these courses have a high rate of drops and failing grades (Horowitz et al., 2013; McKinney et al., 2019; Popejoy & Asala, 2013). It is even more concerning that students do not typically elect to take these introductory courses, but rather are required to take them, either for their selected major or future career goals, predominantly for entrance to medical school. When a student ceases to persist in chemistry, this impacts their grade point average, choice of major, and/or pursuit of career goals. Mindset theory suggests that the decision not to persist is strongly linked to beliefs about the nature of intelligence. With an appropriate chemistry-specific measurement
tool, chemistry education research can pursue understanding of the underlying mechanism behind the tendency to persist or quit when challenges arise. Also, the explanatory power of a well-tuned mindset framework for chemistry can be leveraged to understand differences in affect and achievement and can even influence student outcomes. Furthermore, comparisons of mindset between different student groups can be made to search for trends, demographic gaps, or underprepared students.

Several conceptual issues require consideration in transferring the implicit theories framework to 1) an undergraduate population and 2) chemistry-specific learning environments. A broader goal of this work is to improve understanding of the nature of student mindset in chemistry through qualitative studies. In tandem, this work aims to produce an appropriate measurement instrument for chemistry mindset and begin to examine its usefulness for understanding student outcomes in chemistry courses.

1.1 Literature Review

1.1.1 Implicit Theories of Intelligence and the “Meaning System”

Dweck and Leggett were the first to synthesize previous research findings to create a theoretical framework for the effects of the implicit theories students hold about intelligence (1988). The early stages of research were focused on explaining differences in behavioral patterns between children who displayed mastery strategies as responses to challenge as opposed to those who displayed helpless responses (Diener and Dweck 1978, 1980). Years later, differential achievement goals were highlighted as explanatory for determining behavioral responses to failure feedback (Elliot and Dweck, 1988). To answer the question of why students operated out of particular goals, the theory of implicit beliefs about intelligence was born (Bandura and Dweck, 1985).
Two implicit theories were discovered: entity theories and incremental theories. The first theory considers intelligence (or other traits) to be an “entity” that is stable over time. The second theory considers intelligence as something “incremental”, or malleable over time (Dweck and Leggett, 1988). These two theories were originally considered to be individual differences similar to a personality trait (Dweck and Leggett, 1988). People tend to endorse one view or the other and this is claimed to be observed in equal frequency (Molden and Dweck, 2006). Despite an individual’s proclivity toward one theory or the other, beliefs about intelligence malleability have repeatedly been shown to be manipulatable in experimental studies (Dweck et al., 1995b). The formation of a particular belief system in line with one or the other theory occurs during childhood as the result of parental and teacher messaging about the importance of effort and ability (Dweck et al., 1995b).

The beginning of this line of psychological research has been attributed to a study by Diener and Dweck (1978) that characterized behavioral patterns among children when experiencing failure or negative feedback. Diener and Dweck termed the two patterns as mastery and helpless responses (1978). Details on the cognitive, affective, and behavioral aspects of these response patterns were described by observing key differences between the two types of students as they progressed from repeated success on problems to failures. Students were first categorized as mastery or helpless responders based on attributional measures. During the period of successful problem completion, all students tended to use good strategies for problem-solving. However, marked changes in cognition, behavior, and affect were observed for the helpless group. Expressions of negative self-beliefs were made such as comments about having poor memory and lacking the necessary intelligence or appropriate problem-solving skills. These students also began making negative affective expressions, such as boredom, anxiety, and dislike.
of the task. Similarly, behaviors became more task-irrelevant, serving as a distraction from their ability, performance declined, and poor strategy use became common. Students in the mastery group did not perceive their failed problems as failures, but rather as challenges to overcome. These students began using solution-oriented problem-solving strategies, at times even improving their strategies over previous problems, and began self-monitoring their task engagement. Some students began expressing positive affect such as enjoyment of such challenging problems and persistent optimism (Diener and Dweck, 1978).

Elliot and Dweck (1988) explained this vast difference in responses to failure as a function of the types of achievement goals students set. Achievement goals are often discussed dichotomously with learning (or mastery) based goals and performance-based goals. Performance goals are often considered from an approach-avoidance perspective, where a performance-approach goal aims at achieving high scores, while a performance-avoidance goal aims at avoiding poor scores. In light of these goals, Elliot and Dweck conducted an experimental study in which the goal emphasis in each task was manipulated as well as the feedback students received to manipulate their perceived current ability levels. Patterns of cognition, affect, and behavior resulting from the goal emphasis were observed to test the hypothesis that learning goals lead to mastery responses and that performance goals lead to helpless responses with the onset of failure. When students estimated their current ability to be low and the nature of the task was evaluative (performance-orientation), students opted for an easier task and displayed a helpless pattern of cognition, affect, and behaviors. When the task was mastery-oriented or focused on skill development rather than evaluation, the students’ estimate of current ability was irrelevant and they tended to exhibit mastery response patterns and select more challenging problems (Elliot and Dweck, 1988). This tendency toward mastery
responses in the face of failure is reasonable when evaluation is not important, suggesting that challenges are more enjoyable when they are for the purpose of learning and the threat of evaluation is removed.

Bandura and Dweck later showed that late elementary students’ implicit theories were a determining factor for the types of achievement goals they set (1985). Students who endorsed incremental theory beliefs were more likely to set learning goals relative to students ascribing to entity theory beliefs. Combining the findings from the experiments with elementary students regarding responses to failure, goal setting, and implicit theories of intelligence, Dweck and Leggett (1988) proposed a social cognitive framework. This framework for understanding differential behaviors as a function of different belief orientations is summarized in Table 1 below. The goals aligning with each implicit theory creates a lens for interpreting and responding to events such as receipt of negative feedback. This is because a student-focused on performance believes that effort and ability are negatively related. That is, if you had enough ability, effort would not be needed. Instead, a need for effort implies lack of ability. The opposite relationship is perceived by a student-focused on mastery or learning, effort and ability are positively related, such that effort increases one’s ability (Dweck and Leggett, 1988). Because performance is more associated with entity beliefs and mastery is more associated with incremental beliefs, these interpretive lenses apply to each opposing theory about intelligence as well.

Table 1: Implicit theories of intelligence as a social cognitive framework for failure scenarios (Dweck and Leggett, 1988).

<table>
<thead>
<tr>
<th>Theory of intelligence</th>
<th>Achievement goal orientation</th>
<th>Estimate of current ability</th>
<th>Behavior pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entity</td>
<td>Performance (both approach and avoidance)</td>
<td>High</td>
<td>Mastery response</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Helpless response</td>
</tr>
</tbody>
</table>
The two implicit theories drive attributions for failure or success, level of engagement in the presence of challenge, endorsement of a particular goal type, and source of motivation for persistence. Blackwell, Trzesniewski, and Dweck (2007) conducted a longitudinal study with middle school students in math classes during which they induced incremental beliefs through an intervention in an experimental group and compared their results to a control group. They found a positive correlation between incremental theory beliefs and effort beliefs, as well as the use of positive strategies and endorsement of learning (or mastery) goals. Incremental beliefs were also negatively correlated to helpless strategy use, which supports the claim that entity beliefs are more prone to driving use of helpless strategies if the two theories are true opposites.

The patterns described for children’s responses to challenge and failure have, likewise, been observed in adults (Dweck and Leggett, 1988). Robins and Pals (2002) conducted a longitudinal study across four years of college to observe changes in implicit theory beliefs as well as related student outcomes as a test of Dweck and Leggett’s social cognitive framework (1988). They found that the sample of college students remained stable in their implicit theory beliefs across the four years, higher stability than that found in an earlier study with elementary and middle school students (Pomerantz and Saxon, 2001). Entity and incremental theorists had similar perceived success and self-confidence in their academic ability, although entity-oriented students had significantly higher SAT scores. The theorized links between entity beliefs and performance goals as well as incremental beliefs and mastery goals were supported by this study’s results. The correlation between entity beliefs and performance goals was stronger for those who perceived failure relative to success. Furthermore, entity theorists tended to make ability attributions for failure (and not success) and otherwise uncontrollable attributions for both
success and failure, indicating helpless attributions overall. Incremental theorists tended to make effort attributions for their success. Positive affect and mastery responses were associated with incremental beliefs and negative affect and helpless responses with entity beliefs. Finally, the most interesting finding of this study involved self-esteem. Entity theorists were found to have lower self-esteem relative to incremental theorists overall, but also experienced a significant decrease in self-esteem throughout college that was not observed for incremental theorists. This resulted in a self-esteem gap between the two groups of students (Robins and Pals, 2002).

Overall, these foundational studies aimed at understanding the implications of implicit theories have been described as a meaning system students employ in interpreting events, stemming from their assumptions about intelligence and learning (Hong et al., 1999). Social cognitive theories provide explanations for how people ascribe meaning to their experiences (Molden and Dweck, 2006). In the case of implicit theories of intelligence, this sense-making is most prevalent in performance and evaluative scenarios. Particularly, with the perception of failure, a belief that an attribute (i.e. intelligence) is unchangeable leads to interpretations that failure signifies an insufficient amount of that trait. Self-regulatory processes that follow will be more centered on reducing the importance of that failure feedback, rather than improving for the future. Examples of these processes include distracting from detection of one’s ability level by using procrastination or reducing the importance of the failure by disengaging in that pursuit. These responses are attempts to protect one’s self-esteem and cope with a perceived lack of control over the circumstance. Quite the opposite, an interpretation of failure feedback as a challenge to overcome, more common for people who believe their attribute to be changeable with effort, leads to increased attention to effort so that their self-esteem can be improved through conquering the challenge. These two approaches to sense-making and responding to
stimuli have been studied across a range of traits, such as intelligence, morality, and personality (Molden and Dweck, 2006). Thus, implicit theories have implications in psychology beyond educational relevance; however, our focus is on the implications for chemistry learning environments.

1.1.2 Modeling Behavioral Regulation of Implicit Theories

Several studies have employed statistical models to test the theoretical connections between implicit theory beliefs and behavioral regulation (Burnette et al., 2013; Howell and Buro, 2009; Lou and Noels, 2016; Robins and Pals, 2002). The work by Robins and Pals (2002) discussed previously represents one of the early comprehensive modeling studies and incorporating multiple alternative path models to test hypotheses derived from the social cognitive framework put forth by Dweck and Leggett (1988). This study was particularly important in showing the validity for using this framework to understand related phenomena at the undergraduate level. Behavioral consequences of implicit theory beliefs were incorporated into the model and found to align with theoretically expected relationships. It is important to note that these findings apply to a general academic setting, such as the entirety of college, and not to specific courses or majors.

A study by Howell and Buro (2009) was designed to test the relationship between implicit theories and procrastination behaviors, as well as the mastery-oriented achievement goals (approach and avoidance) and procrastination. The sample studied were undergraduate psychology majors and they responded to survey measures of their general implicit theories of intelligence, achievement goal orientations, and procrastination behaviors. Multiple regression models revealed that a) entity beliefs significantly predicted procrastination behaviors, b) mastery avoidance goals positively mediated the relationship between entity beliefs and
procrastination behaviors, and c) mastery-approach goals negatively mediated the relationship between entity beliefs and procrastination behaviors. It was argued that entity theorists use procrastination to obtain short-term rewards, such as partaking in activities other than studying, because they have poor expectancy for long-term rewards, such as overcoming challenge (Howell and Buro, 2009). This study adds to our understanding of a particular behavior common among undergraduate students (procrastination), and was conducted within a particular domain (psychology), but used domain-general measures.

Another study by Lou and Noels (2016) aimed to examine a domain-specific model of behavioral regulation for non-native speaker students learning English in Canada. The methods involved manipulation of both the implicit theory of language ability condition as well as the perceived language competence through feedback manipulation. The goal was to ascertain the relationship of implicit theories condition according to feedback condition with achievement goals, responses to feedback, and affect. The sample studied here were non-native undergraduate students enrolled in a beginner English course. Path modeling techniques were used to test hypothetical relationships of a larger model. Perceived language competence negatively predicted performance-avoidance goals, and when crossed with entity beliefs, positively predicted performance-approach goals. Entity beliefs negatively predicted learning goals. Learning goals positively predicted mastery responses and intention to continue learning English. Performance goals were positively associated with helpless responses, anxiety, and fear of failure, and negatively related to intention to continue learning English (Lou and Noels, 2016). These findings provide support for Dweck and Leggett’s (1988) behavioral model through an experimental approach within a specific domain at the undergraduate level.
A meta-analytic technique was used by Burnette and colleagues to test a reframed behavioral regulation model they termed the “Setting/Operating/Monitoring/Achieving” (SOMA) model (2013). The SOMA model was derived from merging self-regulation theory with the implicit theories social cognitive framework as a mechanistic explanation for the processes involved in mastery and helpless responses and strategies. Self-regulation theory explains behavioral control, monitoring, and responses that individuals employ toward goal achievement (Bandura, 1986; Carver & Scheier, 2001). The SOMA model provides a theoretical framework for the interrelations between implicit beliefs and behaviors through a self-regulation lens. The types of goals students set are associated with their implicit theory beliefs: learning 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 selects are moderated by the presence of an “ego threat,” or a challenge. Students monitor their progress to inform future behaviors and will likely adjust their strategies to improve their goal operation. The monitoring component was operationalized as expectations and negative emotions.

The SOMA model is useful in considering the interpretation of challenge as an ego threat that moderates behavior. Through this model, the operating strategy, whether mastery or helpless, is the response to that ego threat interpretation. The setting, operating, and monitoring stages are all considered mediating factors between implicit theory beliefs and goal achievement. Burnette and coworkers’ analysis included 85 studies with a total of 113 independent samples across domains, including environments external to academia, for the purpose of testing the theoretical model described. Path models yielded significant mediation of goal setting, operating, and monitoring between implicit theories and goal achievement. This effect was also moderated
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by the presence of an ego threat (Burnette et al., 2013). This approach operationalizes self-regulation theory to explain the impact of implicit theories on achievement and is a helpful model for explaining differences in achievement observed for individuals with opposing implicit beliefs. It should be noted that the studies examined in testing this model represented a variety of domains, even incorporating studies from weight-loss programs, thus may not hold within one specific domain, like chemistry.

1.1.3 Undergraduate STEM-Specific Mindset

Science, technology, engineering, and math (STEM) fields have persistent cultural stereotypes regarding the level of brilliance required for success and the type of person capable of success (Leslie et al., 2015; Lytle and Shin, 2020). Some of these stereotypes are linked to personality types (e.g. analytical, introverted, etc.) (Morris et al., 2020) and others are linked to gender, such that females are perceived to have lower ability in math-based subjects (Burkley et al., 2010; Good et al., 2012; Kalender et al., 2022; Malespina et al., 2022). These cultural perspectives yield lower participation amongst females and gender minorities in courses, majors, and careers such as physics or engineering (Malespina et al., 2022; Porter and Ivie, 2019). An example of differences in ability perceptions across domains was provided by Siegle and colleagues (2009). They observed that undergraduate students with entity beliefs reported a more negative perception of their own ability in science relative to other domains despite the majority of the sample being science majors (Siegle et al., 2009).

Many students are more vulnerable to poor course experiences due to factors such as stereotype threat if they belong to a group about whom negative academic stereotypes are salient (Aronson et al., 2002; Burkley et al., 2010; Good et al., 2003). Likewise, achievement gaps are a concern for students from underrepresented racial and ethnic minority groups (Canning et al.,
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2019; Fink et al., 2018) as well as lower socioeconomic backgrounds (Claro et al., 2016) that participate in STEM undergraduate courses (Harris et al., 2020; Little et al., 2019). These gaps are believed to be a major contributing factor to the lower representation of students from some demographic groups in STEM fields. Mindset research specific to STEM domains should yield valuable tools for decreasing stereotype threat within STEM course environments and addressing students’ beliefs about their own ability to succeed in STEM.

Several studies have provided insight into the effects of and influences on mindset in STEM domains. Lytle and Shin (2020) examined implicit beliefs among first-year college students enrolled in a STEM-intensive university from a university-wide subject pool. They found that students’ implicit beliefs predicted their STEM interest and belonging with a mediation effect of STEM self-efficacy beliefs. This was found to be moderated by the course of study in that, the relationship only held for STEM majors (Lytle and Shin, 2020). Another study linked instructor trust and mindset beliefs in human anatomy and physiology courses, showing that trust (that the instructor understands, accepts, and cares about their students) predicted mindset. Also, trust and mindset together predicted engagement in the course, a commitment to active learning strategies, and course grades (Cavanagh et al., 2018). During college math and science summer courses, Barger (2019) observed differences in the associations of mindset beliefs with instructor messages. Comments made by instructors that students should ask questions or seek help from the instructor were associated with students’ fixed mindset beliefs. Additionally, these beliefs were more prevalent in courses where instructors made conciliatory remarks, such as “Don’t get hung up on things you don’t know or don’t understand,” when discussing how to read a research article (Barger, 2019). These findings provide evidence that
experiences in STEM courses influence students’ learning beliefs and thereby can impact a variety of behaviors and course outcomes.

It is well documented that students’ incremental implicit beliefs decline (and entity beliefs increase) during undergraduate STEM courses (Dai and Cromley, 2014; Flanigan et al., 2017; Limeri et al., 2020a; Malespina et al., 2022; Scott and Ghinea, 2014; Shively and Ryan, 2013). Flanigan and colleagues used general intelligence mindset measures during computer science courses to examine trends in beliefs (2017). They found that students’ beliefs shifted toward a belief that intelligence is unchangeable, but with a small effect size. The small effect was explained by examining belief differences for various motivational profiles as well as students from different majors. Students with a helpless motivational profile significantly increased their entity beliefs over the semester. Additionally, students whose majors were computer science, engineering, or physical sciences experienced less change over the semester, while those who were business and computer science dual majors significantly increased in their entity beliefs (Flanigan et al., 2017).

A study by Limeri and coworkers examined another factor contributing to changes in implicit beliefs throughout the semester of a STEM course (2020a). This study was conducted in organic chemistry courses and measured general intelligence implicit beliefs across four time points. At the end of the semester, students were asked whether they encountered struggles and were able to overcome them. This allowed for comparisons between students who perceived themselves successful without struggles, successful despite struggles, and unsuccessful because of struggles in organic chemistry. Latent growth models were used to detect differences in group trajectories. It was found that students who perceived failure at overcoming struggle in organic chemistry significantly declined in their implicit beliefs, while students who overcame struggle
experienced a recovery in their beliefs (an initial decline that reversed) toward the end of the semester. Additionally, the group that did not overcome their struggles had the lowest mindset scores compared to the other groups. It was argued that initial implicit beliefs likely impacted the students’ course performance, but that performance feedback influenced implicit beliefs in tandem (Limeri et al., 2020a).

Latent growth models of implicit theories of biology ability by Dai and Cromley (2014) revealed similar trends. Incremental beliefs exhibited an upward growth and entity beliefs declined over the course of a one-year biology sequence. The initial levels of incremental and entity beliefs were predicted by students’ biology domain knowledge and inference-making skills at the beginning of the year. Both the initial level and trajectory of incremental biology ability beliefs predicted STEM major dropout, and this relationship mediated the link between student cognitive readiness factors and STEM major dropout. Course grades were associated with later implicit beliefs, even 6 months after course completion, suggesting the importance of implicit beliefs in STEM major retention (Dai and Cromley, 2014).

Individuals hold different implicit theories about each domain (Molden and Dweck, 2006), thus general intelligence mindset is not the most relevant construct in undergraduate learning contexts as students engage in domain-focused studies based on personal beliefs, goals, and values (Shively and Ryan, 2013; Scott and Ghinea, 2014). Beliefs in multiple intelligences such as math, language, analytical, and spatial intelligence (Gardner, 2006; Scott and Ghinea, 2014) also support the notion that students' beliefs about their abilities in chemistry are likely different compared to those in physics or biology and possibly unrelated to their beliefs about general intelligence.
Evidence in support of the domain-specificity of the mindset construct itself has begun to surface in the last decade. A study in technology education by Buckley et al. (2019) probed qualitatively for characteristic behaviors of intelligence in STEM. They identified a total of 84 unique characteristics and refined these through exploratory and confirmatory factor analyses into 18 separate characteristics within 3 larger categories: social competence, general competence, and technological competence. It was argued that intelligence in STEM was perceived to be a fluid trait and that a multiplicity of definition is most appropriate (Buckley et al., 2019). This provides evidence that even the definition of intelligence in STEM may be unique; therefore, students’ malleability beliefs associated with it may not relate to their general intelligence mindset beliefs.

Further, when comparing STEM domain-specific mindset to general mindset, STEM incremental beliefs are much lower relative to general incremental beliefs (Gunderson et al., 2017; Scott and Ghinea, 2014; Shively and Ryan, 2013). Gunderson and colleagues (2017) surveyed students across four age groups ranging from early elementary through college regarding their implicit theories of intelligence in math and language with respect to students their own age and adults working in those fields. It was found that students at all age levels perceived adult jobs in math fields to require more natural intelligence and that older students are more likely to have fixed mindset beliefs about math relative to language (Gunderson et al., 2017).

Shively and Ryan (2013) observed higher entity beliefs about math relative to general intelligence in college algebra courses. Students also reported that effort was more important in improving one’s general intelligence. Math-specific beliefs were more strongly negatively impacted during the course experience and correlated more strongly with algebra course grades.
(Shively and Ryan, 2013). In a similar study, Scott and Ghinea (2014) observed more rapidly declining and lower incremental beliefs about programming ability relative to general intelligence. These beliefs were also more predictive of students’ programming practice throughout the semester. Early course performance moderated the relationship between programming ability beliefs and programming practice (Scott and Ghinea, 2014), giving further evidence for the relationship between performance and the dynamic nature of STEM mindset beliefs.

Several studies have utilized discipline-specific or STEM-specific mindset measures, but few have conducted sufficient validation studies to support the instrument selection, development, or modification (Dai and Cromley, 2014; Gorson and O’Rourke, 2019; Malespina et al., 2022; Scott and Ghinea, 2014; Shively and Ryan, 2013; van Aalderen-Smeets et al., 2018). The majority of the STEM-specific measures used employed simple modifications to the Dweck Mindset Instrument (Dweck, 1999), altering the trait language from “intelligence” to phrases such as “biology ability” (Dai and Cromley, 2014), “programming aptitude” (Gorson and O’Rourke, 2019; Scott and Ghinea, 2014), “math intelligence” (Shively and Ryan, 2013), or “STEM ability” (van Aalderen-Smeets et al., 2018). Two physics-specific studies developed items to measure several subfactors of physics mindset and incorporated a variety of trait terms (e.g. “intelligence in physics,” “excel at physics,” “be good at physics,” and “get better at solving physics problems”), targeting beliefs about self and others (Kalender et al., 2022; Malespina et al., 2022). A 6-item math-specific mindset instrument was created by Cury et al. (2006) that uses language such as “changing ability level in math.”

Qualitative justification for item language is crucial to support the validity of measurements with new instruments. Of the studies incorporating STEM-specific measures with
modified language, only the two physics studies (Kalender et al., 2022; Malespina et al., 2022) have reported conducting cognitive interviews regarding their items and student interpretations. Cognitive interviews were used to eliminate any items that were not interpreted as intended and to verify the remainder were interpreted appropriately. In order to create broadly useful domain-specific mindset instruments, STEM education researchers should substantiate the validity of items through the use of qualitative methods like cognitive interviews or open-response questions.

To date, two intervention studies have been conducted in undergraduate chemistry learning environments with conflicting results. Fink and colleagues (2018) implemented an experimental intervention, comparing a mindset condition to a control condition within a general chemistry 1 course. The intervention was conducted through online course management as a series of assignments and was semi-randomized to release each condition based on student ID numbers. They found that when accounting for academic preparation (college admissions math scores) for general chemistry, an achievement gap existed in the sample for underrepresented minority (URM) students relative to white students’ final exam grades. When including intervention condition in ANOVA calculations, a significant main effect of mindset condition was observed on final exam grades. The interaction between mindset condition and URM status was also significant, revealing that the effect of the mindset condition was selectively beneficial for URM students and not for white students. Adding academic preparedness to the model revealed a neutralizing effect of the mindset condition on the achievement gap previously uncovered. This was argued to be a result of minimizing the effects of stereotype threat through intervention and was persistent through general chemistry 2, indicating long-term effects of the mindset condition on URM student achievement (Fink et al., 2018). This study did not confirm
changes to student mindset through measurement of mindset pre- and post-intervention, which is a limitation to the interesting and significant results obtained.

Another study compared two intervention types to a control condition in general chemistry 2. One condition targeted utility value as a motivational intervention and the other was a mindset intervention (Wang et al., 2021). Group conditions were randomly assigned by student ID number and the interventions involved online homework assignments aligned with each condition across the course. A modified version of the ASCI-v2 was used to measure emotional satisfaction and utility value at the beginning and end of the semester to monitor the effect of condition on student attitudes toward chemistry. The utility value intervention was found to have a stronger effect on exam grades by the end of the course relative to the mindset intervention and the control group. This relationship was also observed for URM students alone. Both utility value and mindset interventions significantly predicted increases in utility value attitudes for students who initially scored low on this value. The utility value intervention was the only significant predictor of emotional satisfaction increases in attitude measures by the end of the semester. Of the two attitude measures, emotional satisfaction was a stronger predictor of final exam grade, providing a possible mediational explanation for the effect of the utility value intervention on exam grades (Wang et al., 2021). These results do not support the success of a growth mindset intervention in a chemistry course, yet again, measures of mindset were not included in the study to examine the impact of condition on beliefs.

Mindset studies in physics in recent years have shed light on the layers of complexity that may be more prevalent in STEM-specific contexts or undergraduate-level courses. Little and coworkers (2016, 2019) have highlighted the context-dependence of student beliefs as well as seeming contradictions in student views with their responses to challenge. For example, students
who ascribe to fixed mindset beliefs about physics sometimes exhibit persistent behaviors out of their desire for a good grade. The authors 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 (Little et al., 2019), which could be equally important in other STEM domains like chemistry. The studies by Kalender et al. (2022) and Malespina et al. (2022) present the layer of complexity to beliefs about self as a separate dimension from beliefs about others, particularly in physics. One example of a student who may experience this misalignment is a female student who believes that she lacks natural ability for physics, but believes that others can grow in their physics intelligence. These findings suggest that a deeper understanding of the various undergraduate STEM-specific mindset perspectives is needed, along with an examination of contextual influences on the expression of these beliefs in chemistry and other STEM courses.

1.1.4 Measures of Mindset and Conceptual Issues

Dweck’s Mindset Instrument (Dweck, 1999) originally contained 8 items (4 entity and 4 incremental statements) but has taken on many variations over time. Some variations involve wording changes to impact response-process and others involve selection of a few items or a single subscale. Several studies report using as few as two or three items as a measure of mindset (Suzuki et al., 2020; Yan et al., 2014; Yu and McLellan, 2020), yet this efficient survey approach is not supported by factor analysis techniques. Even Dweck herself began using a few items to represent implicit theory beliefs, referred to as the “short version,” stating that entity and incremental are logical opposites and that additional items are repetitive (Claro et al., 2006; Dweck, 2000). This shortened approach is seen in the Mindset Assessment Profile developed by Mindset Works ® as a quick assessment tool for classroom teachers. This tool incorporates 2 of
the traditional mindset items and 6 behavioral items derived from theory on the mindset meaning system (Burgoyne and Macnamara, 2021).

An alternative mindset instrument, titled the “Personal Conceptions of Intelligence Scale” (PCIS) was created by Faria and Fontaine (1997). This scale incorporates 26 items and is targeted toward younger students (elementary and middle school ages). The importance of effort and ability are included as dimensions of this alternate assessment tool. They argue that children do not understand the interdependence of effort and ability until about 10 years of age, thus their beliefs will be different relative to older students. Nearly all items use the word “intelligence” or “intelligent,” yet some target feelings or behaviors associated with the static versus dynamic intelligence concepts (e.g. “Failure in a task can make you feel less intelligent” and “The mistakes/errors you make must be forgotten because they prove that you are not intelligent”). To corroborate their claims about age-related conceptualizations of intelligence, they presented results with students from elementary through high school grades. It was found that beliefs about intelligence became more dynamic with age and that socio-economic differences in intelligence beliefs disappeared as students progressed through high school (Faria and Fontaine, 1997).

Another instrument development study built on the PCIS was conducted by Abd-El-Fattah and Yates (2006). Three items from the PCIS were included along with several items the researchers created to achieve a total of 7 incremental and 7 entity theory items. Again, these items used the word “intelligence” consistently and incorporated some of the behavioral implications of mindset theory. This new instrument was titled the “Implicit Theory of Intelligence Scale” (ITIS) and was tested with undergraduate students at institutions in two different cultural contexts, Egypt and Australia. This allowed for measurement invariance and psychometric testing with two populations. They found that the factorial structure was invariant
between the two country samples as well as between males and females within each sample, which speaks to the strengths of the ITIS as a general domain instrument for use with undergraduates in various contexts (Abd-El-Fattah and Yates, 2006).

Often, studies lack explanation of how they categorize students as having entity beliefs or a fixed mindset. An alternative to breaking the continuous (or ordinal) scale into segments for categorical analyses is to observe correlations between values of implicit theories scales with other outcome variables, an approach often used (Blackwell et al., 2007; Cavanagh et al., 2018; Flanigan et al., 2017; Scott and Ghinea, 2014). Considering the original theoretical framework for implicit theories, the ability to identify students with a fixed mindset about their intelligence seems most relevant to practitioners as they seek to assist students in developing positive learning strategies. A few categorization techniques have been used, but the most common starting point for this process is to consider entity and incremental beliefs scales as logical opposites, and merge them into a single continuum by reverse scoring the entity scale (Blackwell et al., 2007; Hong et al., 1999; Yeager and Dweck, 2020). The unified scale can then be split based on cutoff values as an *apriori* logical designation of fixed beliefs (e.g., < 3 out of 6 represents entity and > 4 represents incremental beliefs; Hong et al., 1999), or use of terciles or person-centered techniques can be implemented to identify the group with the least incremental beliefs in the sample (Chen, 2012; Yu and McLellan, 2020). The second option is more commonly used due to skewed response distributions toward growth beliefs, leaving very few students reporting beliefs below prescribed cutoff values (Malespina et al., 2022; Tempelaar et al., 2015).

As a further critique on the justifiability of assuming the two subscales of implicit theories to be opposite measures of the same construct, studies have frequently yielded
inconsistent factor structure results. Faria and Fontaine’s (1997) PCIS items yielded two factors distinct from one another. Cury et al. (2006) observed good fit of the two-factor structure for implicit theories of math ability using confirmatory factor analysis, indicating that entity and incremental were viewed as separate constructs by their adolescent sample. Dupeyrat and Mariné (2005) tested a Dweck-style mindset scale adapted from Hong et al. (1995a) with returning to school adults and found that entity and incremental subscales were significantly negatively correlated, but with a moderate relationship implying that treating them as opposite poles of a single continuum oversimplifies the true construct structure with this sample. Tempelaar et al. (2015) used Dweck’s Theories of Intelligence Scale—Self Form for Adults (1999) and tested both the uni- and bipolar models with confirmatory factor analysis. They found a strong negative relationship between the two subfactors and determined the merge into a single bipolar construct to be feasible (Tempelaar et al., 2015).

To bring in additional complexities to measurement of implicit theories, the person referred to in the instrument items affects responses. De Castella and Byrne (2015) adapted Dweck’s Implicit Theories of Intelligence Scale so that the items used the referent “I/me/my” rather than “you/your.” It was observed that student responses about their personal ability to change their intelligence were more predictive of motivational and achievement variables compared to statements about people in general (using second-person language, De Castella and Byrne, 2015). This caveat to measurement was a focal point of the related studies in physics education by Kalender et al. (2022) and Malespina and colleagues (2022). This work proposed the referent as a second dimension beyond the dimension of growth/fixedness, resulting in four subfactors of mindset regarding physics intelligence (Kalender et al., 2022; Malespina et al., 2022). Factor structure is important to consider for any instrument development process, yet the
implicit theories structure has faced scrutiny across multiple studies due to conflicting results and/or lack of testing with each sample. If only entity items are used, a major assumption is being made that this sample views entity and incremental statements as true opposites. Likewise, if only items regarding people in general are included, a second major assumption is being made that students hold the same beliefs about others as themselves.

At times, additional reasoning is employed in decisions to use only entity statements, that individuals find incremental statements very compelling, or socially desirable (Hong et al., 1999). That a student would be persuaded to agree with more positive statements (incremental) and use that agreement to determine their responses to negatively worded statements (entity) is highly possible. Evidence for social desirability could be drawn from observations that response distributions to implicit theories scales tend to be skewed toward agreement with incremental statements (Faria and Fontaine, 1997; Malespina et al., 2022; Tempelaar et al., 2015). Faria and Fontaine (1997) used the same reasoning in the development of the PCIS to create only entity (or static) belief items. However, if the argument stands that students frequently respond quite differently to each subscale, one cannot simply exclude the incremental items. Even if entity beliefs are more aligned to research interests as their own factor and thus can be sufficient for the goals of a study, these items may have social desirability associated with them to some degree, in that disagreement with apparently negative statements makes one appear to be a better person.

To combat these issues, alternative approaches could be considered to address the social desirability of the measure. Luftenegger and Chen (2017) suggested one such approach – removing the two-factor structure completely by shifting toward semantic differential response scale items as opposed to Likert-style responses. Although this measurement alteration had been
considered previously (Dweck et al., 1995b), it has not been tested thoroughly and is far from 
common practice.

As mentioned previously, items aimed at measuring implicit beliefs about intelligence 
generally use the wording “intelligence” and may apply differently to adult students compared to 
the young students they were originally developed for use with. When researchers themselves 
struggle to define intelligence for purposes of intelligence testing (Oliveira-Castro and Oliveira-
Castro, 2003; Sternberg, 2000), how can one expect a sample of undergraduate students to 
homogenously interpret this word when reading an instrument item? Sternberg (2000) claimed 
that the definition of intelligence itself is context-dependent, in that the sociocultural context 
defines what traits are valued.

Several studies have considered these nuances in interpretation associated with this term. 
For example, Eastern cultures often place emphasis on characteristics such as morality, wisdom, 
and diligence as key markers of intelligence while Western cultures might place more emphasis 
on cognitive abilities and academics (Aditomo, 2015). The concept of multiple intelligences 
(Gardner, 2006) is popularized in modern society and may raise questions as to which type of 
intelligence the instrument item is referring to. Limeri and colleagues (2020b) asked students to 
define intelligence and found two common themes: knowledge and ability. These two definitions 
could yield very different general beliefs about malleability as one is inherently growable 
(knowledge), while the other may not be (ability). Add to this the possibility that the meaning of 
“intelligence” changes with the domain of interest, likely as a result of sociocultural values in 
different domains, and the wording issue becomes more complex because mindset measurements 
typically are conducted within a particular domain. These claims and observations raise
questions about wording usage and its impact on item meaning for students of different backgrounds or characteristics (e.g., age, regional culture, ethnicity, nationality, religion, etc.).

A more recent notion of the complexity of measuring mindset involves the dynamic nature of mindset beliefs themselves. Not only might beliefs shift with experiences and contextual factors (Little et al., 2016, 2019), but they also can be manipulated (Molden and Dweck, 2006), suggesting that individuals hold both beliefs simultaneously and activate one or the other depending on the environmental needs. Some mindset-related factors that influence outcomes in academic environments include: 1) the mindsets of peers in the class along with perceived competence of said peers (Sheffler and Cheung, 2020), 2) the mindset (Canning et al., 2019; LaCosse et al., 2020; Muenks et al., 2020) and messaging (Barger, 2019) of instructors, and 3) perceptions of the learning environment mindset (Good et al., 2012). Although the original theory approached implicit theories as personality traits, rather than contextual beliefs, rebuttals to such critique state that individuals are more prone toward one implicit belief than the other (Molden and Dweck, 2006). As a further confounding issue, Little and colleagues (2016) found in qualitative interviews that, at times, the question itself influenced students’ responses regarding their beliefs, suggesting measurement of the true belief to be highly challenging.

In addition to mindset measurements themselves presenting concerns, the mindset meaning system has attracted some criticism when being tested with adult students. Study findings with adult students are particularly relevant to intentions to examine mindset in chemistry undergraduate courses. Specifically, Burgoyne and colleagues (2020) raised questions about the strength or “profoundness” of effects of mindset on various outcome variables and theoretically intertwined constructs (e.g. learning and performance goals). To address these questions, several premises were tested using undergraduate student surveys. The effect size for
data analysis regarding each premise was compared to a value of $r = .20$ as a mean effect size found in social-psychological research studies. They found significant, but much weaker than expected predictive relationships between growth mindset and learning goals and fixed mindset and performance goals. They found no significant relationship between fixed mindset and the belief that talent alone leads to success or between growth mindset and persistence or resilience after failure (Burgoyne et al., 2020). In another publication, Burgoyne and Macnamara (2020) commented that the theoretical mindset meaning system overstates the impact of mindset beliefs on achievement goals; however, they did not discuss the possibility that the meaning system applies differently to adults relative to children, with whom the meaning system was theorized.

Several differences in undergraduate students could apply to conclusions drawn from mindset studies. The first is that intelligence is viewed as more complex by older students, possibly resulting from more diverse life experiences (Dupeyrat and Mariné, 2005). Another is that direct effects of mindset on achievement might not exist, but rather the relationship is mediated by multiple other variables, such as basic psychological needs satisfaction and self-efficacy (Macakova and Wood, 2020). Likely for this reason, meta-analyses by Costa and Faria (2018) as well as Sisk and coworkers (2018) detected very weak correlations between adult students’ mindset beliefs and achievement across a large sample of studies. This was also the case for conclusions about the successfulness of mindset interventions with adult students (Sisk et al., 2018). It may be that simple models of mindset with achievement do not yield a large enough effect to detect consistently without the incorporation of mediating variables. Adult students are likely to be responsible with school work and thus strive to perform well in order to achieve their personal goals post-college, reducing the differential effects of belief systems.
Attempts to understand chemistry mindset at the undergraduate level require consideration of these observations as developmental stage certainly plays a role in the target population.

1.2 Study Goals

The initial driving goal of this study was to examine the impact of chemistry mindset on students’ course experiences. The focus of the work shifted toward appropriate measurement of chemistry mindset in an undergraduate context as the complexities and conceptual issues described above became apparent in pilot surveys. Exploratory qualitative studies were necessary to understand student perspectives on wording interpretations for item development. Additionally, validity evidence was needed to support the development of a chemistry-specific mindset instrument, achieved through combined qualitative interviews and quantitative analyses. To understand the functioning of interrelated factors affecting the mindset meaning system within chemistry contexts, in-depth qualitative interviews with students were needed. Finally, to characterize the impact of mindset on course experiences, the types of challenges students faced and how they aimed to overcome them would need to be considered as interacting factors with their mindset beliefs about chemistry.

1.3 Organization of the Research Questions and Findings

The following chapters present a series of studies designed to address the goals described above. Chapter 2 presents the qualitative findings on terminology interpretations to inform item development. Specifically, the following research questions were addressed in this study: RQ1) What are students’ reported mindsets when using a modified implicit theories scale with “chemistry intelligence” substituted for “intelligence?” RQ2) How do students interpret the
attribute terminology commonly used in measures of mindset? RQ3) To what extent is the mindset construct valid within this undergraduate chemistry course population?

Chapter 3 presents the development and validation studies for a chemistry-specific mindset instrument intended for use with undergraduate students in introductory (general and organic) chemistry lecture courses. This study specifically targeted the following research questions: RQ1) How can item wording be modified to produce improved student response-process and construct measurement? RQ2) How can the instrument’s response-scale and dimensionality be modified to produce improved student response-process and construct measurement?

Chapter 4 is a two-part study that examines the interaction between mindset and challenge in chemistry to investigate the impact of chemistry mindset beliefs on course experiences. The first part of the study presented in this chapter utilizes a more qualitative approach to characterize the types of challenges common in chemistry and the strategies students use to overcome them. This portion addressed the following research questions: RQ1) What challenge themes emerge from open-response descriptions of challenges students face during chemistry courses? RQ2) How do students respond to challenges in chemistry courses? RQ3) How do perceived challenges impact course performance? The second part of the study on challenges incorporates a more quantitative approach to examining the relationship between challenges and mindset as an outcome of chemistry-specific beliefs. This portion addresses the following research questions: RQ1) What are the common challenges students face during introductory undergraduate chemistry courses? RQ2) How are challenges students face in chemistry courses related to their mindset beliefs? RQ3) How do challenges impact course performance?
Chapter 5 is also a two-part study that uses a multiple-case study analysis approach. This study was drawn from the in-depth interview data collected in the larger study as a way to examine the experiences of several students from a variety of data sources over several semesters. The goal of this work was to characterize the mindset meaning system as it applies to chemistry undergraduate learning contexts. Part 1 of this study used a within-case analysis to examine each student individually to understand that students’ mindset beliefs as it interacts with challenge and behavior in chemistry. The research question of this portion was: How do students’ chemistry mindset beliefs relate to their interpretations of challenge and behavioral responses? Part 2 of the study made comparisons across cases to consider the various types of chemistry mindsets that emerged from the study and how it can inform theory on chemistry mindset as a whole. The research questions addressed in this portion are: RQ1) How can differences in chemistry mindset be characterized considering the nature of abilities relevant to chemistry, interpretations of challenge, and responsive behaviors? RQ2) 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?

The 6th and final chapter summarizes the findings from the multiple studies to generate conclusions holistically. The combined work will be considered for its implications on research in the area of chemistry mindset, domain-specific mindset, and STEM education as a whole. Additionally, implications for teaching practice will be considered through combining the findings over the course of the larger study.
2 DEFINING CHEMISTRY INTELLIGENCE: CHARACTERIZING STUDENT RESPONSES

2.1 Introduction

Introductory chemistry courses at the undergraduate level, such as general and organic chemistry, meet the criteria for gateway courses in that they are foundational, high risk, and high enrollment (Koch, 2017). Failure rates are known to be high in these chemistry courses (Amaral et al., 2013; Harris et al., 2020; Pienta, 2014), which are commonly taken by non-majors pursuing other sciences or professional career paths. Chemistry failure rates are likely linked to the relative difficulty of this academic domain (Lyons, 2006), which leads to increases in setback experiences for many students (Grant and Dweck, 2003). There are many factors that contribute to a students’ decision to withdraw from a chemistry course (Horowitz et al., 2013; McKinney et al., 2019). However, persistence is a key quality exhibited by some students who face challenges yet achieve success. A persistent response to academic setbacks is more common in students who have growth mindset beliefs about their intelligence in that domain (Binning et al., 2019; Henry et al., 2019; Hochanadel and Finamore, 2015; Karlen et al., 2019; Murner and Hessler, 2020). It is possible that chemistry instructors and programs could improve student outcomes by identifying and targeting students with fixed chemistry mindsets and implementing strategies to alter their beliefs about learning chemistry.

Mindset, here, refers to beliefs about the ability to improve one’s intelligence. To date, very few studies have been published regarding mindset (or implicit theories of intelligence) in chemistry learning environments (Bedford, 2017; Fink et al., 2018; Limeri et al., 2020a). However, some studies provide evidence that perceptions of difficulty and challenge associated with STEM courses affect students' implicit beliefs about STEM domains (Burkley, et al., 2010;
Gunderson et al., 2017), in addition to producing more opportunities for setbacks which may cause students to confront those beliefs (Limeri et al., 2020a).

A few studies have reported a decline in domain-specific mindset beliefs, but not general intelligence mindset beliefs, over a semester-long period within STEM-related courses (Scott and Ghinea, 2014; Shively and Ryan, 2013). Dai and Cromley (2014) found that both the rate of decline and initial level of biology ability mindset predicted STEM major dropout. Gunderson and coworkers (2017) showed a preferential benefit of growth math beliefs for secondary and post-secondary students on math achievement compared to reading or writing, which was argued to be a result of the perception that math is a more challenging domain. Scott and Ghinea (2014) compared the effect of general intelligence mindset and computer programming aptitude mindset on frequency of programming practice using early course grade as a moderator and found that the domain-specific mindset scores were more predictive of programming practice. These and other studies provide evidence to support that each domain may have its own separate mindset construct with respect to that of general intelligence and that the difficulty of STEM courses lends greater importance to growth beliefs about those domains (Costa and Faria, 2018; Shively and Ryan, 2013; van Aalderen-Smeets et al., 2019; Yu and McLellan, 2020). Thus, if chemistry mindset indeed exists, the ability to determine students’ implicit theories of chemistry intelligence hinges on accurate measurement of this construct.

2.1.1 Theoretical Framework

Students hold different theories about the nature of intelligence and other attributes. These theories are formed throughout their development as a consequence of cultural or environmental messages, personal experiences, and observations of others (Barger, 2019; Dweck et al., 1995b; Limeri et al., 2020a; Macnamara and Rupani, 2017; van Aalderen-Smeets et al.,
Based on Dweck’s social-cognitive theory, a student’s implicit theory refers to beliefs about the extent of malleability of a trait, such as intelligence, and is commonly called mindset (Dweck, 2006; Dweck and Leggett, 1988). These theories are labeled “implicit” because they are internal perspectives that impact external actions; however, they may not be explicit to the individual who holds them (Levy et al., 1998; Yeager and Dweck, 2012).

There are two general categories of implicit theories: incremental and entity. Students who have a “growth mindset” believe that intelligence can improve over time and thus hold incremental theories about the nature of intelligence. Incremental theorists generally believe that effort is important for learning (Chen and Pajares, 2010) and are more likely to exhibit persistent behaviors in the face of challenges (Karlen et al., 2019). Incremental beliefs can impact the goals students set (Burnette et al., 2013) and yield adaptive learning behaviors, which are theorized to improve their likelihood of success (Blackwell et al., 2007; Cavanagh et al., 2018). The opposite is true for students who hold entity theory beliefs about intelligence, that it is a stable and natural quality. Entity theorists, who possess a “fixed mindset,” attribute their success to ability, believe that effort is only required if you have low ability, and are more focused on performance rather than learning (Blackwell et al., 2007). Maladaptive behaviors such as disengagement, helplessness, and failure-avoidance can result from entity beliefs in the presence of setbacks (Hong et al., 1999; Tempelaar et al., 2015).

Growth mindset does not imply the belief that all people hold equal capacity in all domains; however, it does hold that any ability can be developed with effort (Blackwell et al., 2007). An individual may be set in a learning environment within a particular domain about which previous experience or current performance communicates that they possess low inherent aptitude. The response to these conditions from an entity theorist would likely be helplessness.
and avoidance of demonstrating low ability. If it is the first time this student has encountered major academic setbacks, it may be the first time their implicit theory is elucidated and necessitates a decision between adaptive or maladaptive behaviors (van Aalderen Smeets et al., 2018). On the other hand, a student with incremental beliefs would exhibit greater resistance to giving up or losing hope in this circumstance because their perspective is one of improving and learning (van Aalderen Smeets et al., 2018).

Students who hold implicit beliefs on either extreme should yield greater disparity in behavior and outcomes if observed during a time of increased likelihood of facing challenges (Dupeyrat and Mariné, 2005; Limeri et al., 2020a). These responses to setbacks are particularly relevant within challenging courses such as general and organic chemistry, due to the presence of many students who lack personal interest in chemistry and who may experience challenges with learning and performing in those classes. An incremental theory of general intelligence may provide some benefit to these students; however, it is more likely that chemistry-specific incremental beliefs are vital to increasing the accessibility of the adaptive behaviors necessary to improve and achieve desired outcomes.

2.1.2 Considerations when measuring mindset

Several variations of Carol Dweck’s general mindset scale have been produced over the years, but nearly all utilize the term intelligence for the attribute in question (Blackwell et al., 2007; Dweck, 1999; Hong et al., 1999). Dweck’s mindset scale was developed primarily for K-12 contexts but has been used with college students without the extensive validation studies necessary for the use of any psychometric tool with a different target population (American Educational Research Association, 2014; Dweck et al., 1995a; Hong et al., 1999; Levy et al., 1998). Recently, an increasing number of studies and meta-analyses have questioned the
practical benefits, straightforwardness, and validity of the mindset meaning system as a predictive theory (Burgoyne and Macnamara, 2020; Burnette et al., 2013; Costa and Faria, 2018; Sisk et al., 2018). It is probable that developmental stage, in addition to culture, impacts the theories students hold about intelligence, which could affect the nature of the mindset construct itself within different student populations (Anderson, 1995; Dai and Cromley, 2014; Yeager and Dweck, 2020).

Two meta-analyses of mindset literature have concluded that mindset interventions produce inconsistent and smaller effect size results with regards to improving student achievement at the undergraduate level. However, significant correlations are consistently observed in younger student samples (Costa and Faria, 2018; Sisk et al., 2018). One explanation provided in the analysis by Sisk and coworkers (2018) is that, with the increased course choice freedom at the college level, growth mindset students might be less deterred by difficult courses but obtain lower GPAs relative to other majors as a result of the differential challenge-level.

In an attempt to understand the causes of this age effect on mindset intervention success, some questions have been raised over undergraduate interpretations of terminology used within the typical items of the implicit theories of intelligence instrument, such as “intelligence” or “ability” (Dupeyrat and Mariné, 2005; Limeri et al., 2020b; Oliveira-Castro and Oliveira-Castro, 2003; van Aalderen-Smeets et al., 2019). Aditomo (2015) points out that cultural dimensions influence individuals’ definitions of the term intelligence, in that, many non-Western cultures view intelligence as involving knowledge, wisdom, and morality. When assessing the mindset of a culturally diverse student sample, the terminology may have strong influences on interpretation and response patterns.
Interpretations of “intelligence” and “ability” likely vary depending on the domain associated with them, as evidenced by cultural views on expectations of special ability levels, especially in STEM fields, which influences beliefs about the type of person who can succeed in a particular field (Leslie et al., 2015). Buckley and coworkers (2019) reported that students’ descriptions of intelligent behaviors in technology fields aligned with a fluid definition of intelligence according to theory on fluid and crystalline intelligences, which supports the notion that the domain can alter the type of intelligence called to mind when one reads a survey item. It is possible that undergraduates believe that theories of multiple intelligences or context-dependence apply (Gardner, 2006; Sternberg, 2000), even to a term like “chemistry intelligence.” Regardless of domain-specificity, these terms may still yield a high degree of variation in meaning to students and thus require a clearer understanding of these interpretations before incorporating them into mindset measures.

2.1.3 Construct validity and domain-specific mindset

In the process of instrument development, validity of the measure, or the extent to which evidence supports the interpretation of test scores for an intended purpose, is of prime focus (American Educational Research Association, 2014; Wren and Barbera, 2013). Construct validity is the overarching concept within modern validity theory and evaluates “the degree to which certain explanatory concepts or constructs account for performance on the test” (Messick, 1987). It is important to consider potential threats to validity in the development of a new measure for domain-specific mindset.

As previously noted, several meta-analyses show weak to no relationship between mindset and achievement with adult subjects across a large number of studies (Costa and Faria, 2018; Sisk et al., 2018). As these results do not align with the theoretical prediction of outcomes
established with younger students (Blackwell et al., 2007), they suggest potentially weak construct validity of implicit theories measures for these subjects (Costa and Faria, 2018; Messick, 1987; Sisk et al., 2018).

According to the Standards for Educational and Psychological Testing (2014), validity is addressed through the accumulation of evidence pertaining to content, response process, internal structure, and relation to other variables. Standard 1.10 states that when the interpretation of a test depends on the appropriateness of the content, content-oriented evidence, such as a thorough description of procedures used to generate test content for a particular target population and construct, should be included as a rationale. Additionally, Standard 1.14 states that when the intention is to interpret subscale scores or score differences between individuals, sufficient evidence should be provided as a rationale for the appropriateness of those interpretations (American Educational Research Association, 2014).

In examining the validity of the mindset construct for adult chemistry students, variations on views regarding the meaning of intelligence to these students is an important aspect to consider, given the many cultural aspects embedded. To this point, Limeri et al. uncovered two distinct themes in interpretation of intelligence from a sample of organic chemistry undergraduate students: “knowledge” and “abilities” (Limeri et al., 2020b). This finding provides evidence for a lack of homogeneity in the meaning of mindset items to undergraduate students. Construct validity can be affected by these different meanings, in that an interpretation of intelligence as “knowledge” is likely considered to be more malleable with respect to intelligence interpreted as “ability,” and might reflect different constructs.

Most often, in studies incorporating a domain-specific measure of implicit beliefs, the name of the domain is simply attached to the attribute without much consideration of potential
alterations to psychometric functioning (Komperda et al., 2018) (for example, “chemistry intelligence” (Limeri et al., 2020a), “biology ability” (Dai and Cromley, 2014), or “computer programming aptitude” (Scott and Ghinea, 2014)). One can question the validity of these changes in how it might affect understanding of implicit theories items and the variety of ways a term like “chemistry intelligence” could be understood by a new target population. As many wording selections for the malleable/stable attribute have been presented in the literature, it is crucial to explore chemistry students’ perspectives on various attribute terminologies so that the influences these may have on responses can be better understood.

The goal in measuring implicit theories is to identify different implicit beliefs in order to analyze their effects on other variables or to assist those with fixed mindsets in developing adaptive learning beliefs and behaviors. The commonly cited technique for identifying a fixed mindset from an implicit theories scale is to reverse score the entity items then set a cutoff value in the lower half of the Likert scale for the average score of all items (Costa and Faria, 2018; Hong et al., 1999; Yeager and Dweck, 2020). This technique assumes that entity and incremental scales are true opposites of one another and thus a singular construct, a topic heavily debated in the literature (Dupeyrat and Mariné, 2005; Dweck et al., 1995b; Hong et al., 1999; Lüftenegger and Chen, 2017; Tempelaar et al., 2015).

Mean mindset scores reported for populations within undergraduate STEM courses are often extremely high, where a growth mindset is easily interpreted as the normal belief a student would hold and a fixed mindset is an extreme belief (Dai and Cromley, 2014; Flanigan et al., 2017; Lytle and Shin, 2020; Shively and Ryan, 2013). Due to this skew toward growth mindset, the use of the cutoff score categorization technique results in the conclusion that an overwhelming majority of STEM undergraduate students have growth mindsets. Understanding
the relative prevalence of a fixed mindset in a population is important because any advantage provided by interventions or student support should cause apparent outcome improvements.

One compelling argument for the underlying cause of the more extreme skew observed at the undergraduate level is that social desirability of a growth mindset towards others, and thus oneself, is more prevalent amongst undergraduates compared to younger students. Also, this perspective aligns well with a relativistic view on the nature of intelligence, an aspect of the predominant culture in US higher education (Brown, 2008; Hong et al., 1999; Lüftenegger and Chen, 2017). Measurements affected by social desirability have construct-irrelevant threats to validity, or “excess reliable variance that is irrelevant to the interpreted construct” (Messick, 1987). For example, in later iterations of Dweck’s implicit theories instrument used with adult subjects, the incremental items were often removed because of social desirability (Hong et al., 1999). This removal of the incremental subscale for social desirability purposes would not be fully justified, in terms of internal structure of the measure, if the debated two-factor structure is the most accurate representation of the construct (Lüftenegger and Chen, 2017). It is also possible that the high frequency of students reporting growth mindset may be, in part, due to variation in interpretation of attribute wording, allowing a more malleable view of intelligence for many students relative to others (Limeri et al., 2020b), which may not truly reflect the same construct. At any rate, the question of item wording must be resolved to provide some qualitative evidence of validity of the measure for use with undergraduate students, and more specifically if targeting a new intellectual domain (chemistry) as a separate mindset construct.
2.1.4 **Purpose of the study**

The work presented here is part of a larger study to design a chemistry-specific mindset instrument. In this study, attempts are made to establish validity evidence for the content of modified implicit theories items targeted at a chemistry-specific context.

A major objective of this qualitative study is to better understand possible interpretations of terminology commonly included in domain-specific survey items. This step is important in order to justify any modifications made to the instrument items, such as attribute terminology. This qualitative work has not been carried out thus far for chemistry-specific attribute terminology with adult students in a chemistry context.

Another major objective is to uncover evidence of fixed mindset beliefs as a fairly common trait present within the target population. One consideration is that individuals may hold elements of both entity and incremental theories and the selective activation of one belief over another is determined by whichever is subconsciously viewed as most useful within a specific context (Anderson, 1995; Lüftenegger and Chen, 2017; Scherr et al., 2017). Student descriptions of the attribute terminologies previously mentioned are examined here for expressed views on the nature of chemistry intelligence. Knowledge and characteristics of different beliefs about the nature of chemistry intelligence can inform the development of more sensitive measurement tools to detect chemistry-specific entity and incremental theorists.

To better understand the mindset construct within undergraduate chemistry students, the following questions were investigated: RQ1) What are students’ reported mindsets when using a modified implicit theories scale with “chemistry intelligence” substituted for “intelligence?” RQ2) How do students interpret the attribute terminology commonly used in measures of
mindset? RQ3) To what extent is the mindset construct valid within this undergraduate chemistry course population?

2.2 Methods

2.2.1 Participants

This study was presented to students enrolled in all general and organic chemistry courses at a large, diverse public research university in the southeastern United States during the fall 2020 semester. Students were invited to participate in a study at two survey time points - the first three weeks of the semester and the last three weeks before the final exam. All sampled courses were large lecture sections (N > 200) administered in an online format due to the COVID-19 pandemic policies in place. The sample was composed of students from two general chemistry I sections and one section each of general chemistry II, organic chemistry I, and organic chemistry II. The total number of consenting participants in the pretest survey during fall 2020 was 1080. Quality control items were used to identify and remove careless responders, defined as those students who lacked sufficient attention to survey instructions (e.g. “This is a quality control item. Select “disagree.””) After the removal of careless responders, the sample consisted of 851 students.

Student demographics according to course level are shown in Table 1. Of the total sample, only 5.1% were enrolled in non-STEM-related major programs. The rest were STEM majors, pre-professional, or post-baccalaureate students, with only 6.0% chemistry majors. The sample was majority female, which reflects the approximately 70% female STEM course enrollment at the institution. More than half the sample is considered to be from a low-socioeconomic household and about a third of the students are first-generation college students.

A second, smaller sample of organic II students (N = 100) was included in some analyses and was surveyed during the last three weeks of spring semester 2020 with a similar demographic
makeup. A negligible amount of extra credit in the course was offered as an incentive to participate in the surveys and the students accessed the Qualtrics survey through a link posted to their online course page. The students voluntarily participated in the study or were otherwise permitted to complete an alternative assignment to earn the same amount of extra credit.

Table 2: Sample demographics by course level and semester.

<table>
<thead>
<tr>
<th></th>
<th>Fall 2020</th>
<th>Spring 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>General I n = 322</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General II n = 174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic I n = 253</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic II n = 102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic II n = 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Response Rate</strong></td>
<td>29.0 %</td>
<td>34.2 %</td>
</tr>
<tr>
<td></td>
<td>55.6%</td>
<td>32.5%</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>30.0%</td>
<td>28.7%</td>
</tr>
<tr>
<td>Female</td>
<td>71.7%</td>
<td>70.7%</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>31.1%</td>
<td>37.4%</td>
</tr>
<tr>
<td>Asian</td>
<td>32.6%</td>
<td>21.8%</td>
</tr>
<tr>
<td>White</td>
<td>18.0%</td>
<td>21.8%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>11.5%</td>
<td>13.2%</td>
</tr>
<tr>
<td>Other</td>
<td>6.8%</td>
<td>5.7%</td>
</tr>
<tr>
<td><strong>Pell Eligible</strong></td>
<td>55.3%</td>
<td>55.7%</td>
</tr>
<tr>
<td></td>
<td>54.5%</td>
<td>48.0%</td>
</tr>
<tr>
<td><strong>First Generation</strong></td>
<td>32.9%</td>
<td>43.4%</td>
</tr>
<tr>
<td></td>
<td>30.4%</td>
<td>29.4%</td>
</tr>
</tbody>
</table>

1 Pell Grant is used here as a proxy for socioeconomic status as it is a need-based governmental financial aid program
2 First Generation status refers to students who reported that none of their parents or grandparents have attended college

2.2.2 Data collection

The survey was administered online via Qualtrics survey software (QualtricsXM, Provo, UT) and included open-ended questions and a modified version of the Implicit Self-Theories of
Intelligence scale derived from De Castella and Byrne (2015), in which we changed the term “intelligence” to “chemistry intelligence” or “chemistry ability.” To gauge students’ definitions associated with these three terms, each participant was asked two open-ended questions about two of the three terms (e.g., “How do you define chemistry intelligence? What experiences or observations have led you to this belief? Please write at least 3-4 sentences.”). After formulating their responses for each term, the corresponding implicit theories scale was provided for response using a 6-point Likert scale. Four entity statements were provided regarding beliefs about the stability of the trait (e.g., “My chemistry intelligence is something about me that I can’t change very much.”), while four incremental statements were provided regarding beliefs about the malleability of the trait (e.g., “No matter how much chemistry intelligence I have, I can change it quite a bit.”).

It was desired that the responses to the instrument items would reflect the previously contemplated definitions students had provided. The sequencing of the definition prompt prior to implicit theories scale likely allowed the participants to be more thoughtful when selecting a response, rather than trying to guess what the researcher’s definition may be. To reduce survey fatigue, two survey versions were created so that each student responded with regard to only two of the three terms. The versions were randomized by the Qualtrics logic, providing approximately 50% response each to the “chemistry ability” and “intelligence” questions, while all students were presented with the “chemistry intelligence” questions.

2.2.3 Data analysis

2.2.3.1 Descriptive analysis of implicit theories measure

Incremental and entity theory scores from the implicit theories of chemistry intelligence scale were computed as an average of the four items within each subscale, where a score of 6
represents strongly agree. A high score in incremental theory combined with a low score in entity theory would thus be theoretically interpreted as a growth mindset. The distributions of subscale means across the sample were examined through histogram plots.

2.2.3.2 Open-response coding

The open-ended questions were subjected to an iterative content analysis strategy that began inductive in nature and became more deductive toward the end of the analysis (Hsieh and Shannon, 2005). Two researchers separately coded identical samples of 40 responses (of the approximately 1,900 collected) from each open-ended item at a time in an inductive manner during the code category development phase. In order to faithfully represent the responses provided by students, researchers did not begin with a predetermined list of codes and instead allowed the codes to arise organically from the text data. This cross-coding of identical samples was done in an iterative process, during which, the two researchers independently coded the text data then convened to discuss their findings. The goal at each step was to merge the separate lists of codes into a new combined list. This refinement process was carried out for several iterations with novel codes being identified and incorporated into the code list whenever appropriate and mutually agreed upon.

During the codebook development, a single term was examined during a single iteration, but all three terms were incorporated into separate iterations of codebook development. During each iteration, a new sample of 40 responses was coded. This process uncovered new categories over time because of differences in interpretations of different terms, but in the end a merged codebook (see Appendix A.1) was deemed appropriate due to the high degree of code category overlap and the intent for comparison across terms. Cohen’s kappa was calculated at 0.71 for the overall interrater reliability after four iterations. Based on this moderate to good indicator of
reliability (Watts and Finkenstaedt-Quinn, 2021), along with higher than 90% percent agreement for individual codes, it was determined that sufficient agreement on the usage of each code was achieved.

The finalized code list was utilized in the coding of representative samples of all open-ended responses provided by students in each of the four courses surveyed during the Fall semester. The representative coding samples were prepared by systematically alternating response selection from the larger sample split by course. This selection resulted in a 50% response selection from each course. In this way, coding samples were representative of course levels. Due to the high diversity of the overall sample and the size of the coding selection, it is assumed that the subsample displays fair representation of all student demographics listed in Table 1, even without intentional demographic selection requirements. The code frequencies of different definitions and beliefs regarding the terminologies were analyzed to compare facets of the word interpretations by this student sample and identify themes.

2.2.3.3 Qualitative mindset sorting

A separate analysis was conducted using the chemistry intelligence open-ended prompt to qualitatively sort responses into groups based on the explicit mention of the origins or nature of chemistry intelligence acquisition. The purpose of this analysis was to examine if the chemistry mindset construct can be elicited qualitatively through discussion of beliefs about the nature of chemistry intelligence implicit to many students’ definitions.

Several criteria were derived from Dweck’s mindset theory to identify a response that belonged in a particular group. For example, students who described chemistry intelligence as something that is unequally distributed among people naturally or that is unchangeable, a “gift,” or superior “smartness” in that area, were grouped as “fixed mindset” responses. Those that
highlighted the ability to improve over time, the ability of anyone to achieve it, or explicitly described their own gains in chemistry intelligence were categorized as “growth mindset.” And those that mentioned some aspect of both categories or had a more inclusive view, stating that chemistry intelligence could be represented by many different types of skills, were placed in a “middle mindset” group, which aligns with the theoretical existence of a “mixed mindset” (Dweck et al., 1995a; Luftenegger and Chen, 2017). These groupings were compared with their respective implicit theories of chemistry intelligence scale responses in order to investigate the effectiveness of distinguishing different mindsets quantitatively with the existing instrument.

The first author (DLS) sorted students into groups and excluded those that did not discuss origins or the nature of acquiring chemistry intelligence. The second author (HG) independently coded the open-ended response samples corresponding to each mindset group. A total of 291 responses were selected for this analysis based on meeting the mindset group criteria (see Appendix A.2), which represents about 34% of the full data. Interrater reliability analysis for response coding of these mindset groups yielded a Cohen’s kappa value of 0.79, indicating good reliability. Further evidence of the distinctiveness of the groups was provided through analysis of their code frequencies and how they define and attribute chemistry intelligence in significantly different ways.

2.3 Results and discussion

In order to align the study findings with its purpose, the following results are framed by the research questions.
2.3.1 *RQ1: What are students’ reported mindsets when using a modified implicit theories scale with “chemistry intelligence” substituted for “intelligence?”*

Mindset in domain-specific contexts differs from general mindset. The literature described previously accomplishes measurement of domain-specific mindset through attachment of the domain name to the attribute within the implicit theories items. The same method was employed with this chemistry undergraduate sample and the average subscale scores are shown as distributions in Figure 1. The incremental beliefs about chemistry intelligence are shown on the right side of Figure 1 and have a substantial negative skew with a mean of 4.80 and narrow standard deviation of .88. This result signifies that the majority of the sample self-report having a growth chemistry mindset as measured by this domain-modified instrument. A similar skew is observed in the sample distribution for the entity scale, also representing low agreement overall with the fixed nature of chemistry intelligence (mean = 2.18, SD = .95). These results align with those reported in STEM-specific studies with other adult student populations (Dai and Cromley, 2014; Flanigan *et al.*, 2017; Lytle and Shin, 2020; Shively and Ryan, 2013). It is unlikely that nearly all students in the sample truly have a growth mindset if the theoretical links to adaptive behaviors and achievement from Dweck and colleagues’ meaning system are considered. The misalignment between reported beliefs with typical outcomes may be the result of a measurement problem, prompting further investigation into student interpretations of “chemistry intelligence” and an alternative way to identify students who have a fixed mindset, beyond simply setting a potentially arbitrary cut-off point.
2.3.2 **RQ2: How do students interpret the attribute terminology commonly used in measures of mindset?**

2.3.2.1 **Variability of definition**

When designing survey items, it is important that students interpret the wording similarly. The open-response questions allowed for a detailed examination of how chemistry students define terms of interest for use in mindset scale items: intelligence, chemistry intelligence, and chemistry ability. After coding representative samples of these open-response questions across all course levels, the frequencies with which specific codes appeared were examined. Each term elicited more than ten different definitions, which demonstrates the high degree of variability in interpretation for all three wording choices. Common definitions that fell into a specific code category are provided in Table 2, along with usage examples. Figure 2 displays the code categories by percent frequency across the three different terms students were asked to define. This broad range of ways students interpret each term is evidence that items incorporating them may not yield consistent meaning to students, suggesting variation in the construct meaning to
different individuals. Across all three terms, the same three definitions were consistently reported at a higher relative frequency: knowledge, understanding, and ability to apply. This finding suggests that these three definitions are the most common amongst chemistry undergraduate students in this sample and that they remain of somewhat equal importance regardless of the term in question.

Table 3: Content analysis codes for definitions of attribute terminologies. Bolding within example responses indicates the term that was being defined.

<table>
<thead>
<tr>
<th>Definition Code</th>
<th>Description</th>
<th>Example Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>ability to apply</td>
<td>knowledge, concepts, skills</td>
<td>“Intelligence is the ability to recall and utilize information. However, this ability must also be done in a manner that is appropriate or beneficial to the situation at hand. I define it this way because there are people who can memorize things like trivia, but they have no skill to analyze or use that information to their benefit…”</td>
</tr>
<tr>
<td>abstract thinking, visualization</td>
<td>molecular perspective, three-dimensional representations</td>
<td>“[…Chemistry intelligence…] Things like the ability to visualize the 3D structures of molecules, to understand the shape of orbitals and the transfer of particles and charges. I find things like 3D molecule structures easy to visualize, while I find things like energy diagrams harder to understand…”</td>
</tr>
<tr>
<td>communicate, explain</td>
<td>teaching, explain to others, communicate effectively, speak well about knowledge, sound like you know what you're talking about</td>
<td>“I would define chemistry intelligence as not only knowing the materials covered but knowing the concept and being able to explain it… I find that I do better on tests if I try to teach it to my mom beforehand because she does not know science. If I can get her to understand it, then I know the concept well enough.”</td>
</tr>
<tr>
<td>domain-specificity</td>
<td>different kinds of intelligences, multifaceted, better in one area than another</td>
<td>“…Intelligence is not linear, as I may be intelligent for some things and lack intelligence in others.”</td>
</tr>
<tr>
<td>Chemistry-Specific Mindset</td>
<td>Efficacy for Learning</td>
<td>Emotional Maturity</td>
</tr>
<tr>
<td>---------------------------</td>
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</tr>
<tr>
<td>ease of learning, learn quickly, understand quickly, get it better than others, independence in learning</td>
<td>“I define intelligence as the capacity to learn new information easily. Someone with high intelligence can readily absorb new information more than someone with low intelligence...”</td>
<td>“I define intelligence as the ability to adapt and understand a variety of situations and be able to identify and overcome challenges. Intelligent people focus on the outcome and learning rather than the output. Intelligence also includes one's ability to identify mistakes and continue to grow and improve from them.”</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>Critical thinking, analytical skills, logic and reasoning</td>
<td>“Intelligence is the ability to use information that you know to find solutions to problems. Simply memorizing numbers and facts is not enough to be intelligent. You have to be able to think outside the box. Using the information you memorized to think of a creative and inventive answer to a problem is true intelligence.”</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Psychomotor</td>
<td>Do chemistry, actions, handling chemicals, performing experiments</td>
<td>“I believe chemistry ability is being able to execute tasks relating to chemistry. The way that my lab instructors can perform experiments effortlessly is amazing to me. That shows a clear understanding of the subject, to me.”</td>
</tr>
<tr>
<td>Subjective</td>
<td>The definition is subjective, defined by society, societal construct</td>
<td>“...I don't think that intelligence as a whole can be properly based on how much information someone has because that brings up the debate of what information is considered valuable and who gets to decide that…”</td>
</tr>
<tr>
<td>Understanding</td>
<td>Conceptual understanding, connecting concepts</td>
<td>“[Intelligence is] the ability to intake new information and overlap from all areas of existing knowledge you have to come to a logical conclusion that both allows success in understanding related material and opens the floor for more complex and developed information. A level of understanding that is not basic or elementary in any one subject.”</td>
</tr>
</tbody>
</table>
Figure 2: Relative code frequencies across all three terms as a percentage of total number of definition code references.

In addition to the broad range of definitions, providing evidence of the subjectivity of each term, several students explicitly stated that intelligence is subjective.

“Intelligence can differ depending on the situation and circumstance. Someone can show a high level of intelligence in street-smarts but that may not correlate with his/her level of intelligence in aeronautical sciences (and vice versa). Some people can have a jack-of-all-trades versatility to their intelligence while others may be savants in a more limited number of fields or even just one. In my experience, if what is defined as intelligence is limited to a few spectrums, it is an incomplete and not a fully thought out definition. I have come to this understanding of intelligence because when growing up I learned from people from different educational and vocational backgrounds and because what I learned helped me in life in some way or another, to me this shows that the definition of intelligence is not owned by one ideology, even if it may be the socially accepted one.”
Other students expressed similar sentiments toward the term by stating that “it is very difficult to define intelligence because of how intelligence means something different to different people.” Another aspect mentioned by a few students was the societal influences on our understanding of the term, ‘intelligence,’ such as “school definitions of intelligence as well as...family and friends and even social media,” and that to define it “requires a quantification of the value of certain cognitive skills.” One student even stated the assumptions he believed the researchers were employing in the act of asking these questions:

“I think in general intelligence, especially specific types of intelligence, is a useless term because it is used too broadly and can mean almost anything. So, I would like to say chemistry intelligence doesn't exist. Given the later question about "ability to change chemistry intelligence level" I infer that the researchers believe "chemistry intelligence” to be some type of innate knowledge about chemistry, or more generously knowledge the student acquired before the course. This is a concept I am against in principle as I believe that anyone given the right time and resources can become proficient at anything. Therefore, I think asking the student if they think they can change their chemistry intelligence level is rather backwards because it is a combination of the resources they have available to them, including time.”

These types of responses could be used to conclude that the term intelligence can evoke negative affect for some students based on how they believe others to define it. This could present a problem for inclusion of the term ‘intelligence’ for those students who hold principled views that the act of measuring and labeling individuals with a certain innate amount of ability is a controversial issue.

One goal in the item development phase is to collect evidence supporting the desired interpretation of the wording utilized. These results suggest that students may not be responding in the same way when reading the same item due to variation in interpretation. When asking
students if they can change their chemistry intelligence, how ‘chemistry intelligence’ is defined can be important. Some cognitive abilities are likely viewed to be more malleable than others, such as knowledge, which increases with study. Students who believe chemistry intelligence is the “ability to understand” might be less likely to say that it is a malleable quality compared to “knowledge” (Limeri et al., 2020b). This variability in the meanings students ascribe to intelligence may obscure the mindset construct by producing inconsistencies in the measured construct meaning. If this is the case, it would not allow a clear distinction of growth mindset individuals from those who believe chemistry intelligence to be more stable.

2.3.2.2 Terminology impacts item meaning

The variety in wording that has been used in implicit theories studies suggests a need to understand how the domain of chemistry affects the understanding of the trait itself (e.g., “intelligence,” “ability,” “aptitude”). It has been argued that a general implicit theories scale given in a domain-specific context may not be a true reflection of students’ beliefs within that domain (Scott and Ghinea, 2014; Shively and Ryan, 2013). In comparing the definitions provided by students regarding general and chemistry intelligence, it is clear that there are differences in the ideas that come to mind for many students. For instance, “general intelligence” primarily highlights “knowledge” and “ability to apply,” but students uniquely mentioned the idea of multiple intelligences (Gardner, 2006) (“domain-specificity” code) and emotional maturity (open-mindedness, wisdom, adaptability, objectivity). General intelligence tended to have a less specific definition because many students recognized that it can be a diverse range of skills or abilities, depending on the person and context.

Chemistry intelligence responses yielded a different focus on “understanding” and “knowledge,” while also highlighting “motivation” (willpower, interest, effort), and more
distinctly, “mathematical thinking” and “abstract thinking” (or visualization). Many students referred to “understanding” as requiring time and effort and contrasted it with memorization: “For chemistry, you have to really understand what goes on instead of simply memorizing things.” When defining chemistry intelligence, many students recognized the underlying concepts as key to success at higher levels: “A lot of chemistry involves understanding basic concepts that build to more complicated concepts and reactions.”

Mindset, in the literature, seems to be context-dependent and the change of interpretation of the term intelligence, when specific to chemistry, supports the argument that measurement of general mindset for use in a specific domain may not be fully valid. These findings support the idea that the abilities students believe they are required to have in order to be considered “intelligent” in chemistry are more domain-specific than those deemed as general intelligence. Thus, it is pertinent to create implicit theories items that specifically probe beliefs within the chemistry domain.

When considering which trait term (i.e., “intelligence” or “ability”) is best used in the items we may develop, it is important to compare the students’ open-ended responses for the terms “chemistry intelligence” and “chemistry ability.” As seen in Figure 2, the associations of both terms with understanding, applying, problem-solving, math, and motivation seem to be consistent across the two terms, which suggests that the reference to “chemistry” elicits these definitions more so than the trait term alone. The frequency of the “knowledge” code is much higher in reference to intelligence and a more unique description of a “psychomotor” definition becomes the focus for chemistry ability. This psychomotor category was applied each time students mentioned someone’s ability to “do chemistry” or perform experiments and was typically used in a laboratory context. Additionally, chemistry ability was more commonly
defined as “performance,” which is typically described as an ability to achieve good grades in chemistry.

Some students stated that they view “chemistry intelligence” and “chemistry ability” as highly interrelated, while others claimed that they are different and that one is easier to achieve than the other: “Chemistry ability is the skills and knowledge that one possesses about chemistry to complete a task. A person's chemistry ability does not equate to chemistry intelligence because a person can score high on a chemistry test, but their ability may only stop there. They would not know how to apply the knowledge they have to the real world.” Other students seem to say that intelligence is more deserving of respect, “I think that with hard work and dedication that you can increase your chemistry ability to chemistry intelligence.”

The ‘ability’ term had a higher association with an external performance aspect and ‘intelligence’ had a closer association to internal cognitive potential. This difference in association clearly shows that the words ‘ability’ and ‘intelligence’ are not simply interchangeable. Many studies have exchanged the term ‘intelligence’ for another word without much justification other than ‘intelligence’ is too broadly defined. The term ‘ability’ also brings up a broad range of definitions and these may not be aligned with beliefs about the particular cognitive abilities the items are intended to probe. Care should be taken in selecting the term that best fits the research needs and desired construct to be measured.

2.3.2.3 Context associations

In addition to providing definitions, students tended to reference a particular context in which the definition would be applicable. Context codes were developed based on those commonly mentioned: academic, real-world, lab, and “street and book smarts” (a colloquial way to state intelligence as both academic and real-world.) Some important trends are observed
(Figure 3) for the different definitions in reference to context. For instance, general intelligence was equally weighted in frequency across all contexts except for lab. This can be contrasted with chemistry intelligence, which appeared most frequently in the academic context. The lab context was also occasionally referenced with regard to “chemistry intelligence,” but a more noticeable association was made for the lab context with “chemistry ability.” In addition to strict concerns over the definition of a term, the context brought to a student’s mind by a particular wording might very well be important to validity arguments. If one is intending to measure beliefs pertaining to an academic classroom setting but use terms that invoke thoughts of real world or laboratory applications, the responses may not consistently reflect the intended context.

*Figure 3:* Relative context code frequencies across all three terms (those with “Unspecified” context not shown).
2.3.3  **RQ3: To what extent is the mindset construct valid within this undergraduate chemistry course population?**

2.3.3.1 **Qualitative detection of mindset groups**

Students’ open-ended responses to the definition of chemistry intelligence were sorted according to explicit mention of the origins of the trait, such as a natural ability or something that is developed with effort. A small subset of the data (N = 291) met the criteria (see Appendix A.2) and was placed into a mindset group representing the same viewpoint on its origins. The first author (DLS) conducted the filtering and sorting, then the second author (HG) coded each sample to examine differences in definitions, contexts, and origins according to the previously established coding scheme. The “Fixed” and “Middle” mindset groups resulted in 79 students each, while the “Growth” mindset group was slightly larger (n = 133). The first 79 out of 133 responses from the Growth group were coded to yield homogeneous coding group sizes. After cross-coding the groups, the reliability (Cohen’s κ = 0.79) was calculated to verify that interpretations of the content were sufficiently reliable between the two coders for analysis of group differences. Examples of a response from each mindset group, along with the corresponding selection criteria, are shown in Table 4.

**Table 4:** Open-ended response examples sorted into each group based on specified grouping criteria. The highlighted segments contain coded content referencing origins of chemistry intelligence. The colors are to differentiate between portions of text which met different criteria within the same response.

<table>
<thead>
<tr>
<th>Mindset Group</th>
<th>Open-ended response</th>
<th>Grouping criteria met</th>
</tr>
</thead>
</table>
| Fixed         | “I'm not sure. I think that people who are chemistry thinkers are a whole different breed of people. There are people who love chemistry and hate chemistry. There has to be some sort of predisposition toward the subject in order for the person to thrive at it and enjoy it at the same time. I think that chemistry intelligence is...” | - Some people have it and others do not  
- Natural inclination                                                                                                                                                                                                 |
is not as abstract as other intelligences, but more concrete and factual, as most sciences are.”

Middle “Chemistry intelligence is to be able to understand chemistry. Some people can understand more easily than others because it's a complex subject. However, with time, practice, and effort, anyone can increase their chemistry intelligence even if it's just a little. But it's different for everyone because it may take more time for someone than someone who understands chemistry well. It’s quite difficult though because just for any subject, we have our strengths and weaknesses.”

Growth “Chemistry intelligence is something that can be built over time. When I first started taking chemistry classes, I always felt like it was too difficult and that I could not handle it because it is something that just comes to a person naturally. Over time, I realized once I sit and really understand the material, I can fully understand the material and so could anyone if they put their mind to it.”

Some key differences were observed in the ways these groups described the nature of chemistry intelligence (Figure 4) and defined the term (Figure 5). Figure 4 represents the origins of chemistry intelligence described by students without prompting and provides insight into the characteristic perspectives of each group. For instance, the “Growth” group frequently described intelligence as malleable, developable, and requiring effort, while these views were not characteristic of the “Fixed” or “Middle” groups. This finding aligns with mindset theory, in that, students who hold incremental theories about intelligence believe it to be a malleable quality, while those with entity theories believe it to be stable over time, which can also imply that it is endowed at birth or something natural.

The Middle group often cited more inclusive terms, such as many aspects can be considered chemistry intelligence or that anyone can attain it (“equality of attainment”), while
also commonly stating that it is natural for some people. An example of this viewpoint is: “I would define chemistry intelligence as one who grasps and/or has an affinity in the subject of chemistry. I would say this is so because some people grasp chemistry faster/slower than others. I do think this is subjective though and depends on who you ask.” Students placed in the Growth group were much more committed to the malleability concept: “...Someone can work to improve their intelligence. Based on personal experience, intelligence is a fluid entity. Someone can be intelligent in a certain subject and not others. But if they are willing to have an open mindset and learn, intelligence can be raised.” Likewise, fixed group students were more committed to the stability or natural nature of chemistry intelligence: “Chemistry intelligence is having a natural inclination towards chemistry and being good at it. I think I have just seen people around me (not only in chemistry but also in other subjects) be naturally good at a subject. They are able to grasp the material easily.”

![Chemistry Intelligence Origins](image)

*Figure 4: Origins and nature of chemistry intelligence as code frequency percentages for each mindset group (each group n=79).*
When comparing definitions of chemistry intelligence by these mindset groups, our previous claim that some definitions better align with a growth belief is further supported. Figure 4 shows that the Growth group predominantly defines chemistry intelligence with regard to “knowledge,” “understanding,” and “motivation,” while the Fixed group most frequently mentions “understanding” and “efficacy for learning” with nearly no mention of “motivation.”

Knowledge can be expected to align well with malleability beliefs. Knowledge increases, in the sense that we are born with essentially none but acquire it over our lifetime, and this is also the case with knowledge of chemistry. Motivation can also be expected to align more with a growth mindset belief in that it reflects the need for effort to achieve success.

It is interesting to note that the code for “understanding” was equally prevalent in all three groups’ definitions of chemistry intelligence. Students often described “understanding” as something that improves with effort, which aligns with beliefs about malleability; however, many others stated that it is easier for some people to understand chemistry concepts compared to others, which aligns well with beliefs that intelligence is innate and stable. This alternate view of “understanding” is reflected in the high relative frequency of the “efficacy for learning” code in the Fixed group. This code applies when understanding or learning is described in terms of pace and/or differential rates between individuals. Those who learn more efficiently, grasp things more quickly, or understand more easily are considered as having high efficacy for learning. It also seems to be somewhat logical to assume that efficacy for learning could be a natural quality, however, many Middle group individuals express that some natural qualities can be developed with effort. The Middle mindset group provided definitions appearing similar in frequency and distribution relative to those coded from the Growth mindset group.
2.3.3.2 Comparing qualitative mindset groups with implicit theories instrument results

To further investigate the validity of the distinction between these groups, mean responses to the chemistry intelligence implicit theories subscales (incremental and entity) were compared. A one-way ANOVA (N = 291, Fixed n = 79, Middle n = 79, Growth n = 133) of the mindset groups on these subscales showed statistically significant differences between all three group means (according to the Tukey test) for chemistry intelligence incremental responses ($F(2,189) = 39.64$, $p < .001$, $\omega^2 = .210$) and chemistry intelligence entity responses ($F(2,189) = 36.36$, $p < .001$, $\omega^2 = .203$). The effect sizes for both of these mean comparisons are large, which suggests the mindset group differences in open-ended responses reflect meaningful differences in

*Figure 5:* Definitions of chemistry intelligence across all three mindset groups as code frequency percentages (each group $n = 79$).
implicit theories scale means (incremental: $\bar{x}_{\text{growth}} = 5.09$, $\bar{x}_{\text{middle}} = 4.71$, $\bar{x}_{\text{fixed}} = 3.98$; entity: $\bar{x}_{\text{growth}} = 1.89$, $\bar{x}_{\text{middle}} = 2.26$, $\bar{x}_{\text{fixed}} = 3.00$). These quantitative indications of mindset group differences are visible on a group level in examining the mean.

However, when individual response averages to growth and fixed items were placed on a scatter plot (Figure 6), the mindset group quantitative differences became more difficult to identify. Some clustering was observed for the Growth group in the response region associated with a growth mindset (i.e., high incremental and low entity beliefs). However, there was less clustering for the Fixed group; with an increase in spread that centered near the growth mindset response region. The cluster for the Fixed group overlaps with the Growth group (Figure 6). This reveals that many students who qualitatively described fixed mindset beliefs still tended to respond with growth mindset beliefs when using the implicit theories scales. Additionally, this analysis demonstrates that the typical technique of using the scale center cut-off scores for identification of mindset beliefs may result in miscategorization of some individuals in each group, although most noticeably for the Fixed group. The overlap of these response clusters suggests that the simple modification of the mindset instrument through use of “chemistry intelligence” may be insufficient for detecting fixed mindsets.

Given the overlap in typical responses shown in Figure 6, it may not be possible to categorize individuals accurately into mindset groups using existing quantitative measures. While the ANOVA results indicate that these may indeed be distinct groups of student views as indicated by group means, the individual student response patterns have a high degree of variability and overlap. These results provide further evidence that the development of a more sensitive measure of chemistry mindset may be needed to efficiently identify and support those students who could academically benefit from mindset interventions.
Figure 6: Scatter plot of individual incremental versus entity subscale scores. Fixed group students are represented by red plus signs and Growth group students are represented by blue dots. The similarly colored ovals indicate the spread of each group.

2.4 Conclusions

2.4.1 Implications for research

The finding that the simple modification of the existing implicit theories instrument with the addition of the domain name, “chemistry,” yielded a predominantly growth-mindset centered distribution comparable to other STEM-specific studies with adult students suggests that the modification technique requires qualitative backing for construct validity purposes. When selecting an implicit theories scale, both the wording for the attribute name and references to particular academic domains affect the interpretations in breadth and content. Terms like “intelligence” are understood differently by various individuals and likely yield inconsistent response patterns in survey scales. The most prevalent categories of definitions uncovered in this
analysis were “knowledge”, “ability to apply”, and “understanding”, which could have different levels of malleability associated with them to different individuals.

One potential direction for improving implicit theories measurements within a particular course is to incorporate more specific terms which align with common views of “intelligence” and “ability” in that domain. For example, the highest frequency definition provided by students in our sample was “understanding.” This could lead researchers to modify an item which states, “My [chemistry] intelligence is something about me that I personally can’t change very much,” (De Castella and Byrne, 2015) to, “My ability to understand [chemistry] is something about me that I personally can’t change very much.” This modification strategy could serve to reduce ambiguity in meaning of the scale items and provide qualitative evidentiary support. This could particularly address ambiguity for those students who claimed that they had never heard of “chemistry intelligence” and therefore could not define it. It also removes the need for the student to “guess” or “infer” the meaning intended by the researcher, since the specificity of the new wording may have a clearer definition. As the term intelligence was observed to invoke thoughts of ability to carry oneself in the real world, and chemistry ability often evoked mention of laboratory, shifts toward including specific definitions might remove the implications of academic, societal, practical, or workplace success and retain the pure belief about the domain dissociated from a context.

Another measurement aspect considered in this work was the ability to detect different mindsets (i.e., those who hold stronger incremental or entity beliefs). Given the observation that a vast majority of students self-report growth mindset on both entity and incremental chemistry intelligence scales, a possible interpretation is that almost none of the undergraduate chemistry students in the sample hold fixed mindset beliefs. Due to the prevalence of students who
encounter challenges in these courses and fail to overcome them, it was pertinent to investigate the qualitative responses for some indication of the nature of chemistry intelligence to compare with these self-report measures. The detection of three mindset groups with different views on the nature and origins of chemistry intelligence suggests validity of the mindset construct within the target population, as well as of the likelihood of “fixed,” “growth,” and mixed (or “middle”) views being present in the sample.

The fixed mindset is theorized to represent a significant portion of student samples (Hong et al., 1999), and not just an extreme belief. Our identification of 79 students (27% of the sample that explicitly mentions origins, which accounts for 34% of the entire sample) who described fixed views about the nature of chemistry intelligence indicates that it is a fairly common belief. If implicit theories are measured solely through existing quantitative measures, these fixed mindset students would be difficult to isolate based on their self-report averages alone. This is due to the heavy overlap of responses with the other two perspectives. These findings suggest construct validity, however, low sensitivity in measurement of the chemistry mindset construct. Further efforts are needed to improve the sensitivity of measures and ability to detect these different perspectives. Additional construct validity can be confirmed through analysis of the theoretical connections to other variables commonly discussed as part of the “meaning systems” students employ in academic contexts, such as attributions for failure/success and achievement goal orientations (Hong et al., 1999).

2.4.2 Implications for teaching

Mindsets about different attributes are known to shift over time based on experiences, which means that chemistry instructors can play a significant role in nurturing adaptive beliefs and behaviors by creating a learning environment which communicates a growth mindset about
chemistry intelligence to students. The emphasis, during instruction, on particular definitions of chemistry intelligence which are developed over time (more easily viewed as malleable) could serve to reduce comparison of “natural ability levels” with others in the class or the need to demonstrate ability to others. Praising strategic effort and explicitly teaching study techniques conveys positive associations with overcoming academic challenge and developing weaker areas of one’s chemistry intelligence. The instructor can also place emphasis on mastery through the types of teaching strategies and assessments implemented, so that learning, improvement, and understanding are valued above performance. Recognizing that the helpless behaviors of some students are a result of their beliefs about their abilities in chemistry is the starting point to redirecting them toward more adaptive beliefs and behaviors.

The findings presented here suggest caution in drawing conclusions about intervention success or failure based on existing surveys when used in undergraduate chemistry courses. To adequately assess interventions, a sensitive and accurate measure for chemistry mindset would first need to be developed in order to probe and monitor students’ implicit theories of chemistry for evaluating shifts in teaching strategy. However, it is likely that, as students intentionally engage in a positive learning environment that encourages development, they will see improvement and reshape their former beliefs about learning chemistry.

2.4.3 Limitations

This study was conducted at a single institution, which limits the generalizability of the findings; however, the institution is quite diverse across racial and ethnic backgrounds. Further, we collected data from students across several sections of general chemistry and organic chemistry lecture courses. The large, diverse sample accounts for a broad range of possible perspectives and provides insight into the target population’s views.
The nature of US post-secondary chemistry course sequencing and gateway curricula for pre-professional programs may yield different results for US samples relative to non-US university chemistry students. Although many students with international backgrounds attend the university, facets of US educational and societal culture likely play a significant role in both the interpretation of the attribute terms and the views about malleability of intelligence. In US elementary and secondary schools, mindset is often embedded within instruction by teachers who wish to encourage their students to learn. Regardless of whether US students actually develop and hold these beliefs for themselves, they certainly would know the “correct” survey response if they had previous explicit instruction. As such, social desirability and acquiescence bias likely play a large role in the skewed responses to the domain-specific mindset scale. Further investigation with non-US student populations would be of great benefit to understanding how cultural differences may limit or support the generalizability of these findings. Additionally, ongoing cognitive interviews surrounding response process may shed light on the social desirability of particular wording or response options.

Another limitation to the generalizability is that the majority of the respondents were female students, but this gender disparity is reflective of the high (approximately 70%) female enrollment in STEM courses at this university. Although this overrepresentation is expected of this population, similar studies should be conducted with higher male student representation for evidence of generalizability in terms of gender. The low response rate (approximately 30% of enrolled students) may be due to the recent transition to a non-traditional online course format as a result of COVID-19 pandemic institutional policies. The unfamiliar course format likely decreased student attention to detail, such as extra credit opportunities, as navigating online
courses was new to the students. This could limit the generalizability of the study findings, in that, those who responded were likely more engaged or organized at the beginning of the course.

Uncovering themes through content analysis is subject to bias in how the coding categories are formed and designating what constitutes a sufficient response for a particular code. To address this, the development of codes and themes in this work was carried out by two researchers in an iterative process. This served to reduce ambiguity in application of code categories, achieve consensus on code meaning, and consolidate redundant categories while maintaining authenticity with regards to the data. In single paragraph written responses, it can be difficult to interpret the meaning intended by the student without bias, especially considering grammatical errors and lack of elaboration on their ideas. If these students were interviewed, these issues could have been probed further to clarify meaning. However, attempts were made to reduce interpretation bias through use of inter-rater coding comparisons and by searching for only explicit information within the text. The implicit theories quantitative measures which were critiqued for sensitivity in this work employ self-report methods, which may be argued to be contradictory to the description of these beliefs as “implicit” and thereby difficult to elicit in the form of a Likert scale response. It is for this very purpose that we aim to improve and modify the implicit theories scale to attain more valid and reliable implicit theories data in undergraduate chemistry courses and for their subsequent interpretation as representing certain mindsets.

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3 MEASURING CHEMISTRY-SPECIFIC MINDSET BELIEFS: DEVELOPMENT OF AN INSTRUMENT

3.1 Introduction

A variety of beliefs contribute to students’ motivational behavior in chemistry courses, with some of these beliefs specific to the subject of chemistry. Certain beliefs may influence student outcomes more than others, mediated by motivational processes. Specifically, mindset beliefs are linked to student persistence in the presence of challenge and theoretically yield differential academic outcomes aligning with these beliefs (Burnette et al., 2013; Molden and Dweck, 2006; Yeager and Dweck, 2020). Students are well aware that chemistry is known to be a challenging course and this reputation is perpetuated and confirmed by low course retention rates and lower grades relative to other courses (Harris et al., 2020). As STEM educators seek to promote retention in STEM courses and persistence in STEM majors, understanding mindset is particularly relevant in these contexts. Mindset has been qualitatively shown to play a role in the formation of chemistry identity (Hosbein and Barbera, 2020), thus it is important in the retention of students in chemistry majors. There is also evidence to suggest that mindset can support increased STEM diversity through preferential benefits to students who would be more likely to experience stereotype threats in STEM courses (Aronson et al., 2002; Canning et al., 2019; Fink et al., 2018; Good et al., 2003).

To unravel the motivational relations responsible for differences in student outcomes, appropriate measures of each construct must be established. Several researchers have recently criticized the mindset meaning system (Burgoyne and Macnamara, 2021), the measurement quality associated with it (De Castella and Byrne, 2015; Limeri et al., 2020a; Lüftenegger and Chen, 2017), or both (Dupeyrat and Mariné, 2005; Tempelaar et al., 2015; van Aalderen-Smeets
and van der Molen, 2018). Likewise, meta-analyses of the mindset literature have highlighted the inconsistencies of mindset as a predictor of achievement with undergraduate student populations (Costa and Faria, 2018; Sisk et al., 2018). These inconsistent findings may point to inappropriate measurement of the mindset construct with the population of interest, indicating possible lack of validity. Additionally, work published by Santos et al. (2021) and Limeri and coworkers (2020a) found that undergraduate chemistry students interpret the terminology used in mindset instruments (i.e., “intelligence”) in a broad range of ways, which leads to potential response process concerns as some interpretations may have different implied malleabilities associated with them (e.g., knowledge is inherently a grow-able quality). To avoid these varied interpretations and improve response fairness, less broadly defined wording can be used in mindset instrument items.

Post-secondary students cannot be expected to hold the same views that primary and secondary students would have about a complex subject such as intelligence. It is likely that undergraduates hold a more multiplistic definition of intelligence as they increasingly realize that success can be achieved within a variety of different domains and using a variety of cognitive skills. This is supported by arguments that a domain-specific mindset measure is more appropriate at the undergraduate level within domain-specific contexts (Gorson and O'Rourke, 2019; Gunderson et al., 2017; Little et al., 2016; Scott and Ghinea, 2014; Shively and Ryan, 2013). Many domain-specific mindset studies in STEM have incorporated mindset measures that simply modify the item language from “intelligence” to terms such as “biology ability” (Dai and Cromley, 2014), “programming aptitude” (Scott and Ghinea, 2014), or “math intelligence” (Shively and Ryan, 2013). These types of modifications seek to improve the predictive power of mindset on STEM course performance or other outcomes but lack the qualitative justification
necessary to suggest valid construct measurement. Buckley and colleagues (2019) demonstrated that students provide a broad range of definitions for intelligence within the technological domain through the qualitative exploration of characteristic behaviors of intelligent people in technology. These findings indicate that ideas about intelligence within a single domain can be complex for students to define. In addition to supporting the need for domain-specific mindset measures, these findings support infusing specified definitions of domain-specific intelligence within the instrument to yield more consistent interpretations. Based on these prior studies, it is reasonable to assume that chemistry intelligence is a unique and complex trait. Therefore, its meaning should be clarified for students when asked to report their beliefs, especially considering that many have a novice-level understanding of the field.

Another aspect of measuring mindset that has been questioned in recent years is the factor structure intended by typical mindset instruments (Luftenegger and Chen, 2017). Mindset instruments are usually designed to measure two subfactors, entity and incremental theory beliefs (Dweck, 1999; Yeager and Dweck, 2020). Despite the two-factor design, mindset is often treated as a unidimensional measure when interpreting students’ responses by using cutoff values or terciles to identify respondents with a fixed mindset (Hong et al., 1999). Studies have shown inconsistent results in factor structure with some favoring a single-factor model and others favoring the intended two-factor structure (Luftenegger and Chen, 2017, van Aalderen-Smeets and van der Molen, 2018, Gunderson et al., 2017). As a further critique on the validity of measurement in many mindset studies, they often report quantitative results using mindset as a predictor variable yet do not provide evidence of valid usage of the instrument with the studied population as they tend to omit confirmatory factor structure analysis. Therefore, the validity
questions raised here must be taken into account when measuring domain-specific mindset and have driven our development of a chemistry-specific mindset instrument.

### 3.1.1 Theoretical Framework

Mindset theory is a popularized term referring to students’ implicit theories of intelligence. Students can hold entity or incremental theory beliefs about human traits such as intelligence, personality, and morality (Dweck et al., 1995a; Dweck et al., 1995b; Levy et al., 1998). Entity theories are beliefs that the specified trait cannot change or is “fixed.” Incremental theories are beliefs that a trait is malleable or can grow (Molden and Dweck, 2006). Entity theorists regarding intelligence or academic abilities generally place emphasis on innate ability and view effort as a sign of lacking necessary natural skills. Incremental theorists, on the other hand, view effort as a means by which to improve and thus obtain these skills (Dweck and Leggett, 1988).

Theoretically, this results in incremental theorists exhibiting “growth mindset behaviors” such as putting forth more effort and persisting toward success because they believe it to be more attainable relative to entity theorists. Alternatively, entity theorists are more likely to exhibit “fixed mindset behaviors” such as procrastinating, avoiding evaluation, and self-hindering to remove emphasis from their natural ability onto their willful actions (Burnette et al., 2013; Molden and Dweck, 2006). These behaviors are self-protective responses to challenge that reflect ego threat, either as a result of interpreting challenge as a threat to their self-perceived value as intelligent individuals or confirming their negative self-perceptions. These relations suggest a link between mindset, self-efficacy, and achievement behaviors. Self-efficacy, the belief that one can achieve the desired outcome, has been shown to relate to mindset in several motivational analyses and thus is a useful variable to consider for demonstrating external validity (Bedford, 2017; Komarraju and Nadler, 2013; Lytle and Shin, 2020).
The originally proposed meaning system that students utilize based on their beliefs stated that achievement goals differ between growth and fixed mindset individuals (Dweck and Leggett, 1988). Achievement goals encompass two dimensions: mastery versus performance and approach versus avoidance (Elliot and McGregor, 2001). A student who sets mastery-approach goals is focused on increasing understanding of the content, while mastery-avoidance goals imply avoiding lack of understanding. Comparatively, performance-approach goals drive students toward achieving high grades, while performance-avoidance leads to avoiding poor grades. It has been proposed that growth mindset aligns with mastery-oriented goals and fixed mindset aligns with performance-oriented goals (Dweck and Leggett, 1988; Smiley et al., 2016). Empirical support for the link between fixed mindset and performance orientation is weak, and rather most students report some degree of performance orientation (Burnette et al., 2013; Dinger and Dickhäuser, 2013; Karlen et al., 2019; Leondari and Gialamas, 2002). This trend may be due to the increased emphasis on high-stakes testing and grades-based assessment within modern education systems. Finally, as previously discussed, mindset has varying empirical predictive power on achievement measures such as grades, yet theoretically, growth mindset should lead to improved grades through adaptive behaviors (Hong et al., 1999; Blackwell et al., 2007). Achievement goals and course performance variables offer additional potential for demonstrating external validity of appropriate mindset measures.

3.1.2 Goals of Study

The work described in this report represents one part of a larger mixed-methods study investigating the effects of mindset beliefs in chemistry on various outcome variables. This portion addresses the development of a chemistry-specific mindset measure and the validity of data from an introductory undergraduate chemistry student population. It is crucial that the
measurement of this variable be understood prior to its use in future studies focused on drawing conclusions about the effects of mindset on course outcomes and other aspects of student affect. The specific goals of this study were to:

1. Develop an instrument specific to mindset regarding chemistry intelligence intended for introductory undergraduate chemistry students.
2. Determine the reliability and validity of measurements made with the developed instrument when used in the target population.

The two research goals were carried out by addressing the following research questions:

1. How can item wording be modified to produce improved student response-process and construct measurement?
2. How can the instrument’s response-scale and dimensionality be modified to produce improved student response-process and construct measurement?

3.2 Methods

3.2.1 Participants

Different iterations of the surveys were administered during Fall 2020, Spring 2021, and Fall 2021 semesters to students enrolled in introductory chemistry courses (general and organic chemistry sequences) at a large southeastern US research-intensive university. The majority of course sections participated each semester and instructors agreed to provide a small amount of extra credit for students’ completion of the surveys. Students who did not wish to participate in the research study were allowed to complete an alternative assignment or simply decline consent while completing the surveys and were credited the same number of points as those who consented to participate. Students were recruited for cognitive interviews during the Spring 2021
semester from the same courses that participated in the surveys. A compensation of $10 was provided to interview participants. This study was approved by the institutional review board prior to data collection.

Across semesters, the sample was consistently representative of the overall course demographics. The majority of students identified as female (69%), which is representative of the STEM course enrollment at the institution. Most students reported being in their third year (41%) and as a pre-professional or STEM major other than chemistry (90%). The samples were consistently representative of the racial and ethnic diversity at the university according to student reports (37% black or African American, 28% Asian, 15% white, of non-Hispanic origin, 12% Hispanic, 7% other). Approximately half of the students (53%) reported eligibility for a Pell Grant, which can be used as an approximate indicator of lower socioeconomic status. And approximately one-third (34%) identified as first-generation college students.

The rates for student participation compared to enrollment in participating course sections are shown in Table 5 for all surveys by semester. Participation rates in each instructors’ section varied. A quality control procedure was used to flag careless responses through items that directed students to select a particular answer to verify they were paying attention to the content of the statements. After the removal of students who did not select the indicated response for quality control items, the remaining participants’ data were analyzed.

Table 5: Student survey participation totals and course response rates out of section enrollment from Fall 2020 through Fall 2021.

<table>
<thead>
<tr>
<th>Semester</th>
<th>Timepoint</th>
<th>Total Participants</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2020</td>
<td>Pretest</td>
<td>N = 851</td>
<td>45.4%</td>
</tr>
<tr>
<td></td>
<td>Posttest</td>
<td>N = 593</td>
<td>30.5%</td>
</tr>
<tr>
<td>Spring 2021</td>
<td>Pretest</td>
<td>N = 595</td>
<td>30.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>----------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>Posttest</td>
<td>N = 513</td>
<td>30.8%</td>
<td></td>
</tr>
<tr>
<td>Fall 2021 Pretest</td>
<td>N = 514</td>
<td>46.5%</td>
<td></td>
</tr>
<tr>
<td>Posttest</td>
<td>N = 436</td>
<td>67.6%</td>
<td></td>
</tr>
</tbody>
</table>

### 3.2.2 Data Collection

#### 3.2.2.1 Survey Details

Surveys were administered online via Qualtrics© software through a link provided to students in their course management pages by their instructors. All pretest administrations were conducted within the first three weeks of the semester and posttest survey data was collected during the three weeks prior to the final exam. Surveys were administered over the course of three semesters, which included various iterations of the instrument. During the Fall 2020 posttest and Spring 2021 pretest administrations, two response-scale versions were directly compared by randomizing participants between two instrument versions (i.e., Version 2 and Version 3) using logic within the software.

#### 3.2.2.2 Measures

As the Chemistry Mindset Instrument (CheMI) was being developed, a variety of item wording versions and response-scales were trialed throughout the piloting and testing stages. The items and response-scales from each version can be found in Appendix B.1. The first version (Version 1) we implemented modeled Dweck’s original 8-item instrument very closely (Dweck, 1999). Version 1 used both entity and incremental subscales with a 6-point Likert response-scale, but item wording was changed from “intelligence” to “chemistry intelligence.” For example, the incremental item “I can always change my intelligence” was modified to “I can always change my chemistry intelligence.” Version 2 contained 14 items (7 incremental and 7 entity) describing
different aspects of chemistry intelligence, measured on a 6-point Likert scale. Version 3 used the same ability descriptions of chemistry intelligence as Version 2, but used a semantic differential response-scale with 6-points and was condensed to a unidimensional structure. The final modification in Version 4 was the use of a 10-point semantic differential scale. The final version of the CheMI (Version 4) contains 7 items, each incorporating a different aspect of chemistry intelligence as defined by students in an exploratory stage of this study (Santos et al., 2021). For example, one CheMI item states:

*My ability to apply chemistry knowledge is something...*

(I can’t change at all) 1 2 3 4 5 6 7 8 9 10 (I can change a lot)

Additional measures known to associate with mindset beliefs were also included in the surveys (Appendix B.2). Self-efficacy was measured using 6 out of the original 8 items from the self-efficacy subscale in the Motivated Strategies for Learning Questionnaire (Pintrich, 1991). Responses were reported using a 6-point Likert scale ranging from strongly disagree to strongly agree. Achievement Goals were measured using the 2x2 framework proposed by Elliot and McGregor (2001) and the 12 instrument items associated with it. The wording in these items was modified to reflect learning in a chemistry course by changing all references to “in this class” to “in chemistry.” The four subscales in this instrument each contain 3 items ranked on a 6-point Likert scale ranging from strongly disagree to strongly agree. The four dimensions are called Mastery-Approach, Mastery-Avoidance, Performance-Approach, and Performance-Avoidance.

### 3.2.2.3 Grades

Instructors from each participating section provided a spreadsheet with grades for all assignments and assessments throughout the semester. This set of scores was used to compute
formative and summative achievement scores for each student. Formative performance scores incorporated assignments such as homework or writing tasks as well as any assessments during the course of learning such as quizzes or clicker questions. There was variation in the types and grading weights of formative assignments used in each faculty member’s section; however, the overall category weight was consistent across sections. Summative performance scores incorporated all chapter exams and the final exam. To compare across sections with different instructors and grading schemes, all achievement scores were converted into $z$-scores for the sample distribution in the corresponding section prior to merging grades from multiple sections to account for any grading and assignment differences.

3.2.3 Cognitive Interviews

To investigate response-process validity between different versions of the chemistry mindset instrument as well as construct validity of the item wording, cognitive interviews were conducted with five students during Spring 2021. The students who participated in interviews represented the diversity of the overall sample when considering course level, year, gender, and racial and ethnic backgrounds. Interviews lasted approximately one hour and were conducted using a semi-structured protocol (Appendix B.3). Initially, students were presented with a sorting task that prompted them to create their own categories or groups using the chemistry intelligence definition terms from the instrument items (Figure 7). Students were then asked to assign names to their categories and explain why they sorted the terms the way they did. Following the sorting task, students were asked to restate instrument items in their own words to express their interpreted meaning. They were then asked to select a response and explain their reasoning behind a response choice. After responding to multiple versions of the same item, students were asked to compare the response scales in terms of how they felt when selecting a response. All
interviews were transcribed and analyzed for relevant perspectives on each type of response scale as well as interpretations of the items themselves.

### 3.2.4 Data Analysis

#### 3.2.4.1 Cognitive Interview Analysis

All interviews were audio recorded and transcribed. The transcriptions were used to identify relevant comments on response scales and item wording. Any descriptions of feelings associated with a particular response scale or item wording were noted. Likewise, descriptions of wording or format influences on their decision to select a particular response and differences between responses when presented with a different scale were noted. Students' explanations regarding the meaning of a particular value were considered useful for determining their response processes across different item versions.

#### 3.2.4.2 Distribution Normality and Descriptive Analysis

All descriptive analyses were conducted using SPSS© version 28.0 software. As no significant differences have been observed in chemistry mindset mean scores between general and organic chemistry subsamples across instrument version administrations, all analyses were conducted on the full sample data. To analyze the response distribution for items and instrument versions, histograms were generated, along with computation of mean, standard deviation, skewness, and kurtosis values. When comparing separate versions, scale means were computed across all items. Versions with more central mean values were interpreted to show a reduction of social desirability and/or reduction in the ceiling effect of the response scale. Central tendency was expected due to claims that approximately a third of students in K-12 populations report a fixed mindset, which should theoretically yield a response below the middle of the scale (Hong et al., 1999). Standard deviation was used to consider how students might allow some variability
in beliefs regarding different items. More variation could indicate more careful and thoughtful responses to each individual item. Skewness and kurtosis values closer to zero were desired to show improvement of distribution normality.

3.2.4.3 Factor structure

Confirmatory factor analysis (CFA) was used to investigate the data-model fit of finalized items as indicators of a single unidimensional chemistry mindset construct. Mplus® version 8 (Muthén and Muthén, 2017) was used to run all CFA models using maximum likelihood estimation methods. Standardized factor loadings were expected to be greater than .7 to indicate a strong relationship between the item and the latent factor (Kline, 2015). Criteria suggested by Hu and Bentler (1999) were used to evaluate data-model fit.

3.2.4.4 Reliability analysis

The single-administration reliability of response measurement across the items in each version was also considered. Although Cronbach’s alpha is most commonly reported, it assumes that factor loadings for all items are equal (Dunn et al., 2014; McDonald, 1981). As this was not the case in CFA results for any instrument version, McDonald’s omega provides a more appropriate estimate for single-administration reliability (McDonald, 2013). Interpretation of omega values is similar to alpha in that a value closer to 1 indicates more reliable measurements.

3.2.4.5 External validity analysis

To consider the validity of the instrument for detecting theoretically relevant relations between mindset and other variables (Blackwell et al., 2007; Dweck and Leggett, 1988; Hong et al., 1999), Pearson’s correlation values were calculated between scale mean scores on mindset
and the other measures collected. This allowed for correlation values to be computed with each of the four achievement goal dimensions, self-efficacy, and formative and summative achievement scores. The correlation values also indicate significant relationships at Bonferroni corrected $p$ levels. The size of the correlation was considered in relation to the strength of each relationship as indicated in the literature.

3.3 Results and Discussion

3.3.1 Wording Revisions: How can item wording be modified to produce improved student response-process and construct measurement?

3.3.1.1 Wording Changes

During the Fall 2020 pretest survey, the first iteration (Version 1) of the CheMI was tested. This version used “chemistry intelligence” wording in the 8 items presented to students. This initial wording modification was introduced after a prior data collection using the original Dweck mindset instrument yielded a response distribution heavily skewed toward growth mindset in both the incremental and entity subscales. Along with the updated wording, open-ended questions regarding the definition of several terms, including chemistry intelligence, were posed to students. The in-depth qualitative analysis of student responses regarding these definitions has previously been published (Santos et al. 2021). The results from the qualitative analysis were leveraged, during the development of Version 2, to substitute vague language (“chemistry intelligence”) and exchange them for more self-explanatory terms students commonly use to describe it (for example, “ability to apply chemistry knowledge”). Figure 1 presents the wording substitutions selected based on the previous study results (Santos et al., 2021) along with quotes from open-response items highlighting the meaning of each term.
Figure 7: Example student quotes that emphasize each aspect of chemistry intelligence included in instrument items.

3.3.1.2 Evidence from Cognitive Interviews

During cognitive interviews, students read and explained their responses to multiple versions of instrument items to support and further inform development decisions. When asked to respond to the 4 entity belief statements from Version 1 (Appendix B.1), Abraham said, “When I got to the third one, I was like, ‘Okay, this is just the same repeated question.’” He continued to say that he based his answers to the subsequent statements on his response to the first two. In comparison, when responding to items with the different cognitive abilities (Figure 1) inserted as definitions or aspects of chemistry intelligence (see Versions 2, 3, and 4 in Appendix A), Abraham took longer to respond to several items and varied his response value,
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depending on the ability mentioned in the statement. Elena responded quite differently to each
Version 1 statement because of differences in the meaning of descriptive words like “really” or
how absolute some statements seemed compared to others. The other students said the Version 1
Dweck-style items all meant the same thing as one another and thus responded the same across
all items. When responding to the cognitive ability items (Versions 2, 3, and 4), some variation
in their responses was observed due to differences in beliefs regarding their ability to improve
various aspects of chemistry intelligence.

When presented with a range of cognitive abilities relevant to learning chemistry (Figure
7), derived from prior results on definitions for “chemistry intelligence” (Santos et al., 2021),
students in interviews agreed that all were important factors to intelligence in chemistry. A
sorting task was introduced to the students, instructing them to categorize the 7 chemistry
intelligence terms in whatever way they believed they fit together. In the process of sorting these
terms, Benjamin viewed them as abilities that develop sequentially while learning chemistry and
that they all fall under “overall chemistry intelligence” as an umbrella term. During that same
task, Camille commented that overall chemistry intelligence can change depending on
improvements in the other six abilities. She stated that half of the abilities are less changeable
and the other half she labeled as the “growth part of chemistry.” Abraham said that the term
“overall chemistry intelligence” related to all six of the other cognitive abilities listed. When
reading a statement regarding the ability to change one’s problem-solving ability in chemistry,
Abraham responded by discussing the extent to which he believed chemistry intelligence can
change. When asked why he brought up chemistry intelligence, he stated,

“Problem-solving ability connects a good amount with me to chemistry intelligence because if you have the ability to sort of comprehend hard problems, you have a good understanding of
chemistry and you have a better chemistry intelligence than other students do. But not, it's not like all revolving around that. I guess it's like a certain aspect of your chemistry intelligence, which is a big, big thing. But I do think problem-solving is a good portion of chemistry intelligence.”

To support the shift from the Version 1 term “chemistry intelligence” to various definitions (Versions 2, 3, and 4), it is helpful to compare how students responded to the first and final item wordings in cognitive interviews. Students commented about the repetitive nature of the original Dweck-style items (Version 1). This insight, combined with their reported tendency to simply select the same response for all items in a category, suggests that students do not feel the need to consider each item individually, but rather aim to respond consistently. This trend was not observed when asked to respond to items containing the various cognitive abilities as definitions of chemistry intelligence (Versions 2, 3, and 4). For these items, it was clear that students spent more time considering the nuances in their own abilities and beliefs regarding those abilities, thus leading to more variation in answer selection and care in representing their views about each item. These findings support the response-process validity associated with final item wording of the CheMI.

The construct of intelligence is a complex trait and can be defined in many ways. This complexity also applies when referring to intelligence within the discipline of chemistry. Equal emphasis across a broad range of cognitive skills deemed important for intellectual success in chemistry courses was selected for this instrument to provide a multiplistic view of intelligence within the measure. Interviews revealed that when presented with all of these cognitive aspects of chemistry intelligence (Figure 1), students agreed that they are all important and fit within the umbrella of “chemistry intelligence.” When asked what they believe the term “overall chemistry intelligence” to mean, they tended to respond that it meant all of the previously discussed aspects
combined. These responses from students support the inclusion of each of these definitions within the construct of chemistry intelligence as presented in the instrument items. Additionally, cognitive interview findings that students understood the meaning of “overall chemistry intelligence” to refer to the other presented terms suggests that, within the context of the instrument, students are directed to interpret the broader term in light of all of the cognitive abilities referenced. These findings provide face validity evidence for student interpretations of the item wording as representing the same construct intended, chemistry intelligence. It can also be argued that any guesswork associated with interpreting a vague term such as “chemistry intelligence” is reduced within the context of the multiplistic definition as presented.

3.3.2 Response Scale Modifications: How can the instrument’s response-scale and dimensionality be modified to produce improved student response-process and construct measurement?

3.3.2.1 Response-Scale Changes

Version 2 of the CheMI contained 14 items with updated wording and retained the two-dimensional factor structure and Likert response-scale used in Version 1. This version was tested at the end of Fall 2020 in the posttest survey along with a randomly assigned comparison version. Version 3 incorporated a shift from a Likert scale to a semantic differential scale and was also piloted during the Fall 2020 posttest. The two versions were directly compared by random assignment of each student to one version or the other. Version 3 was created with the goal of removing the issue of entity versus incremental beliefs yielding inconsistent factor structure fit for the two-factor and one-factor models, as suggested by Luftenegger and Chen (2017). A semantic differential scale assumes a unidimensional structure yet allows students the freedom to choose a particular viewpoint or any intermediate value on the sliding scale. In
Version 3, the items were converted to a semantic differential scale format to allow students to choose a response that completes the statement to express their belief.

Substantial differences were observed between the Likert scale (Version 2) and semantic differential (Version 3) response distributions and were used to select the semantic differential scale for all future iterations. This decision was further supported through cognitive interview evidence. One last aspect was considered to improve the responses and measurement quality. A ceiling effect may be present for some students when using a 6-point scale, regardless of scale type. The fourth iteration (Version 4) of the instrument, therefore, contained a 10-point semantic differential scale. To test the efficacy of the expanded scale, Versions 3 and 4 were randomly assigned during the survey administered at the beginning of Spring 2021. More detail into the evidence and rationale behind each of the modification decisions made are presented in the following sections.

3.3.2.2 Evidence from Cognitive Interviews

When prompted to compare response scales during cognitive interviews, students did not have a preference for either the Likert or semantic differential, but they tended to say there was more freedom to express how they felt when reading each semantic differential item. Abraham said that he views the two versions as saying the same thing, but in a different way. Benjamin also expressed that the statements had the same meaning despite different formats, but he provided a more extreme response to the Likert scale version. When comparing the two, Benjamin stated that a 5 out of 6 seemed equivalent to strongly disagree on the Likert scale, despite acknowledging that 6 out of 6 technically should be the equivalent value. He also commented that there were differences in meaning between clauses such as “can’t change much” and “really can’t change.” In addition, he described the Likert scale as “more personal,” making
him feel more vulnerable in his response and more strongly about the statement. However, one
student, Desiree, felt it was easier to relate to the Likert-style statements rather than the
“arbitrary” numbering in the semantic differential version. Elena described that the semantic
differential makes her feel like she has to “lean” one direction or the other, while the Likert scale
is “just choosing from a list.” She did not know if one version is better or worse than the other.

Students tended to prefer the 10-point scale to the 6-point scale because it was more
familiar and provided more room for variation in their beliefs between items. For example,
Abraham said, “Because there's more numbers and there's like more ways to put my feeling into
the question. So, I feel like there's more numbers, like, I can better gauge how I feel about this
certain thing. And then the other one, because I feel like, when I say 5 (out of 6), it's more of a
vague answer than whenever I say 8 (out of 10).” Desiree also expressed that the 10-point scale
is more familiar when thinking of the way people often rate things out of 10. When responding to
a 10-point scale item, Elena said that she would choose 5, which aligned with the self-doubt she
had expressed previously in the interview. However, when reading the same item on a 6-point
scale, she stated that she would choose either a 4 or 5, which is much closer to a growth belief
response. She also stated that the 10-point scale is more precise for her to be able to express her
feeling on the statement, while the 6-point scale requires her to be more “decisive.” Camille said
that a higher value on the 6-point scale equates in her mind to a slightly smaller value on the 10-
point scale (5.95 out of 6 is the same to her as 9.5 out of 10). She also said, “So, it's something
that's…1 to 10 is easier to be visualized, at least in my mind, than a 1 through 6, even though,
like, in the end, it's still the same. I believe it can change a lot.” Benjamin commented on the
reason for selecting a higher value on the 1 to 6 scale relative to the 1 to 10 scale, “I guess when
it's like a smaller number range. It feels like it's like, more severe as the numbers go lower.”

Commenting on the precision of each scale, he added,

“I think the smaller scale kind of feels a little more limiting, like it almost over summarizes maybe. As for the 10-point scale, it might be able to be more specific. I mean, again, it's hard to say, because...I don't know what these – it's hard to say, like, what it even quantifies. I mean, because I'm just assuming, like, 6 and 10 are like infinity and then ones are nothings. Then it's like nothing to infinity.”

The cognitive interviews provided useful evidence to support decisions related to students’ response processes but did so most strongly for the transition from the 6- to 10-point semantic differential scale.

3.3.2.3 Descriptive Analyses

Across the four piloted versions of the chemistry mindset instrument, mean distributions shifted in response to changes to the item wording and scale modifications. The full item-level descriptives across the four instrument versions are provided in Appendix B.1. The changes to the distributions can be seen in Figure 8. The difference between sample distributions in the shift from Version 1 to Version 2 was not substantially improved, and in fact, led to a slightly increased incremental belief mean for the overall sample. The following semester, Versions 2 and 3 were directly compared. As seen in Figure 8c, the mean of the distribution for Version 3 is closer to the scale center relative to Versions 1 and 2, and more variation in item responses was observed. Lastly, Version 4 was noted as an improvement over Version 3 due to its increased central tendency and slightly larger standard deviation, suggesting that students may have responded more precisely to individual items, increasing variability across items, as observed in cognitive interviews.
Figure 8: Response distributions across four versions of the chemistry mindset instrument. a) Version 1: Scale means for the Likert-scale 4-item incremental subscale (Fall 2020 pretest). b) Version 2: Scale means for the Likert-scale 7-item incremental subscale (Fall 2020 posttest). c) Version 3: Scale means for the bipolar 6-point semantic differential 7-items (Spring 2021 pretest). d) Version 4: Scale means for the bipolar 10-point semantic differential 7-items (Spring 2021 pretest alternate).

In addition to the improved central tendency of the mean across the instrument iterations, skewness and kurtosis both decreased with the modifications. These values are shown in Table 6. The smallest values for both skewness and kurtosis were observed in the final version (Version 4) of the instrument containing the 10-point semantic differential scale and the seven items with defined abilities. These values indicate a slight negative skew favoring growth mindset beliefs and slightly taller than a perfectly normal curve, but both fall well within the range of an
acceptable normal distribution (Jones, 1969). The skew toward growth mindset has been observed consistently across versions and was most reduced in Version 4. This skew is most likely due to the social desirability of reporting growth mindset that has been noted in prior studies (Hong et al., 1999; Santos et al., 2021) and likely is impacted by the popularity of mindset instruction in K-12 learning contexts. The reduction in skew observed with instrument modification made here is likely due to a reduction in social desirability with combined wording and response-scale modifications.

**Table 6:** Skewness and kurtosis values for scale-mean response distributions across instrument versions.

<table>
<thead>
<tr>
<th>Instrument Version</th>
<th>Sample</th>
<th>Response Scale/Dimension</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version 1</td>
<td>Fall 2020 Pretest</td>
<td>Likert / Incremental</td>
<td>-.837</td>
<td>.761</td>
</tr>
<tr>
<td></td>
<td>N = 851</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall 2020 Posttest</td>
<td>Likert / Entity</td>
<td>.985</td>
<td>.928</td>
</tr>
<tr>
<td></td>
<td>N = 292</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version 2</td>
<td>Fall 2020 Posttest</td>
<td>Likert / Incremental</td>
<td>-.760</td>
<td>1.391</td>
</tr>
<tr>
<td></td>
<td>N = 292</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Likert / Entity</td>
<td>.768</td>
<td>.816</td>
</tr>
<tr>
<td>Version 3</td>
<td>Spring 2021 Pretest</td>
<td>6-Point Semantic Differential</td>
<td>-.202</td>
<td>.248</td>
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<tr>
<td></td>
<td>N = 289</td>
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<td></td>
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<tr>
<td>Version 4</td>
<td>Spring 2021 Pretest</td>
<td>10-Point Semantic Differential</td>
<td>-.188</td>
<td>.187</td>
</tr>
<tr>
<td></td>
<td>N = 306</td>
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*These values are ~50% of those reported in Table 1 due to the random version assignment utilized during these administrations.*

3.3.2.4 **Response Process Validity**

In comparing response-scale formats, students in cognitive interviews tended to select higher response values when using the Likert scale and said they had more freedom when using a
semantic differential because it did not express a positive or negative viewpoint. These two findings support the claim that social desirability or acquiescence bias may play a role in response patterns for Likert versions of mindset items (Luftenegger and Chen, 2017). The less personal use of numbers without expressing a particular view, as seen in the semantic differential items, seems to influence student opinions to a lesser degree. Although the values themselves do not state their meaning (are “arbitrary,” according to Desiree), they hold less value judgment and are left to the student to interpret. This provides evidence that Versions 3 and 4 reduce response-scale format influences on student responses, supporting response-process validity. These influences described in the cognitive interviews are likely a major cause of the skewed distributions observed in Versions 1 and 2.

Finally, consideration of response scale size was used to examine possible ceiling effects associated with limited value ranges. Upon initially responding to an item in cognitive interviews, students did not simply select the same scaled value between the 6-point and 10-point scale versions (e.g., 5 out of 6 and 8 out of 10). They first selected their response, then attempted to explain their response despite realizing it did not align with a direct conversion numerically. A less extreme value was selected when using the 10-point scale, indicating that having more scale options allowed them to feel more comfortable selecting a lower value. Students also said that a number lower than 5 on the 6-point scale seemed to be an “extreme” view to them, possibly indicating the effect of social desirability associations with a growth mindset leading to responses closer to the highest value. This finding aligns with the increased central tendency observed in Version 4 (10-point scale) relative to Version 3 (6-point scale), as shown in Figure 2. Combining these results, we have evidence that a 6-point scale yields a ceiling effect for many student responses, and that this effect is reduced with the expanded 10-point scale. Reduction of
a ceiling effect is beneficial in measurement to obtain better resolution of the distribution by shifting away from the scale edge and toward the center. Further support for the 10-point scale was provided in interview comments that a 1- to 10-point scale is more familiar and that it allowed students to be more precise in their responses, as evidence of response-process improvements. Considering all of this evidence led to the decision to retain a 10-point scale in the final CheMI version. The full final version (Version 4) of the CheMI is shown in Appendix B.1.

3.3.3 Validity Evidence for the CheMI Version 4

3.3.3.1 Internal Structure and Reliability

Confirmatory factor analysis (CFA) was used to test that the unidimensional structure of the chemistry mindset construct aligned with all 7 items developed to measure it in Version 4. The data-model fit of the 7-item single factor model has been determined to be good across both data collections (Table 7).

Table 7: Data-model fit statistics across data collection timepoints using Version 4. Bolded values indicate results were good based on recommendations from Hu and Bentler (1999).

<table>
<thead>
<tr>
<th>Data Collection</th>
<th>N</th>
<th>(X^2) ((df, p))</th>
<th>RMSEA (Confidence Interval)</th>
<th>CFI</th>
<th>SRMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2021 pretest</td>
<td>514</td>
<td>29.34 ((14, .009))</td>
<td>.046 (.022 to .070)</td>
<td>.994</td>
<td>.014</td>
</tr>
<tr>
<td>Fall 2021 posttest</td>
<td>435</td>
<td>28.90 ((14, .011))</td>
<td>.049 (.023 to .075)</td>
<td>.993</td>
<td>.015</td>
</tr>
</tbody>
</table>

Additionally, all items yielded high standardized factor loadings (all loadings \(\geq .727\)), indicating a strong relation between each and the overall latent construct. Figure 9 presents the CheMI Fall 2021 pretest data fit to a CFA model with standardized factor loadings. Similar CFA results were obtained in the posttest administration of the instrument in terms of the strengths of
all factor loadings. To determine the single-administration reliability of responses across the 7 CheMI items, McDonald’s omega (ω) values were obtained for both the pre- and posttest survey administrations. Both time points yielded excellent reliability (ω_{pretest} = .929, ω_{posttest} = .934).

*Figure 9*: CFA model of Fall 2021 pretest Version 4 with standardized factor loadings. Item wordings can be found in Appendix B.1.

In addition to the cognitive interview evidence previously discussed that supports the construct alignment of all 7 items as measuring mindset beliefs about chemistry intelligence, CFA data-model fit and factor loadings corroborate the construct validity. All items strongly correspond to a unidimensional chemistry mindset construct, with no apparent subfactors. Additionally, students respond reliably across all items. As all 7 cognitive aspects appear to contribute to the overall construct according to multiple data sources, all 7 items were retained in the final version of the CheMI.
3.3.3.2 Correlational Analysis

Correlations between data from the final iteration (Version 4) of the CheMI and other measures in the pre- and posttest administrations during Fall 2021 were determined to provide evidence of external validity. These values are shown in Table 8. Bonferroni corrections were applied to all p-values due to the use of multiple correlations.

Self-efficacy yielded the largest external correlations with CheMI scores at both the pretest ($r = .447, p < .002$) and the posttest ($r = .475, p < .002$). This indicates that students with higher reported self-efficacy in their chemistry courses were more likely to report that they can improve aspects of their chemistry intelligence, aligning with findings from prior studies that these two constructs are positively related (Bedford, 2017; Komarraju and Nadler, 2013; Lytle and Shin, 2020). Likewise, mastery-approach goals were observed to correlate with both pre- ($r = .337, p < .002$) and posttest chemistry mindset ($r = .218, p < .002$), suggesting that students focused on mastery are more inclined toward beliefs associated with improving their chemistry intelligence (Dweck and Leggett, 1988). A negative correlation was observed for mastery-avoidance goals and chemistry mindset (pre: ($r = -.139, p < .002$); post: $r = -.226, p < .002$).

Although the mastery-avoidance dimension of achievement goals was not a part of Dweck’s original theoretical framework, the negative correlation with mindset can be expected because students’ fears regarding their inability to learn the content align well with beliefs that chemistry intelligence cannot improve. No significant correlations were observed between chemistry mindset and either of the performance goal orientations. These results aligned well with previous findings that mindset more strongly relates to mastery-based achievement goals relative to performance-based goals (Burnette et al., 2013; Dinger and Dickhäuser, 2013; Karlen et al., 2019; Leondari and Gialamas, 2002). It should be noted here that a ceiling effect was observed.
for two of the four achievement goal dimensions: mastery-approach (significantly correlated with chemistry mindset) and performance-avoidance (not significant correlated with chemistry mindset), which has been observed in another study of achievement goals in chemistry (Lewis, 2018). Ceiling effects may limit the interpretability of the correlations observed; however, the expected relationships with chemistry mindset were observed, reducing this concern. Nevertheless, this may indicate a need for an improved achievement goal orientation measure for chemistry-specific contexts.

The pre- and posttest mindset measures also correlated significantly with both measures of course achievement, formative (pre: \( r = .168, p < .005 \); post: \( r = .293, p < .005 \)) and summative scores (pre: \( r = .228, p < .005 \); post: \( r = .331, p < .005 \)). As inconsistent results or small effect sizes have been observed in correlating mindset and achievement for undergraduate students across numerous studies (Costa and Faria, 2018; Sisk et al., 2018), these findings were positive evidence of an improved mindset measure for chemistry contexts. Others have observed that including mediating variables between mindset and achievement yield significant predictive relationships (Macakova and Wood, 2020); however, lack of sensitivity of the mindset measure itself may further reduce direct predictive power, supporting that this instrument has increased sensitivity to differences in chemistry mindset beliefs.

Table 8: Pearson correlation values between chemistry mindset and other variables during Fall 2021.

<table>
<thead>
<tr>
<th>Pretest</th>
<th>N = 421</th>
<th>Posttest Matched Data, N = 209</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1 Chemistry Mindset</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2 Performance Approach</td>
<td>0.06</td>
<td>1</td>
</tr>
<tr>
<td>3 Performance Avoidance</td>
<td>0.011</td>
<td>.187**</td>
</tr>
<tr>
<td>4 Mastery Approach</td>
<td>.337**</td>
<td>.124*</td>
</tr>
<tr>
<td>5 Mastery Avoidance</td>
<td>-.139**</td>
<td>-0.094</td>
</tr>
</tbody>
</table>
Examining the correlations between the CheMI measurements and other variables (Table 4) addresses one final consideration of validity, namely external validity. Convergent validity evidence is provided through the strength and sign of correlations with self-efficacy, mastery-based achievement goals, and course achievement according to the mindset meaning system (Dweck, 1999, Dweck and Legget, 1988). Literature reports consistent alignment of mindset and mastery-based achievement goals (Burnette et al., 2013) and a few studies have reported alignment with self-efficacy (Bedford, 2017; Komaraju and Nadler, 2013; Lytle and Shin, 2020). Theoretically, mindset beliefs in a domain should predict achievement (Hong et al., 1999; Blackwell et al., 2007), which is the primary incentive for conducting interventions. Yet, inconsistent findings in other studies with similar populations have brought these advantages into question for this academic stage (Sisk et al., 2018). We argue that inconsistent findings may be a symptom of poor measurement quality for the target population’s mindset construct, especially if the domain-specificity of the construct has increased relevance for adult students. Divergent validity evidence was obtained by noting the near-absent correlations of mindset with performance-based achievement goals. Although a fixed mindset was originally found to relate to performance goals for young students (Dweck and Leggett, 1988), the increasing emphasis on performance as students progress toward high-stakes admissions processes is a possible cause for
the lack of relationship between variables commonly reported in studies with secondary and tertiary students (Sisk et al., 2018).

Finally, several mindset-related studies in undergraduate STEM contexts have reported that domain-specific beliefs exhibit downward trajectories over time, indicating that students become more fixed in their beliefs (Dai and Cromley, 2014; Scott and Ghinea, 2014). However, the reported shifts in mindset are not large over a shorter time-scale such as one semester. This means that mindset beliefs at pre- and post-semester collection times should correlate strongly with one another. In our sample, pre- and post-chemistry mindset yielded the strongest correlation between variables (Table 8). This result should be interpreted with caution as many students were excluded from this correlation due to lack of participation at both timepoints (N = 209 for matched data). It does appear that some changes in students' beliefs did occur, as evidenced by the .630 correlation value. Students likely use their prior history with chemistry performance as evidence in the formation of their mindset beliefs, those observed when they begin the course. However, factors such as challenges, the classroom environment, and performance feedback in the current course may cause fluctuations and minor shifts in mindset throughout the semester. Although some students may have changed their views during the course as a response to their experiences and performance feedback (Limeri et al., 2020b), a single semester is a short time span for substantial changes in views.

3.4 Conclusion

The Chemistry Mindset Instrument (CheMI) has been developed and shown to produce data that is valid and reliable according to multiple sources of evidence. The development and testing of this instrument was conducted with general and organic chemistry course populations. The instrument development process involved exploring literature suggestions for alternate response
scales, open-ended responses to determine relevant definitions of chemistry intelligence for item wording modifications, cognitive interviews to determine response-process and face validity, repeated distribution and analysis of each iteration, and confirmatory factor analysis to verify appropriate fit of the data to the intended model for construct validity. Additionally, external validity evidence for CheMI data was provided through significant correlations with relevant variables such as mastery-approach goals, self-efficacy, and both summative and formative achievement scores. The CheMI was evaluated across two timepoints (i.e., early and late semester) to show that it yields data with reproducible psychometric properties and that reported values correlate strongly with one another despite the passage of time. Students’ post-semester chemistry mindset exhibited a stronger correlation with achievement variables, suggesting possible adjustment of beliefs during the semester to align with performance feedback in line with previous findings (Limeri et al., 2020b). The 7-item CheMI can be used to efficiently determine undergraduate students’ chemistry mindset.
3.4.1 Implications for Research and Teaching

Now that a chemistry-specific mindset measure has been developed and shown to produce valid and reliable data, it can be utilized to provide an understanding of the impact discipline-specific beliefs have on other relevant affective constructs. The length and simplicity of the CheMI is ideal for continued studies on the complex motivational pathways involved in student persistence and success in introductory college courses. Additionally, classroom interventions targeted at altering student mindset in chemistry or incorporating research-based teaching strategies can be monitored in terms of changes to chemistry-specific mindset beliefs. Students’ native chemistry mindset belief trajectories in the absence of intervention can also be more adequately examined through longitudinal studies over the introductory course sequences. The CheMI can be useful to researchers, but also to chemistry instructors who wish to identify students who may be at risk for using maladaptive learning strategies as a function of their beliefs (Burnette et al., 2013; Hong et al., 1999). Once students are identified as having fixed mindset beliefs about chemistry, they can be supported with instruction about helpful study strategies, such as metacognitive strategies (Frey et al., 2020), mindset belief intervention assignments (Fink et al., 2018), and encouraged to invest effort and seek assistance. Instructors may also wish to observe how changes to their teaching can impact student beliefs about learning chemistry. Studies have reported that instructor mindset can have a large impact on student outcomes and represent one of the factors that influence students’ own mindset beliefs within that context (Canning et al., 2019; LaCosse et al., 2020; Muenks et al., 2020). Instructors may wish to observe how infusing mindset-related messaging impacts student beliefs about improving chemistry intelligence in their classes.
3.4.2 Limitations

Correlational analyses were used as evidence of external validity in this study, but this technique does not allow for testing hypothesized causality or mediation effects of variables involved. Testing the mindset meaning system was not the focus of the work presented here, but rather verification that chemistry mindset measurements align with external variables as indicated in the literature. Future studies can examine the causal relationships among external variables such as motivational and behavioral measures using the CheMI through path modeling techniques. This can provide additional validity support by considering how data collected with this instrument fits within the hypothesized mindset meaning system. Additionally, this study only examined the CheMI’s psychometric functioning with a student population from one institution, limiting the generalizability of the instrument’s usage. To address this, chemistry mindset should be examined with students from other institutions and nationalities. During the development and evaluation of CheMI thus far, evidence has only been analyzed in aggregate. Therefore, future studies wishing to compare CheMI data across groups are encouraged to determine measurement invariance (Rocabado et al., 2020). To date, this instrument has not been tested with students enrolled in courses other than general and organic chemistry, therefore validity evidence only applies to these introductory level courses. To expand its usage with additional populations, data collection and analysis with higher-level chemistry courses can be used to provide such validity evidence.

Variation in course participation rates was observed; however, the sample was representative of typical STEM course enrollment demographics at the institution across all categories. The different course sections were given different assignments and exams, thus raw average performance scores for formative and summative assessment may represent very
different difficulty levels or assessment types. To mitigate this issue, z-scores for each course section were used to be more directly comparable relative to the performance distribution in each section. Additionally, all other measures were collected as self-report values, and thus may contain variation in interpretation and biases.

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4 CHARACTERIZING STUDENT EXPERIENCES WITH CHALLENGE

4.1 Introduction

Introductory chemistry courses can be classified as gateway courses because they typically have large enrollments, high DFW rates, and are a prerequisite for many professional programs (Harris et al., 2020; Koch, 2017; Tai et al., 2005). Courses such as these have a high probability of presenting students with academic challenges, which is corroborated by the high failure rates across institutions (Horowitz et al., 2013; McKinney et al., 2019; Popejoy & Asala, 2013). Depending on the nature of the challenge a student is experiencing, the individual might need to decide between persevering in efforts to succeed despite the challenge or giving up in the face of it. Mindset research focuses on individual beliefs as factors that drive a student to pursue one of these behaviors (Burnette et al., 2013; Doron et al., 2009; Karlen et al., 2019; Lou & Noels, 2016; Molden & Dweck, 2006). The concept of growth mindset is particularly relevant in challenging contexts, such as difficult college science courses, as an explanatory factor for persistent behaviors and ultimately success in science majors (Henry et al., 2019).

Mindset is described as a context-dependent belief system that can be influenced by a variety of factors (Little et al. 2016), including perceived instructor mindset and cultural STEM stereotypes about who can achieve in these domains (Canning et al., 2019; Muenks et al., 2020). Cultural beliefs perpetuated about STEM fields, and specifically chemistry, may influence students (Sun, 2018) to believe that these subjects are suited to those with “natural” science and mathematical abilities (Lytle & Shin, 2020; van Aalderen-Smeets & van der Molen, 2018) and evaluate their own abilities relative to their observations of others. One's beliefs about their own ability to improve intelligence in chemistry may differ from that of biology, or even general intelligence (Dai & Cromley, 2014; Gunderson et al., 2017; Scott & Ghinea, 2014). These beliefs
may also be heavily influenced by experiences with challenge in chemistry classes and the interpretations held about the implications of challenge in chemistry (Henry et al., 2019).

If no challenge presents itself, mindset may be less relevant, other than theoretical links to goals of performing well over deep learning (Burnette et al., 2013; Hong et al., 1999). When experiencing no challenge, students do not require significant persistence to succeed, thus there are lower stakes to behavioral decisions. Challenges invoke two main responses with disparate results: persistence toward goal achievement and avoidance of failure (Hong et al., 1999; Molden & Dweck, 2006). The type of challenge a student perceives may pose a threat to the self, revealing one’s low ability, or simply signal a need for effort (Burnette et al., 2013). Additionally, different challenges may seem attainable to overcome or as insurmountable obstacles. Chemistry and other STEM courses may pose different and more substantial obstacles for students compared to other subject areas. In order to understand persistent and avoidant behaviors in chemistry, it is important to characterize the challenges commonly encountered by students in these courses and their implications.

4.1.1 Theoretical Framework

Implicit theories of intelligence are the beliefs individuals hold about the ability to improve one’s intelligence (incremental theory) and its relative stability (entity theory) and are commonly referred to as mindset (Dweck & Leggett, 1988). Individuals can hold various levels of each of these beliefs simultaneously and these levels can change with context and over time (Dweck et al., 1995; Little et al. 2016; van Aalderen-Smeets & van der Molen, 2018). A student reporting a high incremental theory of intelligence and low entity theory using traditional mindset measures is generally labeled as a student with a growth mindset (Hong et al., 1999). Conversely, a low incremental theory and high entity theory respondent is considered to have a fixed mindset. As
these two beliefs can change with the domain, context, and over time, it is important to understand the dynamic motivational implications of those beliefs.

Mindset theory encompasses a meaning-system for interaction of challenges and beliefs about ability that predicts behavioral patterns (Hong et al., 1999; Molden & Dweck, 2006). When operating out of a growth mindset, a student focuses more on improvement, effort, and the process of learning (Burnette et al., 2013; Dweck & Leggett, 1988). The opposite mindset leads to focus on performing, demonstration of ability, and the achievement outcome as a measurement of intelligence. These two opposed ways of viewing academics yield disparities in the way challenges are interpreted (Hong et al., 1999). Challenges can be viewed either as a threat or as a call to improve. How one interprets the challenge is what determines the responsive actions and affect (Burnette et al., 2013; Molden & Dweck, 2006).

Theoretically, an individual who encounters a challenge while operating out of growth (or incremental) beliefs would make effort attributions for success and failure, display persistent help-seeking behaviors, and would seek to learn and improve (Burnette et al., 2013; Dweck & Leggett, 1988). These behaviors are characterized as mastery responses to challenge and yield higher likelihood of success outcomes (Dweck et al., 1995). An entity belief would lead one to interpret challenge as a sign of threat to his or her reputation or self-esteem, thus defense mechanisms would be implemented. These defensive behaviors are a response to attributing failure to low ability, leading to avoidance of further evaluation of ability. This can mean procrastination (Howell & Buro, 2009) or task avoidance so that low effort is the attributable cause for failure (Burnette et al., 2013). These maladaptive behaviors are characterized as helpless responses to challenge and likely result in relatively poor outcomes.
4.1.2 Challenges in STEM and relations to mindset and achievement

Challenges in STEM courses are theorized to moderate the relationship between mindset and achievement outcomes. Burnette et al. (2013) termed these challenges as “ego threats,” a form of failure feedback indicative of ability. In their meta-analysis of the mindset literature, they observed a moderation effect of ego threat between mindset beliefs and self-regulatory behaviors. Horowitz et al. (2013) observed that help-seeking behaviors in organic chemistry courses, such as attending office hours or problem-solving help sessions, serves as a predictor for exam performance along with prerequisite course grade. The authors also noted that many students do not seek help when facing challenges, which suggests a need for understanding why certain individuals would be more help-avoidant than others. Mindset is a possible factor that influences these behavioral decisions, impacting achievement outcomes.

Dai et al. (2014) found that initial biology ability mindset and changes to those beliefs throughout gateway biology courses predicted STEM major dropout. Mindset and course grades both mediated the relationship between prior knowledge/cognition and STEM dropout, suggesting that challenges and beliefs are both relevant to retention. Dropout from a STEM major may be an avoidant response to what a student perceives to be an insurmountable challenge. Grant and Dweck (2003) found that the types of goals students set within the challenging context of a general chemistry course had an impact on study strategies and course grades. Learning goals are associated with growth mindset and were observed to predict deeper processing of course material, leading to improved course grades. Additionally, Limeri et al. (2020) observed that students who faced struggles throughout an organic chemistry course had more fixed mindsets relative to their peers and experienced an increase in fixed beliefs throughout the semester. The authors argued that the performance feedback these students perceived as failure negatively influenced their
mindset belief trajectories. These studies point to the moderating link of challenge between mindset and behaviors, which is likely to play a role in challenging STEM courses.

A research area lacking attention in STEM college-level contexts is the characterization of the types of challenges and their related outcomes. The mindset literature does not explicitly define areas of challenge in STEM domains. One study by Little et al. (2019) examined physics students’ descriptions of their experiences and found evidence for challenges and responses aligning with mindset theory. This study also suggested that challenges may be more complex at the university STEM course level due to identity labels, peer and instructor interactions, and context-dependence of beliefs, which are not accounted for in the mindset literature. The authors called for more extensive theoretical development of mindset in conjunction with challenges for physics contexts, which is likely to be necessary for other college-level STEM subjects as well (Little et al., 2019). There is the potential for students to encounter unique challenges in undergraduate chemistry courses and implement responses that align with their perceptions of these new difficulties.

4.2 Methods

4.2.1 Participants

Surveys were administered in introductory chemistry courses (first and second semesters of general and organic chemistry) at a large, diverse, public research institution in the southeastern US in December 2020 and December 2021. These time points represent the end of the Fall 2020 and Fall 2021 semesters, so that students were able to reflect on their challenge experiences throughout the course and their relative success (or lack thereof) in overcoming them. During the Fall 2020 semester, all courses at the institution were offered virtually due to the COVID-19 pandemic and instructors used either synchronous or asynchronous online course designs. The Fall
2021 semester marked the return of classes at the institution to mostly in-person meetings. The survey was administered to sections upon the cooperation of the instructor and on a volunteer basis to the students, with a small incentive of a couple extra-credit points for their course. Those who did not wish to participate were offered an alternative assignment for equal credit or were allowed to complete the survey but indicate non-consent to utilize their data. Surveys were administered online using QualtricsXM© software and participants who did not consent were removed. Additionally, students were removed who failed to respond appropriately to directed responses in quality control items (e.g. “This is a quality control item, please select 4 “Somewhat Disagree”.”).

Overall, the largest categories of students participating in the survey across semesters were those who identified as female (64.9%), Black or African American (33.2%), sophomore (31.8%), and reported having a non-chemistry STEM or pre-professional major (87.4%). A large percentage of the sample came from low socioeconomic backgrounds (as indicated by Pell Grant eligibility, 49.3%) and were first-generation college students (30.8%). The sample was highly diverse academically and demographically, reflective of institutional diversity. In Fall 2020, 65% of participants were general chemistry students (n = 473) and 35% were organic chemistry students (n = 254). In Fall 2021, 28% of participants were general chemistry students (n = 126) and 72% were organic chemistry students (n = 320). The breakdown of these student characteristics is provided in Table 9. A total of 1,375 students participated in the survey and, after removal of non-consenting or careless respondents (according to aforementioned quality controls), 1,135 participants’ data remained for analysis (Fall 2020 N = 727 with no collection of grade data and Fall 2021 N = 446 participants with grade data available for 408).

<table>
<thead>
<tr>
<th>Table 9: Survey respondent student characteristics.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>N = 806</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Course level participation rate</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>General chemistry I</td>
<td>14.7 %</td>
<td>18.1 %</td>
</tr>
<tr>
<td>General chemistry II</td>
<td>63.9 %</td>
<td>26.5 %</td>
</tr>
<tr>
<td>Organic chemistry I</td>
<td>45.5 %</td>
<td>44.1 %</td>
</tr>
<tr>
<td>Organic chemistry II</td>
<td>18.2 %</td>
<td>28.6 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Major</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry/biochemistry</td>
<td>8.1 %</td>
<td>7.2 %</td>
</tr>
<tr>
<td>Other STEM/Pre-professional</td>
<td>85.3 %</td>
<td>91.3 %</td>
</tr>
<tr>
<td>Non-STEM</td>
<td>6.6 %</td>
<td>1.6 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Race/ethnicity</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black/African American</td>
<td>31.5 %</td>
<td>36.3 %</td>
</tr>
<tr>
<td>Asian</td>
<td>28.0 %</td>
<td>28.0 %</td>
</tr>
<tr>
<td>White (non-Hispanic origin)</td>
<td>16.6 %</td>
<td>14.3 %</td>
</tr>
<tr>
<td>Hispanic</td>
<td>9.6 %</td>
<td>11.7 %</td>
</tr>
<tr>
<td>Other</td>
<td>4.3 %</td>
<td>7.2 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pell Grant eligibility</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47.6 %</td>
<td>52.2 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First-generation status</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29.2 %</td>
<td>33.6 %</td>
</tr>
</tbody>
</table>

### 4.2.2 Data Collection

During Fall 2020, investigating challenges within chemistry courses was primarily inductive and exploratory. For this purpose, at the beginning of the survey, we asked students two preliminary questions to categorize them into challenge level groups based on perceptions of success or failure, then followed up with specific open-ended questions targeted toward each challenge group. The initial questions, adapted from a study by Limeri et al. (2020), asked students, “Did you experience challenges or struggles in this chemistry course?” and “Did you overcome these challenges or struggles?” Both questions were dichotomous “yes” or “no” questions and resulted in categories of: “No Challenge” if they indicated they did not face any challenges, “Overcame Challenge” if they indicated that they faced challenges and they overcame them, and “Didn’t Overcome Challenge” if they indicated that their challenges were not overcome. The
survey logic was set to direct each category of participants toward a different open-ended prompt to specifically understand their perspectives.

The “No Challenge” responses will not be analyzed here and represent a small subset of the students (n = 48). These students were not asked about challenges, rather about where they believe chemistry intelligence comes from. Of greater interest were the responses from the “Overcame Challenge” group (n = 337) to the prompt, “Please describe these experiences with challenge during this semester of chemistry briefly and what specifically you did to overcome them.” as well as the responses from the “Didn’t Overcome Challenge” group (n = 201) who were prompted, “Please describe these experiences with challenge during this semester of chemistry briefly and why you think you did not overcome them.” Students typically responded with one to four sentences depending on how much information they were willing to provide about their experiences.

The Fall 2021 end-of-semester survey was designed to qualitatively build on the findings from the open-responses analyzed the previous year. Students, again, responded to the two sorting questions to define the challenge level groups. After, they were directed to respond to multiple-choice prompts regarding the type of challenge faced (discussed in Study Part 2) and how they sought help to overcome them. The multiple-choice prompts were created using the themes uncovered in the previous year (Table 10). An “other” option was provided, but written-in responses fell under previously defined coding categories and were reassigned to the appropriate challenge category. These items provided answer choices that reflected the types of challenges and help-seeking strategies students described using to overcome difficulties in the course. Students also reported their perceived frequency of help-seeking in chemistry during the semester (never, once, once per unit, once per week, or multiple times per week). Aligning with the Fall 2020
sample, a comparable proportion of students self-sorted into the “No Challenge” group (n = 42 total, 39 with grades), the “Overcame Challenge” group (n = 235 total, 211 with grades), and the “Didn’t Overcome Challenge” group (n = 168 total, 158 with grades).

*Table 10*: Multiple choice prompts used in Fall 2021 developed from “Overcame” group coding themes.

<table>
<thead>
<tr>
<th>Prompts</th>
<th>Answer selections</th>
<th>Definitions provided to students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Please select the primary challenge you faced in chemistry this semester.</td>
<td>Time Management</td>
<td>turning things in on time, procrastination, balancing work and schedule, keeping up with content</td>
</tr>
<tr>
<td>2. Please select the second greatest challenge you faced in chemistry this semester.</td>
<td>Motivation</td>
<td>focus, distractions, low importance</td>
</tr>
<tr>
<td></td>
<td>Course Content</td>
<td>difficulty of the material, large amount of content, lack of understanding</td>
</tr>
<tr>
<td></td>
<td>Lack of Resources</td>
<td>schedule conflicts, poor communication, no access</td>
</tr>
<tr>
<td></td>
<td>Outside Circumstances</td>
<td>health, financial, family, etc.</td>
</tr>
<tr>
<td></td>
<td>Teaching Strategies</td>
<td>poor explanations, bad video quality, lack of feedback</td>
</tr>
<tr>
<td></td>
<td>Weak Foundation</td>
<td>previous chemistry courses, lack of preparation, weak math skills</td>
</tr>
<tr>
<td></td>
<td>Chemistry Ability</td>
<td>chemistry is difficult for me, not my strong suit, doesn’t come naturally to me</td>
</tr>
</tbody>
</table>

<p>| No Challenges | 1. What was the most helpful strategy for improvement that you used in chemistry this semester? | Attending Office Hours | asking for help from the instructor |
| | 2. What was the second most helpful strategy for improvement that you used in chemistry this semester? | Tutoring | attending supplemental instruction sessions or tutoring |
| | | Devoting Time | studying more |</p>
<table>
<thead>
<tr>
<th>Changing Strategies</th>
<th>using new study strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer Learning</td>
<td>study group or partner</td>
</tr>
<tr>
<td>Outside Resources</td>
<td>YouTube videos, internet, etc.</td>
</tr>
<tr>
<td>Schedule</td>
<td>creating a schedule or reminders for time management</td>
</tr>
</tbody>
</table>

### 4.2.2.1 Measures and Grades

Currently, published mindset instruments are domain-general or would require a justified modification to use within the chemistry context. Since the intent was to compare challenges in chemistry to chemistry-specific mindset, we utilized our newly developed measure. Students’ chemistry mindset beliefs were measured using the 7-item Chemistry Mindset Instrument (CheMI, Santos et al., 2022).

An example CheMI item is provided below:

*My ability to apply chemistry knowledge is something...*

(I can’t change at all) 1 2 3 4 5 6 7 8 9 10 (I can change a lot)

Responses were measured using a 10-point semantic differential scale across a range of different abilities specific to studying chemistry. An average CheMI score was computed for each student for use in all analyses. The analysis of the CheMI includes single-administration reliability (McDonald’s Omega; 0.934), confirmatory factor analysis of the single-factor structure (factor loadings of 0.727 and above for each item). The CheMI also showed statistically
significant correlations with formative and summative grades and self-efficacy. Cognitive interviews supported the development process of the instrument. All of the items in the CheMI, along with the results of confirmatory factor analysis (CFA) and fit indices are provided in the supplemental documents. These results were used as evidence that the chemistry mindset data produced by the instrument displayed adequate validity and reliability.

Gradebooks were obtained from instructors detailing all assignments, quizzes, and exams. Scores for summative performance were computed by averaging students’ scores across all exams. Formative performance scores were computed by averaging students’ grades across all homeworks, assignments, clicker questions, and quizzes, depending on the course design used by the instructor. In order to directly compare across different classes, both performance scores were converted to z-scores so that the mean and standard deviation within that instructor’s course were accounted for. Both performance measures were then matched to the survey data set for analysis.

4.2.3 Data Analysis

The open-ended responses from students regarding challenges and strategies to overcome them were analyzed using an inductive content analysis approach (Hsieh & Shannon, 2005). The responses were divided into the challenge groups prior to analysis. Two researchers independently coded identical samples of 40 responses at a time using Nvivo12®. Codebook development occurred in an iterative fashion. Initially, the researchers allowed the codes to originate completely from the data. Over time, through analysis of further data, the created codes were refined to develop themes, added to when necessary, and applied to each subsequent sample. This process eventually resulted in data saturation with no new codes arising from new data samples (Guest et
al., 2020). Once data saturation was reached, a group of four researchers coded identical samples of 50 responses using the developed codebook until inter-rater reliability was established (Cohen’s \( \kappa = .79 \)). The established reliability and saturation allowed for the completed codebook to be used in a deductive analysis of a larger sample to identify the most prevalent codes in each group, as well as determine which were more related to mindset theory. The larger sample consisted of 50% of the responses provided from each group (335 total) and was sampled by an alternating selection process, which can be considered semi-random.

After coding the larger sample, the multiple-choice items provided in Table 10 were created using the common themes for overcoming challenges. The data collected using these multiple-choice items in Fall 2021 was analyzed through both qualitative categorization and quantitative comparison methods. The frequencies of each help-seeking strategies were compared across the three challenge-level groups using Bonferroni corrected z-tests (Curtin & Schulz, 1998) to determine significant differences in strategy usage. The normality of the chemistry mindset and performance variable distributions was examined using Q-Q plots, providing evidence that these variables met the assumption of normality. Combined with the sufficiently large sample size for normality to be likely, parametric analyses were conducted. One-way ANOVA tests were used to determine the significance of specific challenges and challenge level groups on students’ chemistry mindset and performance scores. Performance scores were converted from z-scores to percentiles using the normal distribution probability curve and compared across challenge level groups to determine whether perceptions of challenge and success resulted in differences in performance.

The final analysis involved using the challenge category “Chemistry Ability” as a predictor for performance and chemistry mindset, as it was identified in this study as potentially having the
strongest relation to fixed mindset beliefs. A dichotomous variable was created to differentiate between students who selected “Chemistry Ability” as one of their main challenges and those who selected only other challenge types. A between-group analysis was conducted to compare performance and mindset scores of the participants who selected “Chemistry Ability” as their challenge to the scores of those with other challenges.

4.3 Study Part 1: Qualitative Analysis of Challenges and Overcoming

The qualitative work presented here is an exploratory portion within the context of a larger study on mindset influences in the undergraduate chemistry course experience for the purpose of creating a domain-specific mindset instrument. The overall study utilizes mixed-methods; however, understanding the mechanisms underlying student experiences with challenge calls for a more qualitative approach. A goal of this exploratory phase is to understand mindset-related behaviors (e.g. mastery or helpless responses) elicited in a chemistry course context upon encountering challenges. It is also beneficial to the larger study to examine how student beliefs about their chemistry intelligence (mindset) may influence their perceptions of success and the interpretations they hold regarding their challenges. This study was approved by the Institutional Review Board prior to data collection.

4.3.1 Research Questions

This study aims to characterize and identify the key challenges students face in introductory chemistry courses. It is important to understand the nature of the challenges themselves in connection with the perception of success or failure in overcoming them. In addition, we investigated the ways in which students positively responded to these challenges in order to overcome them. The research questions of this study are as follows:
RQ1) What challenge themes emerge from open-response descriptions of challenges students face during chemistry courses?

RQ2) How do students respond to challenges in chemistry courses?

4.4 Results and Discussion

4.4.1 Challenge Themes

To address the first research question presented in this study, the types of challenges students faced in chemistry were examined in their open-responses and were found to fall under three main themes: Life, Self, and Academic. Students’ descriptions yielded a variety of perceived challenges. After code development and refinement, categories for challenge themes were defined and are listed in Table 11 with descriptions. Online learning was in effect during the open-response data collection due to the COVID-19 pandemic. Many students included the distance learning aspect as one of their challenges, even when describing additional challenges. This challenge was coded as “Remote Learning” and was one of the most prevalent codes in the data. The circumstances of the course likely influenced the number and degree of challenges, as well as their ability to overcome them due to lack of preparation and familiarity with the technologies used. The pandemic also produced challenges for many students under the “Outside Circumstances” and “Health” code categories (financial circumstances, family issues, work responsibilities, distractions at home, access to resources, and motivation.) These influences on the data cannot be ignored as they are substantial, however, to understand likely challenges during typical learning circumstances, the other themes will be highlighted throughout this report.

Table 11: Challenge-type coding themes.

<table>
<thead>
<tr>
<th>Underlying Factor</th>
<th>Challenge Code</th>
<th>Code Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Remote Learning: Many students included the distance learning aspect as one of their challenges.
- Life: This category encompasses challenges related to personal circumstances.
- Self: Challenges related to students’ personal and academic growth.
- Academic: Challenges related to the study of chemistry concepts.
<table>
<thead>
<tr>
<th>Category</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Outside Circumstances</td>
<td>family responsibilities, tragedy, work responsibilities, current events, COVID-19 stress, safety</td>
</tr>
<tr>
<td>Remote Learning</td>
<td>prefer face to face, online, self-taught, lack of guidance, disconnect with teacher, at home</td>
</tr>
<tr>
<td>Health</td>
<td>mental health, physically compromised from daily life, physical exhaustion, illness, intensity of course is affecting well-being</td>
</tr>
<tr>
<td>Foundation</td>
<td>course preparation, previous experience, math foundation, previous academic opportunities / support</td>
</tr>
<tr>
<td>Lack of Resources</td>
<td>work schedule conflicts, other obligations, couldn't afford tutor, no quiz or homework feedback, no access</td>
</tr>
<tr>
<td>Self Time Management</td>
<td>balancing course load, turning assignments in on time, procrastinating, keeping up with course pace, work-life balance</td>
</tr>
<tr>
<td>Performance Expectations</td>
<td>low grades / test scores, false confidence in understanding, self-doubt, not meeting potential, grade not reflective of effort or understanding, few extra credit / grade cushioning opportunities</td>
</tr>
<tr>
<td>Motivation</td>
<td>course is exhausting, low focus, irrelevance to life, frustrating, confinement, lack of motivation</td>
</tr>
<tr>
<td>Unsuccessful Effort</td>
<td>trying but failing, not satisfied with progress, not successful despite effort or help seeking, continued using unsuccessful study habit</td>
</tr>
<tr>
<td>Ineffective Use of Resources</td>
<td>didn't use available resources, inconsistent resource usage, tried to use them but they didn't work / help</td>
</tr>
<tr>
<td>Chemistry Ability</td>
<td>weak area for me, not strong suit, difficult for me, natural ability is low</td>
</tr>
<tr>
<td>Academic Course Content</td>
<td>heavy workload, difficult course, lack of understanding, foreign concepts, math challenges, challenging practice problems, confused, lost</td>
</tr>
<tr>
<td>Synchronous Teaching</td>
<td>lack of school routine, synchronous and asynchronous, unreal school feeling</td>
</tr>
<tr>
<td>Teacher Blame</td>
<td>unsatisfactory teaching, bad explanations, hard to understand, confusing lectures</td>
</tr>
<tr>
<td>Communication</td>
<td>hard to ask questions, professor doesn’t respond to emails, instructor accent / language barrier</td>
</tr>
<tr>
<td>Learning Style</td>
<td>visual, “hands-on”, kinesthetic, auditory, lack of photographic memory, “in-person learner”</td>
</tr>
</tbody>
</table>
Assessment Issues  time restrictions on assessments, tests were stressful, difficult test format, unfair grading, misalignment of learning and assessment

4.4.1.1 Life Challenges

During typical in-person learning, many students bring in anxieties, stresses, and distractions from external factors that impact their ability to learn and focus academically. These factors are often outside of the control of the student; however, awareness could allow for improved learning support. Several students described the passing of loved ones, having to financially provide for their family while in school, hospitalization, a loved one being arrested, and emergency circumstances such as suddenly fostering an incapacitated friend or relative’s children. As an example of numerous outside circumstances influencing a single individual, one student wrote:

“I struggled with online learning during a difficult time politically, financially, and personally. There is a pandemic, a great strain to my finances, and threats to my personal safety in my apartment complex forcing us to move in winter, again costing money I did not have. I simply had other priorities and was not able to give chemistry the attention required to be successful.”

Another student taking general chemistry II described an extremely challenging circumstance:

“...The mother of my Goddaughters attempted suicide. Though she survived the attempt, her three children and younger teenage sister did not have a safe place to stay while she was in rehab. My fiancé and I opened our one bedroom/one bathroom apartment to them...We became overnight parental figures to a teenager and four and five-year-old. My whole life changed. I went from full-time student, to full-time impromptu maternal figure. These beautiful children became the center of my life, and while I will never regret helping them, it still affected other aspects of my life. My education was put on the backburner. I was no longer able to just sit down and take a quiz, or listen to a lecture. I was getting a child ready for school at six in the morning, cooking dinner for five, practicing sight words, getting through bath times and tantrums, constantly cleaning up after them, caring for them when they got sick. Soon enough, I began messaging my professors begging for extensions...Every time I asked, it felt like such a burden. It felt as if they didn't
want to help me, or that I was asking for too much. And maybe I was to them, but I know I wasn't. I know that it's not too much...I started with four classes this semester. I am now taking two...I thought that if I withdrew from those two classes, I would at least pass my remaining two. But now that doesn't even seem possible...I struggle with chemistry and tried my best to learn in an unfortunate situation. It is an explanation on my part and for other professors. I tried, I really did. Nonetheless, it just wasn't enough.”

These external factors would most likely impact some “Self” challenges such as the student’s “motivation” to learn, their “time management,” and ability to study sufficiently. One student described a decrease in willpower to complete assignments: “My father got arrested and my will to do assignments tremendously fell. I’m the one who has to deal with the case and help my dad out so there’s so much stress on me that it truly takes a toll.” A student displaying strong persistence with adequate support could overcome some of these challenges and succeed to some level in the course. One student enrolled in organic chemistry I demonstrated this type of resolve:

“This whole semester of organic chemistry has been a rollercoaster of emotions and grades. At the start, I was doing well, and then a lot of outside stressors occurred in my life which definitely caused me to not pay much attention to class hence the not-so-good grades that resulted from that lack of attention. And then when I tried to overcome those previous stressors and focused my attention again into studying, I improved my grades. And from then, I am constantly trying my hardest. It is honestly all that I can do. Practice and try my hardest.”

Although sometimes they can be overcome, challenges arising from lack of control over life circumstances pose a major obstacle to learning. This suggests that the underlying cause of a challenge faced may not necessarily be academic. Life factors produce many substantial hurdles.

### 4.4.1.2 Self Challenges

Many students described more personal challenges such as the inability to figure out how to study appropriately, lack of motivation to put in the necessary effort, and difficulty arranging their schedule to keep up with the course. These factors are more behavioral on the part of the
student and are likely something they have some level of control over. An example of “Motivation” can be observed in the response by this general chemistry II student:

“Even though I did start working fewer hours than previously, I still struggled to focus and get the work done in the class. I ended up doing very poorly to begin the class with my grades because I kept forgetting deadlines. This leads me to be unmotivated and I would do classwork for any other class before I would even touch my chemistry work.”

This demotivation and avoidance of chemistry work after receiving low grades may represent a helpless response to challenge, which is theorized to align with a fixed mindset (Burnette et al., 2013). “Time Management” was the most prevalent code of the “Self” challenges. This response from a general chemistry I student provides an example of this code:

“My biggest obstacle this semester was myself. I waited until the last minute to submit most of my work and relied on cramming sessions before exams in order to pass my exams. I procrastinated so much that I feel like I was not able to overcome my obstacles because it made me perform really bad all throughout this semester.”

This student openly acknowledges her own responsibility in her lack of success. Procrastination is theorized to be an avoidant response to challenge (Howell & Buro, 2009), designed to protect oneself from others’ evaluation of low ability and to provide an obvious explanation for low performance. Many students attributed their time management problems to the new circumstances of learning online: “There is so much material to go through and it is so much more time consuming than when things were in-person and managing this has been difficult.” This type of external attribution for challenge, that the increased workload was too much, may have resulted in helplessness if the student perceived it was outside of her control.

A less prevalent “Self” theme involved not using the resources available to them (“Ineffective Use of Resources”). The “Unsuccessful Effort” code was used when students
expressed frustration with putting in effort that did not yield desired results. This challenge is likely related to the study strategies students were using and whether they sought help as needed. An example of this code can be seen in the following response from an organic chemistry II student: “I took notes, completed the homework, completed the practice workshops and exams, but I still couldn’t get the material to stick.”

Beliefs about ability and what constitutes success were identified as codes under the Self category (“Chemistry Ability” and “Performance Expectations”). Expectations about performance are informed by previous academic experiences (Bandura, 1986), but students also set expectations for performance that they deem successful. Some students felt they did not overcome their challenges because they are typically “A” students, yet they received lower grades in chemistry. An example of this can be seen in this general chemistry II response: “I think I failed to overcome them because the pacing was quite different from the other classes I had. My quiz grades are generally sub-80 and after my failure of a second exam, I was put in a negative feedback loop.” This student appears to view a B as the minimal acceptable grade for an assessment, indicating a possible performance-goal orientation. While goal monitoring, he allowed the “sub 80” failure feedback to produce a helpless response. A student with a growth mindset would likely persist and be encouraged by slight improvements achieved by continued effort (Burnette et al., 2013).

The “Chemistry Ability” code was most interesting for beliefs related to mindset. Responses coded with “Chemistry Ability” described chemistry as a particularly challenging subject for themselves, rather than a course that is challenging in general. This is likely due to comparisons and perceptions of other students’ effort and ability. One student said, “Chemistry has never been my strong suit. No matter how hard I study, I can’t seem to grasp the material.”
Another said, “Chemistry has always been the most challenging subject for me...” One student even explicitly mentioned natural ability:

> “Chemistry doesn't come naturally to me and I actually find it pretty difficult, however, I'm determined to put in work to help improve my performance. I found it most difficult and non-motivating when I studied the content of the chapter and did practice problems only to take the test and either blank or have questions that are more difficult than the ones given for practice.”

Despite believing she lacks chemistry ability, this student expresses a desire to improve performance. Although exhibiting some degree of determination, her belief about her ability may reflect a fixed mindset in that her intelligence is stable, but performance is somewhat malleable. Beliefs about oneself are another aspect of the “Self” that can be an underlying cause of challenge. Addressing student beliefs about what constitutes success or failure may be one way to minimize these challenges, which are likely very demotivating.

### 4.4.1.3 Academic Challenges

The academic environment and course content can present specific challenges to students. The identified codes of “Communication,” “Course Content,” and “Assessment Issues” are the most obvious factors instructors can aim to improve in their courses to mitigate threats to student persistence. One type of academic challenge was attributed to “Learning Style,” which references a popularized, yet unsupported, learning theory (Bretz, 2017; Newton & Miah, 2017). Many American students have taken assessments to discover their learning style and often blame the teaching style for not aligning with how they learn best. An example of this code can be seen in the following response:

> “Online school is very hard for someone who is a visual and kinesthetic learner. I had a very hard time concentrating or staying concentrated at home and I lost motivation very quickly to study and finish work. I think this is due to not having mandatory [virtual] meetings (like they are optional).”
This challenge points to student beliefs about their own learning and the classroom, yet it may also be true that the instructor uses ineffective methods. The “Synchronous Teaching” code was mostly used to describe ineffective online course design, also applying to the previous quote in the comment about optional virtual meetings. This challenge mainly applies to online courses, rather than in-person classrooms. The “Teacher Blame” code can also be related to poor teaching strategies, however, opinions on the teaching quality are fairly subjective. One student taking organic chemistry I said:

“Organic chemistry requires someone who can explain entirely new content and concepts in a simple way and coherently. Unfortunately, my professor is very confusing in introducing and explaining concepts and it has been quite a struggle to learn and retain organic chemistry by myself. This brought me into a situation where it becomes very difficult to know what she wants us to know on the assessments and topped with harsh grading, I have no hope for an A.”

Some may argue that the content itself is confusing, as highlighted by the “Course Content” code. In fact, this code was amongst the most prevalent challenges cited by students. An example of this code is demonstrated in the following response: “Based on my general chemistry courses I knew that I was going to struggle in organic chemistry. The material itself is just hard for me to understand. I feel as if I am really great at retaining the information but in terms of application in mechanisms, synthesis, etc. it is harder for me.” This student’s remarks suggest a belief that she has low chemistry ability in citing previous course experiences as evidence for her own personal difficulties with the material. Rather than claiming that chemistry is objectively challenging for students, she views it as subjectively difficult due to her skill set.

The themes uncovered through this analysis reflect a variety of challenges common to students completing introductory chemistry sequences. Challenges lead to responses appropriate for the goals that student has set, whether that is protecting their chemistry ability from critiques,
maintaining top performer status, or continuing to improve understanding. To verify and quantify the relative impact of challenge on students’ likelihoods of success, we incorporated the uncovered themes into the survey administered the following fall semester.

4.4.2 Strategies to Overcome Themes

The “Overcame” challenge group provided an additional component to their Fall 2020 open-ended responses targeting the strategies they used to overcome their difficulties in the course. The themes drawn from this data are described in Table 12. The strategies described by students fall under three larger help-seeking categories: Self-Improvement, Authoritative, and Informal. It is possible that students who have more fixed beliefs about their ability would avoid self-improvement strategies and authoritative help (Dweck & Leggett, 1988). This behavior would align with a helpless response to challenge. However, it is likely that students who overcome challenges more often operate out of growth beliefs and are more willing to seek help because of the desire to improve and persist.

Table 12: Overcoming challenge strategies coding themes.

<table>
<thead>
<tr>
<th>Help-Seeking Source</th>
<th>Strategy Code</th>
<th>Code Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Improvement</td>
<td>Devoting Study Time</td>
<td>setting aside more time, studying a lot, practicing, preparing for tests, review materials, amount of effort, increasing retention, repetition</td>
</tr>
<tr>
<td></td>
<td>Changing Study Strategy</td>
<td>new study habits, new strategies, timed breaks, learning how to study, removing distractions, test-taking strategies, calendar reminders, improved organization</td>
</tr>
<tr>
<td>Authoritative</td>
<td>Office Hours</td>
<td>asking instructor for help, email professor with questions or clarification, attending office hours and study sessions</td>
</tr>
<tr>
<td></td>
<td>Tutoring</td>
<td>supplemental instruction sessions, departmental tutoring, outside tutor</td>
</tr>
<tr>
<td>Informal</td>
<td>Peer Learning</td>
<td>accountability partner, group studying, study partner, collaborative apps, reaching out to a friend</td>
</tr>
<tr>
<td></td>
<td>Outside Resources</td>
<td>using external resources, online videos and websites, online practice and example problem solutions</td>
</tr>
</tbody>
</table>
4.4.2.1 Self-Improvement Strategies

Amongst the students who persisted through challenges and attained perceived success, the two most common strategies described were “Devoting Study Time” and “Changing Study Strategy.” An organic chemistry I student who implemented extra effort said:

“The main challenges I experienced during this course were adjusting to nomenclature and memorizing mechanisms. Those two topics are the main ones in the course and are very time-consuming to practice and perfect. In order to overcome the challenges I had, I put more time into the course work (homework, textbook problems) and went to every possible office hours [session] I could attend.”

This student recognized the need for extra effort to practice and understand challenging concepts in the course. As a response to challenges with these concepts, she implemented self-improvement efforts by leveraging the course resources and practicing. In addition, this student sought help from an authoritative source through attending office hours. To demonstrate an example of “Changing Study Strategy,” this organic chemistry II student wrote:

“Being strictly online has been an adjustment. It has made me really have to study more and be more “on top of things.” Something that has helped me do well in this class is staying organized. I create multiple calendars (one for the month, the week, and the day). It is important to me that I stay on track with my schedule because even one day behind and I notice a difference in my understanding of the topic.”

This student describes implementing mastery strategies of self-regulation by monitoring understanding to determine if the organization is effective. This suggests that students should find a way to measure the effectiveness of a change in strategy. This process allows for additional changes if needed, as well as selecting the best strategy for their own learning and success. Self-improvement strategies can be tailored to the individual’s learning and schedule needs and require
both dedication and effort. The nature of a growth mindset is to seek self-improvement (Dweck & Leggett, 1988); thus these two themes (“Devoting Study Time” and “Changing Study Strategy”) can easily align with the belief that one’s ability in a domain can improve.

4.4.2.2 Authoritative Help-Seeking Strategies

A student may also seek help from someone who represents authoritative knowledge on the topic. Within the context of academics, these figures are typically instructors and tutors. When approaching an authoritative source, some extent of vulnerability regarding evaluation of one’s abilities is necessary. This lends students operating out of growth mindsets toward seeking authoritative help sources for feedback and improvement, while students with a fixed mindset would be more hesitant to reveal their inadequacies (Dweck & Leggett, 1988). One student who benefited from supplemental instruction (“Tutoring”) stated, “There are certain concepts and chapters that didn’t make sense to me in this course. I tried reading the book and all the resources provided for us, and it still didn’t work. So, I decided to attend [a supplemental instruction] session and it genuinely helped me understand.” Some students may feel unable to learn independently through good strategies and increased effort, and this feeling likely increases their sense of need for external help. For some, a fellow student like a teaching assistant or supplemental instructor may seem more approachable. Others may view the instructor as the primary source for help. A student who leveraged the instructor’s help to achieve success said:

“Organic chemistry is a very tough class and it was even harder this semester since we needed to teach ourselves. But in order to succeed, I made sure to rewatch lectures, redo notes, and do all of the practice problems at least two times. I also went to [my instructor’s] office hours multiple times per week which was super helpful and ultimately allowed me to succeed in the class.”

This student mentions the need to teach herself the material in the online course, so the frequent use of available office hours does not reflect a sense of dependence. The regular practice and
meeting with the instructor simply represent seeking additional support, feedback, and time spent reviewing the material.

4.4.2.3 Informal Help-Seeking Strategies

Very few students in the open-response sample mentioned using “Peer Learning” strategies, however, one student described the benefits:

“I struggled finding motivation during the online semester. It simply doesn’t feel like I am in school anymore, just as if I am repeating the same day over and over. One way I overcame this was having an accountability friend in the class. This friend would check up on me midway through the week just to make sure I am actually studying and to answer any of my questions.”

Several mentioned using study groups to prepare for tests. These methods can be helpful as a regular habit, although some students may use them as a “quick-fix” to avoid the necessary independent effort. The informal help source most commonly reported as a useful strategy was “Outside Resources.” Students frequently mentioned that they found helpful video channels to receive a secondary explanation for confusing concepts. One student described the usefulness of this approach as, “When learning new material I would become confused because sometimes I didn't know what to focus on at times when watching the lecture videos until I would see the homework. I practiced to overcome these challenges and watched [online] videos.” This response highlights the issue of confusion over alignment of practice problems with the concepts explained during lecture. Additional explanations assisted this student in making the necessary connections to complete the assignments.

After identifying the themes surrounding commonly described strategies students used in the face of challenges, we sought to compare usage with perceived success. It was hypothesized
that some strategies might align with helplessness and others with mastery, as described in this section. If this were the case, challenge-level group differences in strategy usage might appear.

### 4.4.3 Help-Seeking Strategies by Challenge Group

In Fall 2021, students were asked to provide the most common ways they sought help throughout the semester. Students were also asked to report the frequency with which they sought help during the course. The comparison between help-seeking frequencies by group is shown in Figure 10. The most noticeable group difference is the claim to have never sought help by the “No Challenge” group. There were no observable differences between the “Overcame” and “Didn’t Overcome” challenge groups in terms of help-seeking frequency. This finding suggests that both groups tried to overcome challenges if presented with them, yet most reported seeking help once per chapter or module, rather than more frequently.

*Figure 10: Help-seeking frequency by challenge-level group.*
The challenge-level group comparison for help-seeking strategy usage can be seen in Figure 11. Unlike the challenge-type group comparison, no statistically significant differences between groups were observed in this comparison. The two most prevalent strategies students employed when experiencing a need for help were drawn from the “Devoting Study Time” and “Outside Resources” codes. The “Didn’t Overcome Challenge” group reported using “Outside Resources” most often, but this difference was not significant when compared to the “Overcame Challenge” group ($z = 2.64, p = .008$). Many students in all groups additionally reported changing their study strategies and utilizing peer learning. The “Peer Learning” strategy frequency was higher in the Fall 2021 sample compared to 2020, which is likely due to returning to in-person classes and having more peer interaction.

*Figure 11:* Relative percentages of reported help-seeking strategies by challenge-level groups.
Despite not reaching statistical significance, qualitatively some potential trends could be drawn from the group comparison results. Overall, a low percentage of students reported seeking help from the instructor or a tutor, suggesting that authoritative sources were less utilized relative to informal and self-improvement sources. The majority of students implemented strategies that could be conducted independently, such as altering their studying habits and efforts and incorporating external information for support. These independent strategies may be much more feasible for students after adjusting to the online learning environment, even when interaction became more available. One explanation for the lack of differences between groups for increased study time and changing strategy is that many study strategies are ineffective. It is interesting to note that very few students reported setting a schedule despite the very large number of students who claimed their main challenge was time management. Time management strategies are very important for students to develop, especially when they recognize that challenge affecting their learning. Instructors can encourage accountability to monitor their own study habits through teaching time management strategies.

Therefore, to address the second research question regarding students’ responses to challenge, the open-coding themes were compared across groups. Several responses were found to be more commonly implemented, yet we cannot speak to frequency of strategy usage on an individual basis. The group of students who overcame may have used their strategies on a daily or weekly basis, while inconsistent usage may have occurred for the “Didn’t Overcome” group. At any rate, the most widely used strategies were primarily independent studying methods. Few students sought outside help from a person. In future studies regarding these responses to challenge, a measure of consistent frequency of help-seeking could provide additional explanation for the success outcomes of students.
4.5 Study Part 1: Conclusion

Characterization of open-ended descriptions of challenge from students in introductory chemistry courses yielded evidence for eight challenge-type themes. Some of the challenges students described were more related to academics, while others were behavioral or external life factors.

When examining responses regarding help-seeking frequency, both groups who encountered challenge reported seeking help with the same frequencies, regardless of successful outcomes. The likelihood of specific strategies employed for improvement were not different among the different challenge groups, which suggests the type of challenge perceived by the student might have more influence on successful outcomes compared to the ways in which and the extent to which they seek help to overcome them. Qualitatively, the “No Challenge” group reported devoting more time to studying as their main strategy and the “Didn’t Overcome Challenge” group reported focusing on increased study time and outside resources to support their learning. Both of these strategies are independent activities and do not require approaching a formal or informal source for help.

4.5.1 Implications

The relationship between the type of challenge and outcomes, such as perceptions of success and performance, suggests that instructors should be aware of ways to help students overcome challenges. Likely, “Life”-related challenges are particularly difficult to address, but instructors can be understanding of the complexities beyond the classroom and direct students to on-campus resources to provide support for their external circumstances. Strategies that increase teacher-student dialogue and interaction can foster a positive classroom climate that recognizes student voices and allows them feelings of belongingness and support (Dewsbury & Brame, 2019).
The underlying cause of several of the challenge types perceived by students can be attributed to their behavioral patterns (or the “Self”). These causes can be addressed by instructors through explicitly teaching students study habits and metacognitive strategies, by designing motivating and active learning experiences (Freeman et al., 2014; Theobald et al., 2020), and by establishing accountability or incentive for positive academic behaviors. To address “Academic” challenges, instructors can use formative assessment to reflect on confusing aspects of the material and refine their explanations. Within a course that already presents the threat of challenge to many students, especially to those who hold negative beliefs about their “Chemistry Ability,” instructors can emphasize improvement and encourage the development of relevant skills. These changes can increase the approachability of the content for students and combat negative stereotypes about natural abilities and the subject matter.

### 4.5.2 Limitations

Some of the data were collected during the time of COVID-19 pandemic virtual learning and the rest immediately following reintroduction to in-person classes. Thus, the challenges students faced likely vary compared to typical course conditions. These two time-points may reflect different frequencies of challenge-types, however, the themes developed in 2020 were retained in the second semester and are believed to represent the primary challenge categories students faced in 2021. A student’s perception of their own success is inherently subjective as different criteria can be used to determine success, as well as the different goals they can set as evaluative tools. At any rate, these perceptions are likely more closely linked to students’ self-concept, persistence behaviors, and mindset beliefs than any objective performance measure for these same reasons. In the same line of reasoning, self-reported grade estimates may be more closely tied to these self-perceptions of success compared to more objective assessment scores.
retrieved from other sources. Students evaluate their own performance and success through a similar mental estimation to determine whether they have achieved their goals or demonstrated improvements.

In qualitative analysis, it is possible that some themes may not have been detected, yet they would not represent a large proportion of the sample as data saturation has been demonstrated with the existing codes. Interpretive bias is always present to some degree, although it is minimized through the quality control process of checking for interrater reliability amongst multiple researchers. Although the sample investigated in this work represented a diverse range of backgrounds, the data was collected at a single public institution in the US, therefore some caution should be taken regarding generalization. Student samples from other types of institutions or other nations could be studied to consider the generalizability of the findings.

4.6 Study Part 2: Mindset Interaction with Challenges

4.6.1 Research Questions

This study aims to characterize the key challenges students face in introductory chemistry courses and understand their interaction with mindset. It is important to understand the nature of the challenges themselves in connection with the perception of success or failure in overcoming them. The research questions of this study are as follows:

RQ1) What are the common challenges students face during introductory undergraduate chemistry courses?

RQ2) How are challenges students face in chemistry courses related to their mindset beliefs?

RQ3) How do challenges impact course performance?
4.7 Results and Discussion

4.7.1 Common Challenges (Research Question 1)

To determine the common challenges students face in chemistry so that a multiple-choice prompt could be designed for use in our survey, students’ open-response descriptions of their experiences from Fall 2020 were analyzed. After code development and refinement, categories for common challenge themes were defined and are listed in Appendix A with descriptions. Students’ descriptions yielded a variety of perceived challenges that were narrowed down to capture the key themes. The multiple-choice items were derived from these qualitative themes and were administered in Fall 2021 to collect data that could be easily used to examine trends based on the type of challenge students faced.

The types of challenges students reported facing in Fall 2021 are shown in Figure 13. The most common challenge students reported facing either as their primary or secondary challenge was “Course Content.” This answer selection indicated difficulty understanding the content of the course. Some students may believe that the difficulty of the content is an insurmountable obstacle for someone with their ability level, thus responding to this challenge helplessly. Beyond putting in more effort to understand, it may not easily be overcome. However, others may view course content difficulty as a challenge they can overcome through effort. The second most frequent challenge students reported was “Time Management.” This challenge is more likely perceived as related to effort and personal organization by most students, and thus should be an achievable challenge to overcome. The other answer choices yielded a much smaller frequency of selection by students. “Motivation” was selected by 15.4% of the sample and “Chemistry Ability” by 10%. It is possible that both of these challenges are perceived as something the student is naturally lacking, especially students’ ability in chemistry. Facing a perceived challenge with one’s
chemistry ability may be most closely tied to fixed mindset beliefs, in that students may not apply effort if they believe they have a lower amount of ability relative to others.

*Figure 12*: Common challenges students faced across the full sample (Fall 2021).

It is also important to consider that students in different course sequences may face different challenges. For this reason, we used paired z-tests to compare the frequencies of organic versus general chemistry students’ challenge types. Due to the comparison between eight paired challenge types, it was necessary to use a Bonferroni correction method for multiple tests (8 total comparisons, α_{adj} = 0.006). The frequency comparisons between course sequences are shown in Figure 14. General chemistry students reported facing more challenges with “Teaching Strategies” (z = 15.860, p < .001) and “Chemistry Ability” (z = 3.983, p < .001). This could indicate a higher prevalence of beliefs that challenges are insurmountable obstacles among first-year chemistry students. If students have underdeveloped independent learning skills, likely more common among freshmen, they may be affected to a larger degree by poor teaching strategies. They may also hold the perception of poor teaching in their courses if they are new to university-level learning and are
making comparisons to their high school experiences with teachers. It is important that instructors recognize the impact of their teaching strategies and aim to support student learning. If the instructional strategies are negatively impacting outcomes, they should be reflected upon to address potential weak areas. An alternative explanation associated with mindset involves making external attributions for failure to avoid appearing to have low ability. The “Teaching Strategies” challenge could be a way for students to deflect from acknowledging their own role in overcoming challenge. As most general chemistry students are relatively new to college, many have not academically matured to the same degree as organic chemistry students and undergone the necessary adjustments to a more rigorous learning environment. It is important to note that students in organic chemistry courses are a more selective group, as they have already demonstrated sufficient success in general chemistry in order to proceed to the next course sequence. It is probable that a more selective group with prior undergraduate chemistry course experiences will have adjusted their study strategies to align with typical instructional formats and will perceive different challenges relative to those more broadly permitted entry into general chemistry. The nature of the differences in course population suggests that caution should be used in interpreting these perceived instructional differences.

Organic chemistry students reported facing more challenges with “Time Management” (z = 9.155, p < .001), “Motivation” (z = 2.805, p = .005), and “Outside Circumstances” (z = 3.437, p < .001). Organic chemistry courses likely require increased time commitments for many students to succeed, especially if they perceive general chemistry as less difficult due to the algorithmic nature of typical problems presented with traditional curricula (Grove and Bretz, 2010; Nakhleh, 1993). The cognitive demands of organic chemistry are often higher relative to general chemistry with increased problem complexity, such as multiple solutions to a single problem (Elbulok-
Charcape et al., 2021). It is possible that this difference in the nature of the course sequences can explain why organic chemistry students perceived more challenges with setting aside the appropriate amount of time. The “Motivation” category also aligns with this explanation because challenging courses require significant motivation to invest sufficient time into learning and studying. Likewise, outside circumstances such as health, family, financial matters, and jobs can conflict with the ability to dedicate proper time to learn difficult material.

Considering the discussion above regarding challenge differences between general and organic chemistry students, one explanation to test is relative differences in chemistry mindset between these two course sequences. It is possible that students with a fixed mindset in general chemistry are effectively filtered out for continuation into organic chemistry due to poor performance or lack of persistence in the major as a way to escape feelings of inadequacy. Studies on STEM mindset have consistently observed declines in STEM-related mindset throughout STEM coursework (Dai and Cromley, 2014; Limeri et al., 2020b; Scott and Ghinea, 2014; Shively and Ryan, 2013), suggesting that organic chemistry students may have less growth mindsets compared to their beliefs during general chemistry. One-way ANOVA was used to test for differences in chemistry mindset between general and organic chemistry students and no significant difference was observed ($F_{1,434} = 1.96, p = .162$). This finding suggests that differences in challenge perceptions may be more related to the nature of the courses themselves compared to the mindset of the student population enrolled in each sequence.
Using this categorical response data, we were also able to compare challenge-type frequencies between students with differential perceptions of success. The entire sample self-sorted into categories of “No Challenge” (n = 42), “Overcame Challenge” (n = 235), and “Didn’t Overcome Challenge” (n = 168). Figure 15 represents the challenge-level group comparisons for challenge-type. The two most prevalent challenges selected by students across both groups were “Course Content” and “Time Management.” Most of the types of challenges were selected equally across the two challenge-level groups. This suggests that many types of challenges often impact students regardless of their ability to overcome them.

A few differences were observed according to z-tests between the “ Didn’t Overcome” and “Overcame” challenge groups, after adjusting for multiple comparisons using the Bonferroni correction method (8 total comparisons, α adj = 0.006). The largest group difference was observed for “Time Management” ($z = 3.759, p < .001$), with the group who perceived themselves successful in overcoming challenge expressing “Time Management” most frequently as their primary or secondary challenge. This is explained by considering that this challenge-type can be perceived as
a factor the students can change and persist to overcome, an example of an adaptive response to challenge. Also, the group that perceived failure to overcome was more likely to claim they lacked “Chemistry Ability” \((z = 3.188, p = .001)\). Again, it is possible that a student can attribute this challenge to factors such as naturally inherited and fixed abilities, which may result in a helpless response to challenge.

*Figure 14:* Comparison of “Overcame” and “Didn’t Overcome” challenge-type response frequencies. * significant z-test group difference at Bonferroni corrected \(p < .006\) level.

All other challenge types did not yield significant differences between the two groups, despite many having a likelihood of helpless perceptions associated with them. Most obviously, students are often largely helpless in the face of “Outside Circumstances;” however, some students in difficult circumstances may increase focus on schoolwork because it is something they can apply effort to effect change. Based on studies of achievement gaps in STEM courses (Harris et al., 2020), it could be argued that the categories of “Weak Foundation” and “Lack of Resources”
are likely to yield differences in success perceptions. For example, a student with a weak foundation in chemistry may not have had sufficient science learning opportunities due to factors such as household or regional socioeconomic levels, or even weak science programs in prior schooling. However, this was not the case here, as this sample showed equal probability of perceived success or failure. Additionally, students with lower socioeconomic status may not have equal access to resources like tutoring or the freedom to take time off work to sufficiently study or attend help sessions. Considering that approximately 50% of this sample reported Pell-grant eligibility and thus meet criteria for financial aid, a significant portion of the students likely have socioeconomic disadvantages regardless of challenge group. The “Lack of Resources” challenge did not yield a significant difference in selection frequency across the two groups ($z = 1.898, p = .057$). Additionally, the challenge regarding the instructor’s teaching strategies did not reach significance, although it could be perceived as unfair, resulting in a helpless response to the perception of their learning environment.

Of great interest within the context of mindset theory is the group difference in selecting “Chemistry Ability” as their primary challenge. One’s perceived ability in a given domain can easily be viewed as a factor outside of one’s control if operating out of a fixed mindset. Very few students who overcame their challenges reported facing low chemistry ability as their primary obstacle. It is likely that students who believe they are being challenged due to their low ability in a domain also believe that some amount of that ability is natural and stable. These students would likely seek to “just get through” the course because they doubt their ability to genuinely improve. Students focused on protecting themselves from appearing to have low ability and undervalue effort to improve would likely respond in a helpless way, resulting in poor outcomes.
4.7.2 Challenges that Relate to Mindset (Research Question 2)

To understand how challenges students face in chemistry may relate to their chemistry mindsets, we sought to examine which, if any, challenge types yielded differences in mindset scores. Reported challenge types were examined as a predictor of mindset scores using two-way ANOVA to account for students’ primary and secondary challenges. The interaction of primary and secondary challenges was found significant, which led to examination of the main effects of primary and secondary challenges. The ANOVA results can be seen in Table 14. Both main effects of primary and secondary challenges yielded significant differences in chemistry mindset, indicating that challenges do relate to mindset.

Table 13: ANOVA results for interaction and main effects of challenge types on chemistry mindset.

<table>
<thead>
<tr>
<th>ANOVA Factor</th>
<th>Effect Type</th>
<th>F</th>
<th>p</th>
<th>Partial η²</th>
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<td>.104</td>
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<tr>
<td>Secondary Challenge</td>
<td>Main Effect</td>
<td>5.05</td>
<td>&lt;.001</td>
<td>.093</td>
</tr>
<tr>
<td>Chemistry Ability Dichotomous</td>
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<td>35.79</td>
<td>&lt;.001</td>
<td>.082</td>
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</table>

Figure 16a summarizes the mean mindset scores for each challenge type when selected as the primary and secondary challenge students faced. Tukey tests were used to identify which specific challenges yielded significant differences. For primary challenges, students who reported “Chemistry Ability” reported the lowest mindset score ($\bar{x} = 5.64$). Students who reported this primary challenge had significantly lower mindset scores relative to students who reported challenges with “Time Management” ($\bar{x} = 7.34$), “Outside Circumstances” ($\bar{x} = 7.56$), and “No Challenges” ($\bar{x} = 8.35$). Likewise, upon examining Tukey’s test results for the main effect of secondary challenges, “Chemistry Ability” yielded significantly lower mindset scores ($\bar{x}$
= 5.97) relative to “No Challenges” (\( \bar{x} = 8.31 \)). Other challenges that consistently yielded significantly lower mindset scores relative to “No Challenges” were “Weak Foundation” (\( \bar{x}_1 = 6.10, \bar{x}_2 = 6.57 \)), “Course Content” (\( \bar{x}_1 = 6.56, \bar{x}_2 = 6.74 \)), and “Teaching Strategies” (\( \bar{x}_1 = 6.63, \bar{x}_2 = 5.98 \)).

All of these challenge types that students reported along with lower chemistry mindset scores could be considered as possible external attributions students make to explain their perception of being unsuccessful. However, “Chemistry Ability” stands out as one challenge that interacts strongly with mindset because the belief that one’s ability is low relative to others aligns most strongly with fixed mindset beliefs, produced the lowest mindset scores across all challenge types, and even produced significantly lower mindset scores relative to several other challenges. For this reason, “Chemistry Ability” was coded dichotomously as a variable for students who selected this challenge as either their primary or secondary challenge. One-way ANOVA was used to examine the effect of this specific challenge on chemistry mindset. Table 14 also presents the results of this analysis, which detected a significant mindset score difference between this challenge relative to all other challenges (\( F = 35.79, p = .001, \text{partial } \eta^2 = .082 \)) with a medium effect size. To determine how this challenge might be related to performance as an external indicator of the validity of this connection, one-way ANOVA tests were conducted using the dichotomous chemistry ability variable on formative and summative performance z-scores. Both of these performance measures indicated significant differences between students who selected “Chemistry Ability” challenges relative to students with other challenges (formative: \( F = 5.55, p = .019, \text{partial } \eta^2 = .015 \); summative: \( F = 13.73, p = .001, \text{partial } \eta^2 = .036 \)). However, the effect sizes were fairly small (Richardson, 2011). These results are summarized in Figure 4b, converted to percentile scores using normal distribution probabilities.
(chemistry mindset scores are also multiplied by 10, converting it from a 10-point scale to align with the 100-point scale for performance variables). Cumulatively, these findings further support the conclusion that students who perceive this challenge are more likely to hold fixed mindset views about chemistry.

Figure 15: a) Challenge type relates to chemistry mindset (*indicates significant score differences). b) Chemistry ability versus other challenges as a predictor for course outcomes and mindset beliefs (chemistry mindset 10-point scale average multiplied by 10 to place on same scale).
4.7.3 Challenge Impacts Course Outcomes (Research Question 3)

In addition to responses regarding challenges, instructors provided grades for all participating students in Fall 2021. To consider how the presence of challenge and students’ perceptions of their success in the face of challenges relates to their actual course performance, we compared the challenge level groups in terms of their formative and summative performance scores using one-way ANOVA tests. The results of these tests, as well as the results of group comparison on chemistry mindset scores, are presented in Table 15. The sizes of the effect of challenge level group membership across all three variables are considerably large, suggesting a strong link between students’ perceptions of success or failure in the face of challenges and their performance and beliefs about their ability to improve.

<table>
<thead>
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<th>Variables</th>
<th>$F$</th>
<th>$p$</th>
<th>Partial η$^2$</th>
</tr>
</thead>
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<td>Challenge Group on Formative Performance</td>
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<td>&lt;.001</td>
<td>.154</td>
</tr>
<tr>
<td>Challenge Group on Summative Performance</td>
<td>52.93</td>
<td>&lt;.001</td>
<td>.222</td>
</tr>
<tr>
<td>Challenge Group on Chemistry Mindset</td>
<td>46.88</td>
<td>&lt;.001</td>
<td>.190</td>
</tr>
</tbody>
</table>

The results of the challenge-level group comparisons regarding performance and chemistry mindset scores can be observed in Figure 17. Each group yielded significantly different average performance scores according to both types of assessments (formative and summative). The “No Challenge” group, unsurprisingly, has aligned their perception with the relatively high performance scores they obtained over the semester. The “Overcame Challenge” group has acknowledged that they faced difficulties, but were able to become successful despite the presence of those challenges. This category of challenge interaction most likely aligns with higher growth mindset beliefs because these students did not allow challenges to discourage them from persisting
and achieving success. As could be expected, this group obtained performance scores that fell between the other two groups’ scores but this was also the case for their average chemistry mindset scores.

This points to the interesting result that the “No Challenge” group reported the highest mindset scores of all challenge groups. One explanation for this finding could be that these students were not confronted with the need to challenge their reported beliefs because negative performance feedback was not received. Another possible explanation is that students with very high ability (and likely high self-efficacy) are less likely to perceive challenges and simultaneously hold growth mindset beliefs regarding themselves. At any rate, the “No Challenge” group appeared to have received very little failure feedback in the way of assessment scores. This group did not perceive difficulties and thus never were confronted with a decision between protecting themselves from revealing low ability or continuing to exert effort to perform well. As students in this group could have high ability and performance consistently, both growth and fixed mindsets could be present. The lack of perceived challenge could be due to having growth mindset combined with high ability, or it could be due to beliefs that challenge indicates lack of ability and their performance feedback did not suggest low ability.

The group with both the lowest performance scores and most fixed reported mindset beliefs was the “Didn’t Overcome” group. These results are not surprising when considering how challenge (or the presence of negative performance feedback) can threaten students’ egos that hold fixed mindset beliefs, inducing poor coping strategies or avoidance behaviors (Burnette et al., 2013). Contrastingly, it could be argued that challenge, coupled with negative performance feedback, was the driving factor for developing fixed mindset beliefs about chemistry as the semester progressed (Limeri et al., 2020a). It is possible that many students in the “Didn’t
Overcome” group received such low grades in the beginning of the course that they did not feel it was possible to improve, resulting in helpless responses to challenge.

Figure 16: Challenge group trends for a) formative performance scores, b) summative performance scores, and c) chemistry mindset scores.

As noted earlier, the “Chemistry Ability” challenge-type has the strongest theoretical connection to a fixed mindset. This finding of differential performance based on perception of a mindset-related challenge highlights the impact of these beliefs on an individual’s experience in the course. As hypothesized, mindset and challenge appear to interact in course experiences, particularly beliefs regarding one’s perceived ability relative to others. Negative beliefs about one's ability and its improvability detrimentally impact performance. These results suggest that experiencing challenges relates to performance, as well as mindset beliefs, and the type of challenge perceived may affect this relationship more strongly.

4.8 Study Part 2: Conclusion

Eight challenge types were derived from characterization of open-ended descriptions from students in introductory chemistry courses and were used to assess relationships with performance, challenge perceptions, and chemistry mindset. The most common challenges students faced were
examined across the entire sample, between organic and general chemistry students, and according to reported challenge level groupings. It was found that “Course Content,” “Time Management,” and “Motivation” were the most frequently reported challenges overall. Additionally, general chemistry students were more likely to perceive that their challenges were related to “Teaching Strategies” or “Chemistry Ability,” suggesting they are more likely to believe challenges are related to their natural ability level or to deflect blame for their performance onto a factor other than their own ability as a defense mechanism. The “Overcame” group was significantly more likely to attribute their challenge to “Time Management,” a factor that may be perceived as easily overcome with applied effort and organization. The “Didn’t Overcome” group was more likely to believe that their challenge was related to their ability in chemistry, which suggests a higher prevalence of fixed mindset beliefs in this group, a possible explanation for their relatively poor outcomes.

Challenge group membership showed significant differences in grades across the semester, as well as mindset scores. Performance feedback likely contributes to the students’ perceptions about success and failure and may influence students’ beliefs. The inverse is also possible, students may end up in a particular challenge level category based on the differential effects of their initial mindset beliefs. The final interesting result from this study was obtained from examining which challenge types related most strongly to fixed mindset scores. “Chemistry Ability” was highlighted as the most aligned with fixed beliefs and significantly predicted performance outcomes and mindset beliefs relative to all other challenges. It was found that students who perceived a challenge with their chemistry ability had lower grades on average across the semester compared to those with other challenges. This finding corroborates the theoretical underpinnings of mindset-
related challenges, such as the interpretation of challenge indicating that one has a low, fixed ability in a subject, leading to maladaptive behaviors and poor outcomes (Burnette et al., 2013).

4.8.1 Implications

Further research into the mechanisms of challenge interpretation and response to failure would be beneficial to understanding the interaction of challenge and mindset in chemistry contexts. Performance feedback relates to students’ perceptions of challenge in chemistry courses, suggesting that the instructor can influence these perceptions positively by use of growth-mindset language in the way performance feedback is given. The relationship between the type of challenge and outcomes, such as perceptions of success and performance, suggests that instructors should be aware of ways to help students overcome challenges. Likely, “Outside Circumstances” are particularly difficult to address, but instructors can be understanding of the complexities beyond the classroom and direct students to on-campus resources to provide support for their learning and circumstances. Strategies that increase teacher-student dialogue and interaction can foster a positive classroom climate that recognizes student voices and allows them feelings of belongingness and support (Dewsbury & Brame, 2019). The underlying cause of several of the challenge types perceived by students can be attributed to their behavioral patterns (e.g., “Time Management” and “Motivation”). These causes can be addressed by instructors through explicitly teaching students study habits and metacognitive strategies, by designing motivating learning experiences (Freeman et al., 2014; Theobald et al., 2020), and by establishing accountability or incentive for positive academic behaviors. To address the challenge “Teaching Strategies,” shown to be particularly relevant in general chemistry, instructors can implement a wide range of evidence-based teaching strategies as well as leverage formative assessment to identify aspects of the material that have not been mastered by students. Within a course that already presents the
threat of challenge to many students, especially to those who hold negative beliefs about their “Chemistry Ability,” instructors can emphasize effort and metacognitive strategies instead of innate ability to encourage the development of relevant skills. These changes can increase the approachability of the content for students and combat negative stereotypes about natural abilities and the subject matter.

4.8.2 Limitations

Some of the data were collected during the time of COVID-19 pandemic virtual learning and the rest immediately following reintroduction to in-person classes. Thus, the challenges students faced likely vary compared to typical course conditions. However, the themes developed in 2020 were retained in the second semester when students returned to in-person learning in 2021 and are believed to accurately represent the primary challenge categories students faced. A student’s perception of their own success is inherently subjective as different criteria can be used to determine success, as well as the different goals they can set as evaluative tools. At any rate, these perceptions are likely more closely linked to students’ self-concept, persistence behaviors, and mindset beliefs than assessments themselves. Although the sample investigated in this work represented a diverse range of backgrounds, the data was collected at a single public institution in the United States, therefore some caution should be taken regarding generalization. Student samples from other types of institutions or other nations could be studied to consider the generalizability of the findings.

5 COMPLEXITY OF CHEMISTRY MINDSET CONSTRUCT: A MULTIPLE-CASE STUDY ANALYSIS

5.1 Introduction

Introductory chemistry courses at the university level present a variety of challenges to many students and thus often require persistence to achieve successful outcomes. Some students can overcome their challenges, while others cannot. General and organic chemistry are considered gateway courses for various science, technology, engineering, and math (STEM) degrees, as well as prerequisites for many medical 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 (Horowitz et al., 2013; McKinney et al., 2019; Popejoy & Asala, 2013). These rates of unsuccessful course completion support the claim that academic challenges are 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. Instrumental in addressing this problem is understanding the nature of students’ decisions to persist or give up in the face of challenge. Several affective variables have been shown to impact student outcomes in STEM disciplines. One such variable, mindset, is a relevant psychological construct to include in this investigation as it involves beliefs about the malleability of intelligence, linked to persistence and challenge-seeking behaviors (Burnette et al., 2013; Doron et al., 2009; Karlen et al., 2019; Lou & Noels, 2016; Molden & Dweck, 2006).

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 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 general mindset beliefs (Scott and Guinea, 2014; Shively and Ryan, 2013; van Aalderen-Smeets et al., 2018). It is likely that cultural stereotypes inform student beliefs about who is capable of success in certain domains, influencing their mindset beliefs about that domain. Many STEM fields, in particular, have associated gender and racial stereotypes that lend some students to experience stereotype threat while enrolled in STEM courses (Aronson et al., 2002; Burkley et al., 2010; Good et al., 2003; Good et al., 2012; Leslie et al., 2015; Lytle and Shin, 2020). Shively and Ryan (2013) examined the domain-specific nature of mindset in the context of college algebra courses over the course of one semester and found that math-specific beliefs were less growth and declined over the semester compared to their general beliefs, which began more growth and remained stable over time. Scott and Guinea (2014) observed a similar downward trend with computer science students regarding their programming aptitude beliefs relative to their general intelligence beliefs. Similarly, Dai and Cromley (2014) found that students in introductory biology sequences experience a decline in their growth mindset beliefs about biology ability over one year and this change is related to STEM major dropout. Course performance along with perceived success has been found to moderate differential mindset belief trajectories of students in STEM courses (Dai and Cromley, 2014; Limeri et al., 2020a; Scott and Guinea, 2014). 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 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 with age. Gunderson and coworkers found that students’ beliefs about peers’ ability in
math become much less growth relative to their beliefs about peers’ ability in language with 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. Older students have an increased degree
of autonomy in selection of academic areas of study and are much closer to pursuit of specific
career fields. By this age, their identities within particular fields are more solidified and they
have come to view different fields as equally valid career choices, yet requiring different skills or
personality types. 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.

Another age-related factor to consider in target populations for mindset studies is the
complexity of a term like “intelligence.” Mindset instruments typically probe beliefs in regard to
words like intelligence, which may be straightforward to younger children but less so as students
mature. There are even varying cultural views on the meaning of intelligence that impact mindset
beliefs in different cultural contexts (Aditomo, 2015). The idea of multiple intelligences
(Gardner, 2006) is prevalent among college students with the increase in popular psychology
awareness of the past few years. It begs the question: Is intelligence in chemistry the same as
intelligence in finance or music? Several recent studies have examined the meaning of
intelligence to students in STEM courses, and particularly for STEM subjects. Buckley and
colleagues used qualitative methods to uncover 84 different intellectual traits students deemed
important to qualify as having intelligence for STEM contexts (2018). After using factor analysis
methods with a second data collection, a 3-factor solution was obtained as best fit, indicating that students viewed STEM intelligence as a multifaceted trait. Limeri et al. found two distinct themes in chemistry students’ definitions of intelligence: knowledge and ability (2020b). This study also examined differences in survey response patterns of students who defined intelligence each of these two ways. Students who defined intelligence as knowledge were more likely to report growth mindset beliefs, while students who defined intelligence as ability reported mindset values across the entire scale range (Limeri et al., 2020b). Similarly, our research team recently found that chemistry students define “chemistry intelligence” differently relative to “intelligence” in general and that both terms yielded a broad range of student interpretations (Santos et al., 2021). These variations in interpretation likely impact the beliefs students report on mindset measures and may influence their beliefs on the topic of mindset.

Reports that students can endorse both growth and fixed mindset beliefs simultaneously have existed since early in the mindset research (Dweck et al., 1995b). However, the notion of mindset beliefs as context-dependent has gained traction in research lately. The learning environment can activate one view over another (Little et al., 2016), which may yield a variety of effects on student behaviors. The shift in beliefs as a function of a performance feedback loop for STEM subjects suggest 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., 2020; Barger, 2019). Even perceptions of peer mindsets have been observed to influence students’ task value and feelings of peer competence (Sheffler and Cheung, 2020), suggesting yet another context-dependent influence on student beliefs. 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. Their study went so far as to claim that the nature of the question or statement itself can influence or “prime” a students’ views and response, as observed in their interviews, but also relevant to survey items, making it particularly challenging to clearly evaluate a students’ perspective on mindset (Little et al., 2016). A deeper understanding of the various undergraduate chemistry mindset perspectives is needed, along with examination of contextual influences on the expression of these beliefs in chemistry courses.

5.1.1 Theoretical Framework

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, two implicit theories about the nature of intelligence were uncovered as an explanatory factor for these differences in behavioral responses by way of setting differential goals (Bandura and Dweck, 1985; Dweck and Leggett, 1988). An incremental theory of intelligence is a general belief that intelligence is an improvable quality and is associated with setting mastery goals. More closely linked to performance goals, entity theories of intelligence state that intelligence is an unchangeable quality (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 to failure and negative affect. These responses can serve to deflect from evaluations of their ability due to the low self-concept arising from encounters with failure. 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 through 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).

In order 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 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 incorporated a meta-analysis to tests the hypotheses embedded in the theoretical framework using path analysis modeling techniques. The model was
CHEMISTRY-SPECIFIC MINDSET

supported by the study results and provides a useful conceptualization of 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).

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 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. 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, but are useful for conceptualizing mindset in a STEM domain as more nuanced relative to general academic beliefs.

5.1.2 Study Goals and Design

The overarching purpose of this study is to examine chemistry mindset as a phenomenon within the context of introductory 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 examined on its own to consider how the individual student can be classified with respect to their expressed chemistry mindset beliefs and behaviors. Additionally, 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 do students’ chemistry mindset beliefs relate to their interpretations of challenge and behavioral responses?

2. How can differences in chemistry mindset be characterized considering the nature of abilities relevant to chemistry, interpretations of challenge, and responsive behaviors?

3. 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, a hypothetical mindset model based on literature was created as a lens through which to analyze each case. The model is presented in Figure 17 and relates three key mindset components repeatedly described in the literature: mindset, challenge, and behavior. At the center of these three lies ego threat, or the meaning associated
with challenge as a function of beliefs that determines behavioral responses. In order to analyze interview content through use of this model, it is necessary to create operational definitions of challenge, mindset, behavior, and ego threat. The research team-created definitions applied during analysis were: a) Ego Threat - An interaction of beliefs about intelligence with challenge indicating threat to one’s sense of self, producing defensive behaviors as a response. b) Behaviors - What students do when learning, challenged, or feeling threatened. 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.

*Figure 17.* Three-pronged mindset meaning model for case analysis.

In a similar manner to hypothesis testing, propositions are commonly developed for case study analyses (Baxter and Jack, 2008). For this study, a set of propositions have been created
based on relationships between challenge, behavior, and mindset discussed in the mindset literature for considering each individual case. Likewise, a few general propositions about possible types of mindset perspectives have been created through a consolidation of the literature for making case comparisons.

We can begin by considering the overlap of mindset and challenge from Figure 17 in presenting the associated propositions. When a challenge is present, a) growth mindset interprets challenge as a need to increase or modify effort strategies, and b) fixed mindset interprets challenge as indicative of lacking ability. When challenge is absent, a) growth mindset interprets the lack of challenge as a demonstration that previous effort has allowed relevant skills to be developed, b) 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 a) helpless responses such as avoiding demonstrating ability or evaluation, sabotaging performance by other means such as procrastination, giving up or disengaging emotionally to deflect blame on level of caring, and b) focus of attention on negative feedback and performance outcomes. Meanwhile, the interpretation of challenge as effort-related or “need-development” leads to a) mastery responses such as seeking help from other sources, altering strategies, exerting more effort, and increasing self-regulation, and b) focus of 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, a) the belief that necessary effort implies low ability reveals a fixed mindset, and b) the belief that effort is the means to improve at any ability
reveals a growth mindset. When considering students’ willingness to change, a) ignoring feedback as useful for improvement and decreasing effort reveals a fixed mindset, and b) attention to improving through feedback and increasing effort reveals a growth mindset.

We can contrast theoretical criteria for identifying growth mindset versus fixed mindset individuals. A student with a growth mindset a) believes that any ability can be developed or improved given the appropriate resources and will to do it, b) will not give up easily in the face of challenge, and c) will focus on understanding and mastery as a litmus test for success. Alternatively, a student with a fixed mindset a) believes that abilities tend to be naturally derived and explain the differences between people in achievement and intelligence, b) will more readily give up in the face of challenge, especially if it is the first serious challenge encountered in life, and c) will focus on achievement and competitive measures of success.

Finally, two middle mindset categories are possible based on discussions in the literature. The first type of middle mindset emphasizes natural strengths and weaknesses combining to form an individual’s intelligence through a multiplistic view of intelligence as a variety of equally valid types. The second type of middle mindset emphasizes that some abilities can be developed but others are more stable, thus having entity and incremental beliefs that are context-dependent.

5.2 Methods

5.2.1 Multiple Case Study Design

This study serves as a qualitative component within a larger study on chemistry-specific mindset and 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 the course of 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 (within-case analysis), and through comparison between cases to identify potential patterns of this three-pronged mindset model (Figure 17).

*Participant Recruitment and Case Selection*

The overall study was approved by the Institutional Review Board prior to any data collection. Participants were recruited from general or organic chemistry lecture courses via participation in a chemistry mindset survey at the beginning of the Fall 2020 semester. Students were awarded a negligible amount of extra credit for survey participation and indicated at the end of the survey whether they were willing to be interviewed. Students who stated they were willing to participate in interviews were contacted by email to schedule a meeting virtually. Students were informed that the interview would last no more than one hour and they would receive a $10 compensation for their time if selected. Selection for interviews was based on previous 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.
During Fall 2021, only case study participants were invited to participate in a follow-up
interview to gain additional insight into their views. For the second interview, a $20 gift
incentive was offered to ensure high participation and reduce attrition.

In order 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 were identified. Eight individuals were selected based on this criterion and all
had supplied data for at least three consecutive surveys during this time frame. Seven were
initially interviewed in Fall 2020 and one, Camille, was interviewed in Spring 2021. The case
study participant student characteristics are described in Figure 18 below. 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 in organic chemistry II courses were not included due to
participation exclusion once they were no longer enrolled in introductory courses (the second
consecutive semester). 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.
Figure 18: Multiple case study participant selection with student characteristics at the time of first interview and data sources.

5.2.2 Data Sources and Collection

Data from each case participant was 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 online course pages. During this time, the Chemistry Mindset Instrument (CheMI) 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. Mindset-related behavior items were adapted from Dweck’s Mindset Assessment Profile and were used to compare with beliefs statements in the CheMI versions. Likewise, a combination of theoretical
and interview descriptions of beliefs regarding others’ chemistry intelligence were used to create four items for use in surveys to compare with CheMI beliefs about the self. All measures, other than the CheMI, were measured using a 6-point Likert scale ranging from strongly disagree to strongly agree. The majority of the measures used are not discussed in this case study analysis, however, they are mentioned to provide context. All survey items or measures that are discussed in the results are provided in Appendix C.1.

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 in nature. The full initial interview protocol is found in Appendix C.2. Interviews took less than one hour and incorporated questions as well as several tasks to prompt deeper discussion of mindset topics. The tasks students completed during these interviews are presented in Appendix C.2. Interviews were conducted online using a virtual meeting platform and students were sent a Powerpoint© file containing the tasks prior to beginning. 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 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, after completing all tasks, students were asked to clearly state their mindset beliefs and explain why they hold such beliefs.

A second interview was requested during Fall 2021 from each of the case study participants. The protocol used for follow-up interviews was different from that used in the initial interviews and is provided in Appendix C.3. 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.

5.2.3 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 interview data pool from other participants in Fall 2020. Two researchers simultaneously coded the same interview file separately then met to discuss and negotiate codes. As described previously, 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, then repeated with each of the other two analysis lenses. Over time, new codes appeared 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 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 considered another data set, data saturation had been reached. This analysis is presented in Table 16. Additionally, interrater
reliability was examined after each interview and an acceptable Cohen’s Kappa value ($\kappa = .705$) was obtained in the final codebook development round with analysis of Isabel’s interview.

<table>
<thead>
<tr>
<th>Interview Participant (Code Development Rounds)</th>
<th>Jasmine</th>
<th>Quinn</th>
<th>Olivia</th>
<th>Vincent</th>
<th>Abraham</th>
<th>Isabel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base set (total number of codes)</td>
<td>29</td>
<td>31</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Run (number of new codes)</td>
<td>+29</td>
<td>+2</td>
<td>+1</td>
<td>+1, -1</td>
<td>+1, -1</td>
<td>+0</td>
</tr>
<tr>
<td>% saturation</td>
<td>--</td>
<td>93%</td>
<td>97%</td>
<td>97%</td>
<td>97%</td>
<td>100%</td>
</tr>
</tbody>
</table>

One final coder meeting was conducted to refine codes further and align names of each theme more closely with terminology from the mindset literature. The final codebook is presented in Table 17. Once the codebook and interrater reliability was established, 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 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.
**Table 16:** Interview analysis codebook descriptions and examples.

<table>
<thead>
<tr>
<th>Lens</th>
<th>Code</th>
<th>Description</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Behavior</strong></td>
<td>Avoidance</td>
<td>self-reliance, ignoring problems, avoiding help or evaluation</td>
<td>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.”</td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td>positive or negative comparison of performance or understanding</td>
<td>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.”</td>
</tr>
<tr>
<td>Decrease</td>
<td>Effort</td>
<td>procrastination, laziness, less effort than others, lack of effort, try less</td>
<td>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.”</td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td>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</td>
<td>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.”</td>
</tr>
<tr>
<td>Helplessness</td>
<td></td>
<td>self-doubt, low confidence, negative thoughts about ability to improve, questioning ability, blaming the topic for struggles</td>
<td>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?”</td>
</tr>
<tr>
<td>Mastery</td>
<td></td>
<td>utility value (usefulness of the content), interest in learning chemistry, relevant to life, process oriented, effort celebrated during</td>
<td>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</td>
</tr>
</tbody>
</table>
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 of chemistry, for understanding and mastering content.

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.

Yosef: “Ask for feedback on how I can improve in chem. I go to office hours, talk to my
<table>
<thead>
<tr>
<th>Challenge</th>
<th>Difficult</th>
<th>chemistry is hard, it's right or wrong, the content is complex or challenging to understand, not getting it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elle:</td>
<td>“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.”</td>
<td></td>
</tr>
<tr>
<td>Learning Environment</td>
<td>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)</td>
<td></td>
</tr>
<tr>
<td>Raquel:</td>
<td>“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.”</td>
<td></td>
</tr>
<tr>
<td>Low Dedication</td>
<td>not interested, amount of motivation prevents success, self challenges, laziness, procrastination, low dedication to success, low commitment, poor time management</td>
<td></td>
</tr>
<tr>
<td>Elle:</td>
<td>“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.”</td>
<td></td>
</tr>
<tr>
<td>Subject Ability</td>
<td>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</td>
<td></td>
</tr>
<tr>
<td>Camille:</td>
<td>“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.”</td>
<td></td>
</tr>
</tbody>
</table>
ability, mental block about changing

Tedious, Dense

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

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

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

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

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
| 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 |
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.”

5.3 Study Part 1: Modeling Student Mindset - A Within-Case Analysis

5.3.1 Results and Discussion

5.3.1.1 Analysis and Summary of Growth Cases: Yosef, Natalie, and Teresa

Case backgrounds

Yosef is a biochemistry major who plans to attend medical school. He has always had a lot of curiosity about science that stems from watching educational shows as a child. His family praised him growing up for his ability in school and cared a lot about his grades. Yosef took AP chemistry in high school because of his interest. He enjoys chemistry and does well by working hard.

Teresa is a premedical neuroscience major who hopes to become a pediatrician. Chemistry is a requirement for her career goals. She has always been passionate about helping people and used to participate in high school programs at a children's hospital. Teresa identifies as Hispanic American and her family originates from South America. She comes from a moderately affluent family and is the first person in her family to pursue a STEM degree. Teresa initially had very low confidence in general chemistry, attributed to low chemistry ability, but has much more confidence in her ability in organic chemistry. She mentions the reputation of...
organic was intimidating to her: “The stereotype of organic that I had always heard is, ‘Oh, it's super hard.’ And I'm sure that some people do find it that way, but for me, I've liked it a lot and it's been one of my favorite ones to do.” The enjoyment Teresa expresses in regards to organic is related to both her understanding and her improved grades.

Natalie is a post-baccalaureate premedical student. She originally pursued a pre-medical degree from a very difficult premed-intensive university that she perceived as having a weed-out approach for undergraduates, but changed major and obtained a degree in psychology. She describes herself as having imposter syndrome, which is attributed as the cause of her delayed pursuit of a medical career. She identifies as a 26-year-old white female who comes from a middle-class stable family. After working for a few years in wilderness medicine, she returned to school to pursue a medical degree. Enrolling in the current program was a tentative decision, but it has gone much better than she anticipated. As a post-baccalaureate student, there was a large gap between high school chemistry and her current chemistry courses for medical school prerequisites. Her confidence has shifted dramatically during the post-baccalaureate program. She self-describes as a nerd, saying that she enjoys learning difficult subjects. Despite having a very positive experience of chemistry in high school, the reputation of chemistry made Natalie a bit afraid to take it in college. But as she has worked through the classes, she has found that she is able to succeed and actually enjoys the content.

Mindset

Views on Effort and Development

All three of these students discuss the need to work hard in chemistry courses to succeed and to improve weaker abilities. They each acknowledge having peers who put forth less effort and are still able to do well, yet they generally believe everyone has to put in substantial effort in
chemistry. Teresa values effort and doesn’t think it reflects poorly on her ability if she has to work hard. “I would say that I'm very big on -- I think you can kind of tell with what I have been emphasizing, but effort. So, you can improve all these things if you put in the effort.” Teresa believes chemistry intelligence is something that can grow, and it grows as you experience more of chemistry. She uses her teachers and tutors as examples since they have more experience with chemistry and thus they have more intelligence for it. While in general chemistry, she said that as she progresses through organic and biochemistry, she will improve her chemistry intelligence with the effort she applies.

Initially, Natalie believed certain abilities in chemistry (namely visualization and memory) are very difficult to improve even with effort. At the follow-up interview, her views had changed because she had seen significant improvements in her own abilities from general to 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.” She says that she changes her chemistry intelligence through effort, practice, and finding her weak abilities to develop. She understands and knows much more than she used to.

In Yosef’s opinion, the biggest driving force to improving your chemistry intelligence is interest. He says that chemistry is tough and all people need to put in effort to succeed. But people who aren’t as interested in it might try to put in the minimum effort to get by and this can lead to more challenges in chemistry. Having a passionate teacher can persuade you to find the content interesting. When this happens, you want to do what it takes to get better.
“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.”

**Natural ability**

These students place little emphasis on natural abilities. They acknowledge that some people are gifted with certain abilities, but that everyone is capable of developing in whatever area of intelligence they wish to. Yosef says that natural ability is like a “God-given talent” that can come from how you’re born or “sprouts” from something in your life. He says that natural abilities for chemistry vary between people, but for him, connecting concepts and real world experiences are two things he’s always been good at. Creativity is something he’s never been good at, but that means he can develop it. He says visualization is hard for people and requires effort to get good at. He described anything he lacks naturally as something to be developed with effort.

Teresa defines intelligence as having a vast range of knowledge on different topics and being able to apply it in different contexts. She says that intelligence characteristics are developed generally and that you can improve with effort. She doesn’t believe natural abilities are genetic, but rather that they appear during development and just allows someone to have an easier time with certain types of learning. The only aspect of chemistry intelligence Teresa characterized as “natural” was strong memory. This was described as something that can be both natural and developed and her reasoning was that, with different strategies, people can train their
memory to improve it. She describes mathematical thinking, abstract thinking, logical reasoning, and problem-solving as developed abilities, but says they can be a bit harder to improve.

Natalie views intelligence as a willingness to learn from mistakes. This view is based on her observations that the doctors she has shadowed frequently express how little they know and their need to continue learning. Natalie believes that intelligence should be equally attainable for people as it is something that develops over time, but there could be major differences due to resources, obstacles, learning disabilities, or confidence.

“We all come into the world with certain strong suits and things that come easier to us. And also, there's like, born with it and then there's also resources provided during development. So, if your parents read to you a lot as a kid, you're probably going to be a better reader. And that in some ways throws off the innate measure, because it's harder to say if someone gets read to all the time and becomes a good reader, were they innately a good reader, or is it because they were read to all the time?...I think exposure to a lot of things sort of, as you're growing and developing and changing, is where you can really develop more skills whether or not you're naturally good at it.”

Behavior

These three students have allowed their experiences with failure to produce increased persistence when challenged. They have learned to ignore the inner thoughts of inadequacy and focus instead on improvement strategies. Yosef says he doesn’t avoid making mistakes, instead he tries to learn his best and doesn’t worry about them. He wants his chemistry work to be
evaluated because he knows that he is not an expert and he wants to improve. He says he attends office hours and asks for help from his instructor. He also says that making comparisons to other students is not beneficial, it only makes a person feel worse. So, instead of being competitive with others, he tries to focus on improving himself and experiencing small intrinsic rewards.

“[I’m] definitely not [competitive] anymore. It's more about just being a better version of myself. You know, like, if I get a B on this test, maybe I'll get an 85 on the next test, or a 90 on the next test. Just slight improvements, that's about it.”

Teresa displayed very large shifts in her behaviors as her confidence improved. She initially questioned her ability when she received low grades, but later said they motivate her to want to improve so that she can demonstrate to herself and her family her ability to succeed. In general chemistry, Teresa said that if other people were performing better than her, it made her feel upset; however, she is no longer making these comparisons because her confidence has increased in organic chemistry. She regularly seeks help from a tutor, as often as three times per week. She is open to feedback on how she can improve. She says that when she makes mistakes or gets the wrong answer, it motivates her to try to figure it out.

Natalie views grades as a way to gauge how well you understand compared to the instructor’s expectations. Her newfound confidence in understanding chemistry is much more important to her than grades and serve as her method of self-evaluation. She describes the need to figure out one’s weak areas of understanding and put in effort to target those. Natalie describes regularly approaching her instructors during office hours to improve her understanding
and ask for help. She says there is value in making mistakes, but it is important to try to figure out how to solve a problem correctly.

Interpretation of challenge

These three students interpret challenges as a sign that effort is needed to improve. Both Teresa and Natalie formerly wrestled with self-doubt in general chemistry when they received negative feedback, but learned to be more confident and resilient toward challenges by the time they were completing the organic chemistry sequence. Yosef discusses having learned this lesson as early as high school. He says that failure is a requirement to produce the drive to improve. He says that intelligence increases dramatically during the young adult stage of life because of the number of failure experiences they tend to encounter.

“"I'm really thinking about what that person goes through, how many failures they've had throughout their life, and how much they learned from those failures...I think failures are really critical...They get a better intuition and they understand the real world better, I would say. You know? They have more like real-world expectations and they just have a better understanding of the real world relative to, like -- maybe without failing, they...wouldn't really see reality as it is.”

Yosef described receiving a low grade on his first chemistry exam as a challenging experience. It made him realize that he needed to change his study habits. He works hard to stick to a routine and incorporate good strategies. Specifically, he had difficulties learning reaction
mechanisms because of the amount of memorization needed to predict outcomes of reactions. His response to this challenge is to “break it down.” He said the entire chapter can make him feel overwhelmed. So, he reads page by page then section by section. He tries to understand one concept fully before moving on to the next one.

Natalie describes challenges balancing work and school, but also switching to online learning during the time when they first learned about molecular orbitals. She took a break when she became overwhelmed, but then searched for useful videos to understand the concepts better. She says that initially, the state of being challenged means her ability is not quite where it needs to be, but she knows that can change as she puts in more effort to overcome it.

Teresa mainly discusses the time commitment needed as well as the building nature of conceptual information in chemistry. She says it is important to learn to balance chemistry with her other classes. In response, she sets aside time when she is feeling challenged to make sure she can work with her tutor, to go over her notes, and to practice. She has learned to set her tutoring schedule ahead of time to keep her accountable for regular practice.

Summary

To analyze this group’s overall mindset, the interactions of mindset, challenge, and behavior were considered according to how they were discussed in interviews. Figure 19 represents this analysis according to the mindset meaning model. These students view chemistry intelligence as something that can improve, no matter your natural abilities. They interpret challenge as an indication that they need to work harder to improve. They apply appropriate behaviors in the face of challenge and in the process of learning to develop and improve their skills. They are focused on self-improvements and persist in pursuing positive changes, even if
they are small. They avoid comparing to others and view everyone as equally able to improve as long as they are willing to do so. Despite differences in emphasis on interest (Yosef) versus developing confidence (Natalie and Teresa), all three can be summarized as having a growth mindset. The growth beliefs of Natalie and Teresa are slightly more tentative and newly developed, while Yosef has held these beliefs longer and thus is more stable in them.

Figure 19: A mindset meaning model analysis of growth cases’ chemistry experiences and beliefs.

5.3.1.2 Analysis and Summary of Middle Cases: Kevin, Johnny, and Camille

Case backgrounds
Kevin is a neuroscience major with scientific curiosity since a young age. He grew up watching shows related to neuroscience topics and greatly enjoyed AP psychology. He tentatively plans to attend medical school. Kevin identifies as Hispanic American male and says his mother is an immigrant. His family is middle income and very Americanized. When he was younger, Kevin was lazy with schoolwork and relied primarily on his ability to do well. He agrees that being smart can be considered part of his identity. He believes his brain works very well with math and logical reasoning and not well with artistic aspects. When applying to college, he faced challenges that made him reconsider his priorities. After rejection from the top two universities in the state, he had to develop a dedication to succeed to motivate himself to move forward in life. He became much more responsible in college with the increase in rigor. Kevin took honors general chemistry and did very well even though it was during online learning and felt that he was teaching himself. By the time he reached organic, he described chemistry as one of his favorite classes. Overall, he has a very positive attitude toward chemistry as a subject.

Johnny is a biology major with a premedical concentration. He has family influences that have pushed him toward medicine. Several of his relatives are or were doctors or medical researchers, including at the CDC. Because of these influences, he is particularly interested in cancer research. Johnny is a nontraditional student, meaning there was a gap between high school and college. He took one semester early on but then took a long break before returning to school. Johnny self-identifies as an African American male and a member of the LGBTQ+ community. His father is an African immigrant and his mother raised him alone, which put some financial strain on their household. His mom has played a significant role in how he views intelligence, in that she has a lot of specific knowledge about things. When he was younger, his family commented that he was smart because of how quickly and easily he
understood things. Johnny mentions having several natural abilities in the “left brain” category (music and arts, specifically). He does not have natural math and science abilities, but he has seen himself improve in them throughout his chemistry courses. Johnny used to have more negative feelings toward chemistry in high school. He was worried that in college the math would be too involved for him to like it. He was surprised at how much he liked general chemistry. In organic chemistry, however, he got to the point where he needed to drop the class because he wasn’t keeping up with it well enough to be successful. Despite this hurdle, he is not worried about taking it again, in fact, he thinks he’ll have an advantage with the previous content exposure.

Camille is a neuroscience major who hopes to become a neuro-oncologist. She has added a chemistry minor so that those courses can count toward part of her degree. She has wanted to be a doctor since a very young age. Camille is an immigrant student from Africa who has lived in the US since the age of seven. She attended a private boarding school for high school and was placed in the gifted program when arriving to an American school. Her parents have always emphasized education and grades. Her teachers have always perceived her as having high ability. Her first experience with chemistry in high school was negative due to a poor evaluation from her teacher based on her first exam score. Her attitude toward chemistry was one of dislike and she did not believe she was good at it. In general chemistry II, she experienced a change. This occurred when she began explaining concepts to others, including her supplemental
instruction leader, and found that she understood it much better than she believed she would. Additionally, her experience in organic chemistry has sparked a lot of interest.

**Mindset**

*Views on Effort and Development*

This group of students places a large amount of emphasis on effort to develop abilities despite believing that natural abilities provide advantages. For example, Kevin views some aspects of chemistry intelligence as less changeable and others as more changeable, but regardless nothing is “set in stone” and effort can be used to improve. Kevin believes he can improve his chemistry intelligence. He likes to believe it is for the most part in his own control. If he wants it to change, he must do what it takes to see that change. He does say that all students who put in the time can be successful. “Everyone has a different floor, but the ceiling, for the most part, lets you go as high as you want to. Whether your growth is linear, exponential, really fast growth, or decaying, depends on the person.”

Johnny also thinks that any aspect of chemistry intelligence can be developed, it just depends on how much time you’re willing to spend with it. Despite expressing that people have different natural abilities, he says that anyone can develop any area they are weak in. Johnny has seen himself improve in chemistry intelligence over time because he’s retained more information and come up with new ways to solve problems. He expresses that knowledge can grow. He
provides evidence for his improvement: that he is now able to apply it to his real life, such as understanding ingredients on labels.

“Mathematical thinking is just one of those things that is a hurdle for me. But I realize even within myself that my expectations of how much I was able to do that stuff or think mathematically were limited. I definitely am capable of doing more than I thought, as far as that's concerned. So, I feel like even my own perceptions of my own capabilities kind of expanded in this last semester. That's why I think - - if it can happen for me, then I feel like it can happen for anyone.”

Camille is a bit less convinced of the impact of effort, but believes that she can improve her chemistry intelligence, mainly because she has seen it happen in her own academics. She expresses having a mental block toward believing that she can 100% change her abilities in chemistry. She says that different people have different abilities, but also that their “negative mindset” can play a role in whether or not someone is successful in chemistry.

“It's when they're trying hard, but they're still always putting themselves down and saying, ‘I'm never going to be good enough at chemistry.’ And yet they're trying hard, that kind of negates itself. And so that's what I believe is one of the contributing factors to people not doing well in chemistry Cause they just decide off the bat like, ‘I'm not good at chemistry and never going to be good at
chemistry. Even if I try my best, I’m never gonna do well enough.’ And that's just going to set you up for failure off the bat.”

Camille also says that environmental factors influence how she feels about her ability to improve on a daily basis. “It depends on my mindset at the time. And as of right now, I feel like my mindset is set on I can change [my chemistry intelligence]. 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.”

Natural Ability

This middle mindset group emphasized beliefs that natural abilities are somewhat relevant to how easily people learn certain subjects or skills. Natural ability plays some role in explaining differences between individuals and their ability to succeed in chemistry. In the case of Camille, she expresses some abilities as natural and stable, while others are only developed. In Johnny and Kevin’s interviews, it became apparent that they believe people have certain starting points, but dependent on effort, any level of intelligence in any area can be developed.

Kevin views intelligence as a combination of a lot of things, but overall can be summarized as wisdom or “thoughtful actions.” He doesn’t think intelligence amount varies too much between individuals, just the types of intelligences people have. He also describes that people have different starting lines based on genetic or environmental factors that make them more or less prepared to participate in various activities. He describes people having different natural abilities in chemistry that make certain aspects easier or more challenging. For some
students, they can grasp that understanding much quicker and they are more likely to be the ones helping others.

“Having a natural ability means you understand it like that (quickly). And if you’re tested on it, or you need to use it as an actual life skill, you can also get better faster. Whereas having less of a natural ability for that, would mean just taking longer to understand the concept itself, or see how it's usable. You can still do it and you still get better at, it's just your natural ability part of it would be your baseline…Some people naturally get numbers better than others. Definitely it's a skill that can be practiced and the more you do it, you do get better at it. However, I get the impression that some people just don't click well with math. I don't know if it's not trying hard enough, or if they just aren't compatible. With this I might need to talk to more people to get a good opinion on it…Because I firmly believe there's nothing that can't be changed.”

Johnny says that people are gifted in different areas but still need to develop their natural abilities. If course content is more related to visual stuff, it will click with people who have more natural visual abilities. If it is more language oriented, it will click better for students who have better language abilities.

“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."

Camille expresses that she has natural abilities for math and writing and an aptitude for understanding patterns in chemistry. She describes intelligence as the characteristics of a good person: learning from mistakes, humility, and self-improvement. She emphasized “street smarts” (ability to navigate the real world) as opposed to “book smarts” (ability to navigate academic settings). She says that chemistry intelligence is understanding and applying knowledge about chemistry. In her opinion, when it comes to specific subjects, not everyone has the same intelligence for them. She gives the example of art class and says that she will never be creative and do well in art. She describes several aspects of chemistry intelligence as natural abilities. Namely, understanding, thinking abstractly, mathematical thinking, strong memory, creativity, and logical reasoning. Only one of these aspects is changeable (understanding) and the others are pretty much unchangeable.

“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.”

Behaviors

Depending on their perceived competence, these students display persistence and an emphasis on mastery. This group of students took pride in their willingness to help other students who were struggling to understand concepts. These were the only students who discussed teaching others and how that activity, paired with receiving support from their peers, boosted their own confidence in their understanding.

Kevin mentioned that he typically has very high grades in chemistry, and thus doesn’t focus on them. He describes holding high standards for himself in terms of understanding, well above the bare minimum. He describes using grades to measure how well he’s doing and how well he understands the content. Low grades mean that he needs to put in more effort to understand. He discusses the increased rigor of the work in college compared to high school and how it requires better time management and more effort to do well. Kevin is open to asking his instructor and peers for help and thinks that evaluation helps you improve. He says he views learning chemistry as a collaborative effort, rather than a competitive environment. He has taken on a leadership role in his chemistry classes by teaching others around him. He believes everyone in the class is trying hard and one’s results only matter for oneself.

Johnny emphasized understanding the concepts more than grades themselves. He sees grades as a reflection of his understanding. However, his low exam grade led to dropping organic chemistry I because he didn’t think an A was possible anymore. He says that how well he understands the material is evident in how he can come up with a creative explanation and help
others understand. He says this helps him feel intelligent. Johnny believes constructive criticism and evaluation are good things that are meant to help you get better. He finds mistakes as something to learn from. He doesn’t think comparing to others is helpful because there’s always someone better and worse than you in a subject. “I wouldn’t say I'm a competitive person in that sense. I think everybody has their lane. And you can have multiple people who excel in the field. It doesn't have to be one on top and everybody else is subordinate. I don't like that kind of mindset.”

Camille says that grades are definitely important because of their career implications and her family upbringing but she is learning to place less emphasis on them. She describes procrastination in preparing for her organic exams when her grades are high and is not proud of this behavior because she should manage her time better. She is willing to seek help when needed and says that making mistakes is important so you can see that you are improving. Mistakes seems to motivate her to figure out the answer and she feels proud when she can figure it out or understand better after trying hard. She is proud of her high grades in organic chemistry, but also takes pride in being able to help others understand. She says that she knows she has mastered a concept when she can explain it to others and find the pattern and thinks studying with other people helps her learn. She feels that she doesn’t completely fit in as a premedical student because she is not competitive toward others, but rather wants to help her peers. She
expresses that people can work together to leverage their different strengths and weaknesses and help each other to understand.

**Interpretation of challenge**

If faced with challenges, these students described enjoying them, like “solving a puzzle.” However, the degree of enjoyment in challenge is related to perceived competence levels. If they perceive themselves to be good at chemistry, challenge is not a threat but a sign to increase effort. If they perceive themselves to have low ability in an area (i.e. language skills, creative skills, interpersonal skills), they are more likely to interpret the challenge negatively. These students do associate some stress or frustration with lack of understanding, a less optimistic response to challenge relative to the growth group.

Johnny describes that his challenges in general chemistry often involved reading a question and not knowing where to begin. In organic chemistry, the challenge he discussed was not knowing how to check his work to see if he was solving problems correctly. He describes becoming exhausted by an overwhelming new topic that he didn’t get right away. Despite this feeling, he says he kept doing practice problems until it felt natural. In addition to searching online, he began asking peers how they solved the problems to see if he did them right.

Kevin mentioned his challenge was related to trying to keep the “rules” in organic chemistry straightened out. He gave an example of not understanding re and si faces the first time it was explained. He got lost and confused it with the concepts of pro-R, pro-S configurations and R, and S enantiomers. He says he tries to let the frustration and stress of not understanding something become productive and drive him to figure it out. If it’s too much and
he’s too exhausted, he knows he should take a break and come back to it when he’s feeling better. Taking a step back and slowing down can help see the bigger picture.

Camille describes a low ability to “use words” in chemistry and poor memory for terminology as her challenges in chemistry. She says that she likes challenges but this wasn’t always the case. In 5th grade, she felt challenged in math and science and gave up because she felt dumb. She says that she now knows not to have that “negative mindset” when she is challenged because she can overcome it. She describes searching online to find a better way to study something when she’s struggling and believes that effort is how you gain the ability necessary to do well.

Summary

These students have some balance between their emphasis on effort and ability. Johnny and Kevin both hold strong convictions that anyone can improve regardless of their “baseline” intelligence in an area and that intelligence is a dynamic characteristic. They also emphasize differences in natural abilities as an explanatory factor for ease of learning certain subjects. Camille emphasizes “mindset” as a driving force for overcoming obstacles in understanding, that is, a need to force confidence on yourself to believe and act on it. She also believes some abilities are mostly unchangeable, like her example of her lack of ability to use language in chemistry. All of these students support their self-confidence through teaching peers and studying with others. They tend to enjoy challenges to some degree, yet describe some frustration with them. They are all optimistic about the effect of effort on improvement and believe they have observed this in their own chemistry intelligence. This middle mindset group’s analysis model can be seen in Figure 20. In considering the additional dimension of “ability” versus “growth” (Kalender et al.,
Kevin and Camille both appear to believe that they have the necessary abilities and that they can grow. Kevin and Johnny apply this belief to others regardless of whether they have the necessary abilities to begin with or not. For this reason, it is possible that Kevin and Johnny’s views fall on the growth side of a **middle mindset** when considering others, while Camille leans more toward the fixed side with regard to others because she believes that weaker abilities are more stable.

**Figure 20:** The mindset meaning analysis of the middle mindset group’s chemistry experiences and beliefs.

### 5.3.1.3 Analysis and Summary of Fixed Cases: Raquel and Elle

**Case backgrounds**
Raquel is a premedical student and says that she is taking chemistry as an important stepping stone course for her future career. She states that her family was always supportive of her education. She says she’d like to think that she’s smart. She defends this by stating that she has mostly A’s in chemistry, yet sometimes doesn’t feel confident. Raquel says that she likes chemistry more than other sciences and that she finds it interesting.

Elle is a nutrition science major pursuing a career in internal medicine or endocrinology. She acknowledges that it is important to understand chemistry to be a good doctor. Her career interest came from watching her mom live with type 1 diabetes and all the medical care she required. Some of her mother’s doctors weren’t that great, so she aspires to be a good doctor and help people. Her parents work in education and emphasize being educated. She identifies as an African American female from a middle-income and stable home. Elle has always been good at math and science, while her sister is more talented in English and writing. She says that she has natural ability in math and science, but not in chemistry. She believes she is smart and capable, but less so in chemistry. Elle does not like chemistry because she cannot relate to it and it doesn’t come easily to her. During her second interview, she said that biochemistry is less uninteresting, but attributed that to the biology involved. She doesn’t try as hard in chemistry because she doesn’t care about an A as much for these classes compared to her other math and science classes.

Mindset

Views on Effort and Development

Both of these students described effort as something that impacts your understanding and grades, which in turn increases your chemistry ability. However, they both express that effort is
not likely to impact your chemistry intelligence much. This creates a distinction between chemistry ability and intelligence similar to responses seen in our earlier studies regarding terminology definitions (Santos et al., 2021). Raquel states that chemistry intelligence can somewhat be changed, but chemistry ability is more changeable. She doesn’t address how she would change her chemistry intelligence, but when discussing chemistry ability, she says that working hard is how you can improve your understanding and get to the point of doing well just like students with high natural ability.

“Your performance in the class, I think like...Where you start, whether you're a naturally chemically inclined intelligent person or not, you can still end up at that same point of having a high chemistry ability and getting like, A’s in the class and understanding the concepts. Yes, if you start further behind, you're going to work harder, but I feel like you are able to get to that point no matter where you start.”

Raquel values effort and regulates it to maintain good performance. At times, she “slacks off” and sees the effect that has on her grades. She mentions that she feels successful when the amount of effort she’s putting in is effective toward her understanding and performance. She says that having the drive and dedication to work on something also demonstrates intelligence. “I feel like a lot of these have to do with work ethic instead of direct intelligence, which to me is more important. I think it says a lot more about a person if you work for something than if it just comes easy to you.”

Elle believes her chemistry ability can improve and states that this would require effort such as practice, studying, and memorization. She says that improving her chemistry ability is
important to her because wants to do well on the MCAT (medical school entrance exam) and be a good doctor. Despite this, she does not put forth much effort in chemistry. She has a hard time motivating herself to work hard in chemistry and has to rely on extrinsic motivators, like being evaluated for medical school based on her grades. She sees herself often only trying the bare minimum to get a B in the class. “I was just giving up in the other semesters, really. Because I just naturally couldn't get it. And so yeah, somebody who doesn't just naturally have it, I think can still work to understand, to understand the concept. You’re not going to be a wiz, but you'll at least understand.” She says that the reason some students struggle so much in chemistry while others don’t comes down to their natural abilities that make them better or worse at chemistry.

**Natural Ability**

Both of these students view natural abilities as important for succeeding in chemistry. Raquel believes that if you have a natural ability, it is changeable, but if you do not have it, it is extremely difficult to change. Raquel labeled creativity, thinking abstractly, and visualization as natural abilities. She said if you aren’t born with these abilities, it is extremely difficult to be taught how to do or improve them. You’re either good at them or not. She says that “brain-wiring” is the reason behind why some students are more logical and others are more creative. She said logical reasoning, rapid comprehension, and problem solving are examples of things that would make someone inherently intelligent in chemistry. "I think being able to work through and solve problems at a fast and efficient rate shows a lot of intelligence, as well as being able to explain concepts to others.” Raquel says that some students don’t have the natural ability to get things quickly or easily in chemistry, but they can put in a lot of effort and improve their chemistry ability and obtain the same outcomes. These natural differences just require much
more effort. The explanation she provided for challenge level differences among students was that students have different natural abilities, different access to resources, and put in different amounts of effort.

Elle views people who have a college education, who are aware of the world, and can communicate well as intelligent. Despite this view of intelligence, she seems to view it as highly related to natural abilities. She said that some don’t have to try hard and can do well in chemistry, while others work hard and still struggle. She mentioned math-mindedness and strong memory as natural and important aspects of chemistry intelligence. Thinking abstractly was also an ability she placed as a natural ability important in chemistry. She believes that these three aspects are pretty stable abilities and make a difference for people in terms of how easily they can learn chemistry.

“A person with a natural ability, their family might have like -- a lot of their family would be considered smart. This is something that...is just in their DNA... it’s just something that they didn't really have to work too much for, but maybe work to improve. Developed with effort is something that you had to work at to improve, like, having to go to the... having to run longer distances to improve your running. Like, if you're not good at naturally running, then you run every day, and then you can become good at running.”

**Behaviors**

These two students exhibit different behaviors which could be attributed to differences in their perceptions of self-competence. Both are avoidant when it comes to negative feedback, but
Raquel is a bit more willing to push through challenges. Both experience some degree of ego threat when comparing their grades to others, yet Raquel more often compares to feel better about her grade. Raquel describes using her grades to monitor how effective the amount of effort she’s putting in is. She admits to sometimes letting other people’s lower grades boost her confidence when she’s unhappy with her own grade. She appreciates feedback on things that she did wrong so that she can learn, but only if it is constructive. If she knows she did something wrong, she says she doesn’t need someone else telling her. “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.” She doesn’t like making mistakes and would try to avoid them, but if she did make a mistake she would want to correct it. She also says she doesn’t skip hard problems because the only way to learn is to get through them.

“I definitely am very competitive, but not...I like to compete against myself instead of other people, because I know what I'm capable of. And if I know that I could have done better, I'll be upset with myself. But it's more of competing against myself than competing against others.”

Elle exhibits much more traditional fixed mindset behaviors due to the ego threat association with poor performance feedback and her beliefs about her low chemistry ability. She says that if she works hard and still gets a low grade, she feels dumb. Grades are highly important to her, as her main measure of success, and she has high standards for her own performance. She says that memorization is the key to learning chemistry and doing well. She expresses that she needs to get high grades because getting into medical school is a competition.
She later says that she’s most proud she hasn’t failed any biochemistry exams, but least proud of her C+ grade in organic chemistry 2. She doesn’t like being evaluated, but knows it is important if she wants to improve. She doesn’t ignore negative feedback because she should learn from a mistake. By the time she reached biochemistry, she had sought out a private tutor and working with the tutor helped her a lot. It makes her feel like not trying when she can’t get the problem right and she’s likely to skip challenging problems. Elle is competitive and doesn’t like when others are performing better than her. This comparison makes her feel dumb, even though she believes she has an average chemistry intelligence. She does not care about proving herself in chemistry to others in the class, but does feel the need to prove herself to medical schools.

“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.”

Interpretation of Challenge
There are some nuances in how these students interpret challenges. Raquel has high chemistry ability perceptions, therefore challenges are usually something she can overcome, but somewhat threatening to her self-perception. Elle, on the other hand, has low chemistry ability perceptions, so she feels helpless in the face of challenges. Challenge confirms her beliefs and she describes the need to “survive” the class.

The only challenge Raquel discussed was related to visualizing crystal structures. When she experienced that challenge, she searched online for images to see as many different representations as she could to try to visualize and understand it better. After that, she had an easier time visualizing things.

Elle says her main challenge was not knowing how to study the material in a way that helps her memorize it. Learning new ways to study for memorization has been her strategy to get better. She often had feelings of giving up earlier in her chemistry classes, but later on she found a tutor and found better ways to “survive” instead of failing. She said her main strategies now are to take a break from the challenging material, then come back and approach it another way. She emphasizes that repetition is the most helpful method, and that memorizing is key for chemistry.

Summary

Raquel and Elle were the only cases examined that reflected fixed beliefs in their challenge interpretations, expressed views, and responsive behaviors. However, they do not seem to belong fully in the same category as there are some key differences. Both expressed natural abilities as difficult to change, yet Raquel distinguished their malleability based on whether you have the natural ability or not. Both expressed some degree of threat from evaluation and negative performance feedback and the tendency to compare to others. They both view effort as
important, but more emphasis was placed on ability. The analysis through the mindset meaning model applied to these two fixed mindset case interviews is given in Figure 21.

Raquel’s overall mindset is slightly more complex to analyze relative to traditional descriptions of a fixed mindset and is best considered through the lens of the model proposed by Kalendar and colleagues (2022), in which views about self are distinct from views about others. Raquel views herself as a high-ability STEM student and believes that she has the natural abilities that lend success in chemistry courses. She simultaneously believes that she is able to grow in her natural chemistry abilities. When discussing her views about people in general, it becomes apparent that it is difficult for students lacking the appropriate natural abilities to grow in chemistry intelligence, yet they can improve their chemistry ability by way of obtaining higher grades through effort. She makes the distinction between who can grow based on relevant natural abilities and whether we are considering their intelligence in chemistry or simply their performance. Because she has high-ability perceptions, she views her challenges as indicative of low effort. Raquel's mindset is fixed, but focused on growing natural abilities.

Elle’s overall views are fairly straightforward to interpret based on the traditional mindset meaning system. She views herself as lacking natural ability in chemistry based on her experiences throughout chemistry courses. She is helpless to change her natural abilities, therefore she avoids chemistry if possible. Her lack of natural ability is likely the reason behind her dislike for chemistry and she justifies the lack of caring based on her interest. She relies on extrinsic motivators to get through chemistry. When she encounters challenge, she employs avoidance strategies despite knowing this harms her outcomes. She is prone to comparison with others and notices those that have natural abilities for chemistry. Elle distinguishes between chemistry intelligence and chemistry ability and implies that she can improve her ability through
effort, resulting in better understanding and grades. Her primary study strategy involves memorization because she does not see chemistry conceptually. She feels that she cannot relate to it and disengages from the content, only doing enough to “survive” it. Challenge is interpreted as a confirmation that she has low ability in chemistry and thus presents an ego threat.

Figure 21: A mindset meaning model analysis of the fixed mindset group’s chemistry experiences and beliefs.

5.3.1.4 Case Summaries by Coding Frequencies

Interviews were coded by considering each component of the mindset meaning model individually. Table 18 presents the coding frequencies for each case’s interview data as percentages of the number of times each category was discussed (behavior and mindset, note: challenges are not included in this analysis). Students in Table 18 are ordered from left to right according to the general mindset perspectives discussed in the previous section, with more fixed views on the left and more growth views on the right. It appears that coding frequencies for behaviors align most closely with the mindset perspectives assigned to each case based on their
interviews. For example, Yosef was categorized as having a growth mindset and had the highest percentage of growth behavior codes of all the cases, but did not have the highest percentage of growth mindset beliefs. In fact, the codes selected as fixed mindset beliefs resulted in Yosef yielding a higher percentage of fixed belief codes relative to Elle, who was identified as the most clearly fixed mindset case. The percentages of growth behaviors generally increase to the right and fixed behaviors generally decrease to the right. This suggests that mindset-related behaviors could be a clearer indicator of a students’ mindset relative to their beliefs alone. It may be helpful to triangulate a students’ chemistry mindset more appropriately through some combination of measuring beliefs and behaviors.

Table 17: Coding frequency analysis across cases as a percentage of the total number of codes in each category.

<table>
<thead>
<tr>
<th>Case</th>
<th>Elle</th>
<th>Raquel</th>
<th>Camille</th>
<th>Johnny</th>
<th>Kevin</th>
<th>Natalie</th>
<th>Teresa</th>
<th>Yosef</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total # Behavior Codes</strong></td>
<td>26</td>
<td>14</td>
<td>31</td>
<td>23</td>
<td>30</td>
<td>19</td>
<td>33</td>
<td>14</td>
</tr>
<tr>
<td>Avoidance</td>
<td>19%</td>
<td>7%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Comparison</td>
<td>12%</td>
<td>7%</td>
<td>0%</td>
<td>4%</td>
<td>7%</td>
<td>11%</td>
<td>12%</td>
<td>7%</td>
</tr>
<tr>
<td>Decrease Effort</td>
<td>15%</td>
<td>7%</td>
<td>10%</td>
<td>9%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Performance</td>
<td>19%</td>
<td>7%</td>
<td>29%</td>
<td>9%</td>
<td>17%</td>
<td>16%</td>
<td>21%</td>
<td>7%</td>
</tr>
<tr>
<td>Helplessness</td>
<td>15%</td>
<td>7%</td>
<td>6%</td>
<td>4%</td>
<td>3%</td>
<td>11%</td>
<td>18%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Percent Fixed Behaviors</strong></td>
<td><strong>81%</strong></td>
<td><strong>36%</strong></td>
<td><strong>45%</strong></td>
<td><strong>26%</strong></td>
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<td><strong>37%</strong></td>
<td><strong>52%</strong></td>
<td><strong>14%</strong></td>
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<td>13%</td>
<td>9%</td>
<td>13%</td>
<td>21%</td>
<td>6%</td>
<td>14%</td>
</tr>
<tr>
<td>Increase Effort</td>
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<td>0%</td>
<td>10%</td>
<td>22%</td>
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<td>12%</td>
<td>21%</td>
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<tr>
<td>Persistence</td>
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<td>43%</td>
<td>20%</td>
<td>22%</td>
<td>17%</td>
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<td>0%</td>
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<tr>
<td>Help Seeking</td>
<td>4%</td>
<td>7%</td>
<td>10%</td>
<td>13%</td>
<td>3%</td>
<td>11%</td>
<td>18%</td>
<td>7%</td>
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<tr>
<td><strong>Percent Growth Behaviors</strong></td>
<td><strong>19%</strong></td>
<td><strong>64%</strong></td>
<td><strong>55%</strong></td>
<td><strong>74%</strong></td>
<td><strong>70%</strong></td>
<td><strong>63%</strong></td>
<td><strong>48%</strong></td>
<td><strong>86%</strong></td>
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<td>4%</td>
<td>13%</td>
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<td>6%</td>
<td>6%</td>
<td>0%</td>
<td>3%</td>
<td>4%</td>
<td>5%</td>
</tr>
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<td>13%</td>
<td>9%</td>
<td>5%</td>
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<tr>
<td>Percent Middle Beliefs</td>
<td>23%</td>
<td>4%</td>
<td>16%</td>
<td>20%</td>
<td>12%</td>
<td>30%</td>
<td>17%</td>
<td>11%</td>
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<td>-----</td>
<td>-----</td>
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<tr>
<td>Willingness to Learn</td>
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<td>8%</td>
<td>11%</td>
<td>3%</td>
<td>4%</td>
<td>0%</td>
<td>0%</td>
<td>16%</td>
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<tr>
<td>Malleable</td>
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<td>15%</td>
<td>34%</td>
<td>23%</td>
<td>31%</td>
<td>29%</td>
<td>43%</td>
<td>16%</td>
</tr>
<tr>
<td>Maturation</td>
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<td>0%</td>
<td>2%</td>
<td>6%</td>
<td>4%</td>
<td>8%</td>
<td>17%</td>
<td>5%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Growth Beliefs</th>
<th>26%</th>
<th>23%</th>
<th>47%</th>
<th>31%</th>
<th>40%</th>
<th>37%</th>
<th>61%</th>
<th>37%</th>
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</thead>
<tbody>
<tr>
<td>Natural</td>
<td>37%</td>
<td>35%</td>
<td>19%</td>
<td>31%</td>
<td>27%</td>
<td>18%</td>
<td>9%</td>
<td>21%</td>
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<tr>
<td>Stable</td>
<td>0%</td>
<td>15%</td>
<td>8%</td>
<td>0%</td>
<td>2%</td>
<td>11%</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>Intelligence Comparison</td>
<td>14%</td>
<td>23%</td>
<td>10%</td>
<td>17%</td>
<td>20%</td>
<td>5%</td>
<td>9%</td>
<td>26%</td>
</tr>
</tbody>
</table>

| Percent Fixed Beliefs  | 51% | 73% | 37% | 49% | 34% | 22% | 53% |

5.3.2 Study Part 1: Conclusion

Evidence for the three general mindset groups of growth, middle, and fixed were observed across the eight cases via a within-case analysis. We can consider these students in groups to draw some conclusions about each mindset perspective. First, we can place Yosef, Natalie, and Teresa together for comparison of the growth perspective. To analyze this group’s overall mindset, the interactions of mindset, challenge, and behavior were considered according to how they were discussed in interviews. These students view chemistry intelligence as something that can improve, no matter your natural abilities. They interpret challenge as an indication that they need to work harder to improve. They apply appropriate behaviors in the face of challenge and in the course of learning to develop and improve their skills. They are focused on self-improvements and persist in pursuing positive changes, even if they are small. They avoid comparing to others and view everyone as equally able to improve as long as they are willing to do so. Despite differences in emphasis on interest (Yosef) versus confidence (Natalie and Teresa), all three can be summarized as having a growth mindset.

Next, we can combine results from Johnny, Kevin, and Camille for the middle perspective. These students have some balance between their emphasis on effort and ability.
Johnny and Kevin both hold strong convictions that anyone can improve regardless of their “baseline” intelligence in an area and that intelligence is a dynamic characteristic. They also emphasize differences in natural abilities as an explanatory factor for ease of learning certain subjects. Camille emphasizes “mindset” as a driving force for overcoming obstacles in understanding, a need to force confidence on yourself to believe and act on it. She also believes some abilities are mostly unchangeable, like her example of her lack of ability to use language in chemistry. All of these students support their self-confidence through teaching peers and studying with others. They tend to enjoy challenges to some degree, yet describe some frustration with them. They are all optimistic about the effect of effort on improvement and believe they have observed this in their own chemistry intelligence. In considering the additional dimension of “ability” versus “growth” (Kalender et al., 2022), Kevin and Camille both appear to believe that they have the necessary abilities and that they can grow. Kevin and Johnny apply this belief to others regardless of whether they have the necessary abilities to begin with or not. For this reason, it is possible that Kevin and Johnny’s views fall on the growth side of a middle mindset when considering others, while Camille leans more toward the fixed side with regard to others.

Lastly, Raquel and Elle were the only cases examined that reflected fixed beliefs in their challenge interpretations, expressed views, and responsive behaviors. However, they do not seem to belong fully in the same category as there are some key differences. Both expressed natural abilities as difficult to change, yet Raquel distinguished their malleability based on whether you have the natural ability or not. Both expressed some degree of threat from evaluation and negative performance feedback and the tendency to compare to others. They both view effort as important, but more emphasis was placed on ability.
Raquel’s overall mindset is slightly more complex to analyze relative to traditional descriptions of a fixed mindset and is best considered through the lens of the model proposed by Kalendar and colleagues (2022), in which views about self are distinct from views about others. Raquel views herself as a high-ability STEM student and believes that she has the natural abilities that lend success in chemistry courses. She simultaneously believes that she is able to grow in her natural chemistry abilities. When discussing her views about people in general, it becomes apparent that it is difficult for students lacking the appropriate natural abilities to grow in chemistry intelligence, yet they can improve their chemistry ability by way of obtaining higher grades through effort. She makes the distinction between who can grow based on relevant natural abilities and whether we are considering their intelligence in chemistry or simply their performance. Because she has high-ability perceptions, she views her challenges as indicative of low effort. Raquel's mindset is fixed, but focused on growing natural abilities.

Elle’s overall views are fairly straightforward to interpret based on the traditional mindset meaning system. She views herself as lacking natural ability in chemistry based on her experiences throughout chemistry courses. She is helpless to change her natural abilities, therefore she avoids chemistry if possible. Her lack of natural ability is likely the reason behind her dislike for chemistry and she justifies the lack of caring based on her interest. She relies on extrinsic motivators to get through chemistry. When she encounters challenge, she employs avoidance strategies despite knowing this harms her outcomes. She is prone to comparison with others and notices those that have natural abilities for chemistry. Elle distinguishes between chemistry intelligence and chemistry ability and implies that she can improve her ability through effort, resulting in better understanding and grades. Her primary study strategy involves memorization because she does not see chemistry conceptually. She feels that she cannot relate
to it and disengages from the content, only doing enough to “survive” it. Challenge is interpreted as a confirmation that she has low ability in chemistry and thus presents an ego threat.

5.4 Study Part 2: Reconsidering the Continuum - A Between-Case Analysis

Comparing across cases, it is apparent that students discuss very different factors as a rationale for their mindset beliefs. Likewise, the implications of their beliefs in their behaviors seem to be dependent on their self-efficacy 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, while only two expressed fairly fixed views.

None of the students’ perspectives completely overlapped, but several similarities can be highlighted. 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. Second, both Teresa and Natalie expressed surety that chemistry intelligence is improvable through effort, yet required performance feedback to create a sense of confidence that growth is possible for them as well. Another similarity was the strength of emphasis placed on natural abilities by both Camille and Raquel, yet they were able to believe themselves capable of growth in chemistry due to their own natural abilities for STEM subjects. Despite this similarity, Camille did express increasing chemistry intelligence as possible through effort focused on developing relevant abilities, though not all were changeable. Raquel expressed a higher percentage of abilities as difficult to change, showing a belief that natural abilities are mostly stable. This leaves Elle and Yosef on the far ends of the mindset spectrum from one another, Elle being most fixed in mindset and Yosef holding the strongest growth beliefs. A possible explanation for the strength of Yosef’s growth
convictions is his own high ability in chemistry, which he doesn’t attribute to natural ability, but rather effort and interest. If he believes he developed chemistry intelligence through combined effort and interest, then he must think that to be true for anyone. Elle has had the opposite experience. She has low interest and low perceived ability. She thinks the ability portion is natural and thus does not have interest in chemistry because it’s not easy or relatable. She does believe effort makes a difference in her performance, but maybe not as much her chemistry intelligence, which she doesn’t care as much about regardless.

Based on the similarities and differences discussed above, several categories of mindset perspectives can be defined. These mindset perspectives are presented in Figure 22 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 22 because their views are fairly 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 has to work hard to be good at chemistry. His main comparison between students who do well in chemistry and those who don’t was based on the amount of effort they apply as driven by their personal interest. He also stated that educators play a significant role in how personally interesting a course is through their own enthusiasm for the content.

Figure 22: Case participants’ mindset perspectives along a continuum.

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 as has been found significant in mindset studies regarding physics-specific beliefs (Kalender et al.,
Students’ beliefs about their own mindset 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 when they consider other people. Ultimately, a students’ deeply ingrained mindset beliefs about self will drive the achievement or avoidant behaviors associated with it. Figure 23 presents a two-dimensional translation from the single-dimension continuum in Figure 22 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, the most optimistic region of the plot, resembling the traditional view of a growth mindset most closely. For this reason, Yosef most obviously 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 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.
Figure 23: Qualitative placement of each case along two dimensions of mindset: myself and others.

To triangulate or corroborate the qualitative findings discussed above, comparing across cases, students’ survey responses across items regarding their self chemistry mindset, beliefs about the nature of chemistry intelligence for people in general, and their behaviors associated with mindset beliefs were compared. Similar to Figure 23, two-dimensional plots were created (Figure 24) using the average values students self-reported on a survey mid-study (Spring 2021 posttest). Figure 24a attempts to corroborate the qualitative self versus others plot described in Figure 23. The theoretical placement of Yosef in the top right quadrant aligns well with his self-report views from the survey when considering tercile trends of the entire sample. Kevin and Johnny hover near this region as well, as predicted from their interview content. Camille,
however, responded much more growth regarding self and others on surveys compared to her emphasis on natural abilities and context-dependence of her beliefs in interview sessions. Natalie also expressed a more growth view about herself compared to others on the survey, misaligned slightly with the views expressed in her interviews. Teresa’s placement in the bottom right quadrant in Figure 23 aligns well with her survey responses, confirming she has more fixed views about herself relative to others. Elle also reported fixed views in both dimensions as expected on the survey, corroborating her placement in the bottom left quadrant of Figure 23. Surprisingly, Raquel reported the most fixed views about others as well as fixed beliefs about her own chemistry intelligence. This could represent a change in her beliefs from the time of her interview in Fall 2020.

Figure 24b considers the relationship between students’ chemistry mindset about self and the behaviors associated with those beliefs as an implication of how deeply held they are. Similar self-placement of students is observed in this figure relative to Figure 24a. One exception is that Raquel and Teresa switch placement. Teresa reports using fixed mindset behaviors and Raquel exhibits growth mindset behaviors. In Teresa’s case, it could be that she had not quite made the shift toward growth beliefs about herself in Spring 2021. At the time of her second interview in Fall 2021, she expressed a much more optimistic perspective on her own ability to improve. Raquel, on the other hand, did describe many growth mindset behaviors in her interview despite having more fixed mindset beliefs, which can be explained by her high-self efficacy. Combining these results, the differing perspectives students put forth in their interview discussions align fairly well with the way they responded on the survey. It provides a bit more credence to the qualitative interpretations of each case taken on such a complex topic as mindset.
To address the second research question, rather than considering three categories of mindset (growth, middle, and fixed) as the traditional mindset literature suggests, 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.

5.4.1 Themes and Propositions (RQ3)

A few important themes were discussed by several students in this case study sample that shed light on the complexity of students’ mindset views. One such theme was interest, a necessary ingredient for the willingness to improve ones’ abilities. Yosef and Johnny both brought this aspect of motivation into the discussion. Johnny described interest as the key to determining who would have the dedication necessary to become a chemist. Yosef viewed
interest as necessary for learning chemistry as well, providing the drive to study and overcome obstacles. Yosef specifically mentioned the role his professors have in sparking his interest in a topic, making him more willing to apply the effort needed to understand a concept. This theme points to the relationship between mindset and motivation in determining achievement outcomes.

Another theme brought up by both Elle and Raquel was the *role of effort in ability but not intelligence*. Both of these students believed effort is valuable and necessary in chemistry, but they did not equate applied effort to increased chemistry intelligence. Rather, effort increases understanding and thereby performance. Intelligence is more closely related to how quickly one understands, therefore requiring less effort. It can be deduced then that effort and intelligence are inversely related to these students, which aligns very well with the traditional view of a fixed mindset (Siegle et al., 2009).

A third theme focuses on the cumulative nature of intelligence when it is defined as *development of knowledge*. Johnny and Teresa both expressed this view of intelligence and therefore both view it as something that develops with exposure. Johnny best explained this perspective in relation to his view of the importance of natural abilities by saying that natural ability is “like clay” and one must mold it into something useful. The exposure to content and effort applied can turn it into increased intelligence. Teresa contrasts this view in that she deemphasizes natural ability playing any role in one’s chemistry intelligence. She simply believes that the more you are exposed to and exert effort to understand, the more intelligent you are in that area. This “intelligence is knowledge” perspective was found to be a more flexible definition of intelligence in previous studies with chemistry students (Limeri et al., 2020; Santos et al., 2021), aligning well with growth mindset beliefs.
One last important theme to mention was related to people having a natural baseline intelligence in each area (i.e. math ability, visualization, etc.). Kevin, Johnny, and Natalie each contributed to this theme. Again, Johnny’s discussion of molding clay as developing and increasing one’s natural abilities was related to this theme. Kevin gave the clearest explanation of this view by saying that everyone has a “different floor” but the ceiling is generally unlimited. This is to say that it may be easier for some initially, but everyone is capable of reaching a high level intelligence in any area with the appropriate dedication and effort. These views align well with a growth mindset while also providing some rationale for the differences these students have observed in their peers’ readiness to learn chemistry.

It is also important to connect the findings from the examined cases back to the propositions derived prior to conducting the interviews:

5.4.1.1 Proposition 1: Mindset determines how a challenge is interpreted.

It was proposed that the difference between growth and fixed interpretations of challenge lies in whether the presence of a challenge indicates a need for effort or lack of ability. Likewise, the absence of challenge was proposed to lead 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 in regards to 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 did express 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 proposition was supported by the findings, yet students whose views were less on the extreme ends of the mindset continuum were more likely to display a mixture of interpretations depending on the presence or absence of challenge.

5.4.1.2 Proposition 2: How challenge is interpreted determines the response to it.

It was proposed that the interpretation of the presence of challenge as ability-related would 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” would 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 engaged in more focus 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 have a tendency to use their grades as an indicator of their improvement in understanding rather than as a comparison point with others. This proposition is supported by the results of this case analysis.
5.4.1.3 Proposition 3: Response to challenge is indicative of mindset.

It was proposed that students who believe the need for effort is a sign of low, stable ability likely have a fixed mindset. This view is coupled with the behaviors of ignoring feedback and decreasing effort because improvement is not viewed as possible. On the other hand, the belief that effort is the means to improvement of an ability reveals that a student has a growth mindset. This view is coupled with behaviors of increasing one’s effort and welcoming feedback to engage in willful improvement. Only one student clearly exhibited a tendency to decrease effort and ignore feedback due to the belief that the need for effort was a sign of her low ability. This student, again, was Elle. She discussed minimizing her effort in chemistry relative to other classes to avoid the disappointment of failure despite effort. Many students described welcoming feedback as a necessary ingredient to improvement and being more motivated to apply effort when a need arose, indicating their ability in an area needed development. These responses to challenge were more common and suggest that undergraduate students may be more aware of the benefits of applying effort and that most students face challenges in chemistry courses. It is likely that many have learned to adapt to challenging academic situations and act accordingly. This proposition was supported by the results of this case analysis; however, identifying a strong growth mindset is a bit less straightforward from this relationship due to the majority of students describing this response to challenge.
5.4.1.4 Proposition 4: A student with a growth mindset can be identified by 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, 
c) focuses on understanding and mastery as a litmus test for success

Considering the statements above, 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 all students in this study were taking part in 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, these factors should be considered careful as they heavily impact student 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 and Natalie were both considered to have growth mindsets and Johnny and Kevin were considered to lie on the growth end of the spectrum, slightly toward the center due to their emphasis on natural abilities. This proposition for identification of students with a growth mindset is mostly supported by the case analysis.

Proposition 5: Two types of middle mindset exist and can be identified by the following: 
a) Type 1 emphasizes natural strengths and weaknesses contributing to different types of equally valid intelligences. 
b) Type 2 emphasizes that some abilities can be developed but
others are more stable, thus having entity and incremental beliefs that are context-dependent.

Considering the above descriptions, we have evidence for both of these types of middle mindset perspectives. Kevin, Johnny, and Natalie expressed the Type 1 middle mindset view. They each discussed natural strengths and weaknesses and avoided comparisons between people when possible. Both Natalie and Johnny explicitly said they do not like comparing intelligence in chemistry with their peers because there are many equally useful abilities that different people have that lend them all to be successful in chemistry. Camille and Raquel both expressed some extent of the Type 2 middle mindset belief as well. Camille explicitly said that her mindset beliefs depend on the day and how she’s feeling about her ability. Both students stated that several abilities in chemistry are natural and can’t really change, but other abilities can be developed. Additionally, they believe that different people have different natural abilities and those that have a natural ability can increase it. Both of these types of middle mindsets are supported by the results of this case analysis and align well with the categorization of students toward the center of the mindset continuum. This does not exclude the possibility that other middle mindset categories may exist. It also does not mean that a student cannot fall into both a middle mindset and a growth or fixed mindset category. This suggests that cutoff values for identifying mindsets from quantitative measures and simple criteria for qualitative separation are oversimplifications of student perspectives.

Proposition 6: A student with a fixed mindset can be identified by 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, c) focuses on achievement and competitive measures of success

Multiple criteria were highlighted to identify students with a fixed mindset. Elle meets all three of these criteria and was classified from the analysis as having a fixed 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. This proposition as an indicator of fixed mindset holds when considering the results of this case analysis.
5.5 Conclusion

Within-case analysis of the mindset meaning model grouped by general mindset characteristics revealed some nuances in each category. First, it appears that multiple types of growth mindset may exist, some more deeply ingrained than others and in regard to self as well as others. Likewise, some variation in middle mindset beliefs were observed in that two students fell 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 different 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.

Furthermore, evidence for multiple dimensions of chemistry mindset beliefs were uncovered in this case study as a function of who is being considered (me 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 was found to correspond to interpretations of challenge and behavioral responses to challenge.

5.5.1 Implications for Research and Teaching

Mindset has long been conceptualized as a meaning system that individuals operate out of (Dweck et al., 1995b). 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 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 of these aspects has not been developed for undergraduate students and particularly not for domain-specific contexts. 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 can be aware of these differences 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 place different degrees of emphasis on the effects of effort toward impacting their intelligence or simply “ability.” Noticeable improvements in mastery or skills can be emphasized by instructors over simple grade improvements or “native abilities.” Another avenue for impacting students was suggested by one of the case participants, Yosef. He perceived his instructors as impacting his interest through their own 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.

5.5.2 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. These students’ views expressed in the study may contain more researcher interpretation relative to those who completed the full process. 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. 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.
6 CONCLUSION

Several distinct aspects of chemistry mindset beliefs have been uncovered throughout the studies presented here. Terminology associated with chemistry-specific mindset has been investigated for the purpose of appropriate item development. Evidence for the existence of different chemistry mindset perspectives was revealed qualitatively, encouraging improved instrument development. A series of instrument versions were created and modified for pilot testing and analysis through quantitative and qualitative means. As the implications of mindset are connected to challenge experiences, challenges and performance outcomes were examined in light of students’ mindset views and verified to be affected by student beliefs about learning chemistry. Finally, eight student cases were analyzed and compared to better understand the complexity of mindset in chemistry learning contexts as shown through the variety of experiences students shared. It was proposed that beliefs about others are relevant to chemistry mindset in addition to beliefs about the self and that many overlapping categories of mindset perspectives are present in chemistry courses. These findings enhance the theoretical understanding of mindset specific to chemistry undergraduate contexts and support more appropriate measurement for future research and teaching innovation.

In Chapter 2, we examined the common phrases used in domain-specific mindset instruments and compared them to the term “intelligence” as used in domain-general mindset studies. The observation of a large skew toward growth mindset, corroborated by other studies, indicated poor measurement of items using “chemistry intelligence” language, likely due to social desirability and ceiling effects. It was demonstrated that the term “chemistry intelligence” yields a variety of interpretations, but many of these are most relevant to chemistry academic environments and not to general intelligence or academics. Likewise, “chemistry ability” is
broadly defined by students, but is more associated with real-world or laboratory contexts as well as psychomotor or performance-oriented skills and is therefore less relevant for lecture contexts. Based on these findings, the decision was made to minimize usage of the terms “chemistry intelligence” and “chemistry ability” altogether in item development as they tend to be somewhat vague in meaning and students do not interpret them homogenously.

Another key finding presented in Chapter 2 was the presence of mindset-related talk in the absence of prompting. A simple prompt for the definition of “chemistry intelligence” yielded a large number of descriptions of chemistry mindset beliefs, such that criteria from literature could be used to sort them into three distinct categories. Chemistry mindset was measured using the CheMI Version 1 (see Chapter 3) and the average scores from these groups of students were compared and found to be significantly different. Despite clear differences of the group means, individual scores represented a range of reported views, such that each group heavily overlapped and was not easily identified through purely quantitative means. These findings supported the validity of the chemistry mindset construct as a set of beliefs about the nature of chemistry intelligence, yet revealed a great need for measurement resolution for clear identification of growth and fixed chemistry mindsets.

Chapter 3 discusses the CheMI development process and provides evidence supporting the validity of measurements made with the final version (Version 4). Cognitive interviews were used to gather qualitative support for item modification decisions and to confirm that student interpretations were in line with intended item meaning. Descriptive analyses of response distributions revealed improvements with several of the instrument modifications, further supporting the changes made toward the final version. The final version pilot data was examined for fit with theoretical factor structure as well as sufficient single-administration reliability. For
external validity support, correlations between measurements of chemistry mindset with the final version were compared at the pre- and post-semester survey administration with other variables commonly linked in the literature to the mindset meaning system. It was concluded that the developed instrument functions as intended with the sample and should be further tested with the target population for additional validity evidence. The CheMI is the first instrument developed for chemistry-specific mindset measurements and provides a vast improvement over the typical method of simple wording modifications to domain-general items.

In Chapter 4, we sought to characterize common challenges in chemistry and understand their relation to chemistry mindset as a perceived course outcome. Open-ended responses from students regarding their challenges in chemistry and ways they overcame them were coded inductively and found to yield several key themes. The challenges were found to fall under three main categories: Life, Academic, and Self. The subcategories of challenge were more specific to the students’ circumstances, but some challenges were likely perceived as outside of the students’ control, whereas others were more likely to be viewed as controllable and thus possible to overcome. For this reason, we also examined the positive responses to challenge employed by the group that overcame their challenges. These strategies used to overcome challenge also fell into three main categories: Informal, Authoritative, and Self-Improvement. It was proposed that some of these categories are likely more associated with fixed mindset views (informal and independent study methods) and others are likely more associated with growth mindset views (seeking help from the instructor or a tutor). However, when examining responses to multiple-choice items in a later semester, no significant differences were observed in help-seeking frequency or type between students with different challenge level perceptions.
Furthermore, we examined links between mindset and challenge as well as challenge perception and course performance. We found that students who perceived themselves as having overcome challenge were more likely to describe their challenge as “Time Management,” a more controllable challenge, whereas those who did not overcome challenge more often described their challenge as “Chemistry Ability,” suggesting that many of these students hold fixed mindset views and perceive themselves as helpless to overcome their struggles. In comparing specific challenges to chemistry mindset scores, students who selected the “Chemistry Ability” challenge also reported the lowest chemistry mindset. This mindset-associated challenge also yielded a difference in course performance relative to other students. Finally, the perception of challenge level was linked to chemistry mindset and performance. Students who perceived no challenge in the course had the highest mindset scores and performance while students who perceived not overcoming challenge had the lowest mindset scores and performance. These findings provide support for the link between mindset and challenge as well as their impact on performance in chemistry undergraduate courses.

Our final study in Chapter 5 described a multiple case analysis of eight students and was designed to provide a deeper understanding of chemistry mindset as a unique phenomenon. Data from the eight students were analyzed according to the literature mindset meaning system as a theoretical lens. Evidence for the relationships between mindset, challenge, and behaviors were uncovered in each case, yet not always aligning with the theoretical descriptions for particular mindset perspectives. This was explained using a between-case analysis, which uncovered a wider array of distinct perspectives than those defined in theory. Inclusion of the theoretical distinction between beliefs about self and others provided a better explanation for the observed variation in views. The findings from this study support expansion of existing chemistry and
STEM mindset measures, such as the CheMI, to include dimensions regarding beliefs about others as well as challenge interpretations and behavioral responses.

Substantial progress has been made in this series of studies toward understanding how mindset applies in general and organic chemistry lecture courses at the undergraduate level. Findings have mostly been in theoretical alignment, with some insight into the development of a more cohesive domain-specific theoretical framework. Specifically, this framework should include chemistry-specific challenges, interpretations and perceptions of these challenges, behavioral responses to challenge, and beliefs about the nature of chemistry intelligence in general as well as its malleability for the self. Space should be created for a wider spectrum of chemistry mindset perspectives compared to the traditional growth-fixed dichotomy with an undefined middle. Additionally, the context-dependence of views must also be considered as course environments vary greatly and have an impact on students’ operating meaning system, especially if they are vulnerable to stereotype threat in that context.

With the development of the CheMI, measurement of chemistry mindset about the self is now possible and can be useful for intervention studies, teaching practice, and further psychometric studies. With consistent observations of small effect sizes for the impact of mindset on outcomes in undergraduate courses (Costa and Faria, 2018; Sisk et al., 2018), it has been suggested that mediating variables play a highly significant role for this developmental stage (Macakova and Wood, 2020; Tempelaar et al., 2015). To conduct quantitative testing of the full chemistry mindset meaning system as a richer explanation for differential success in chemistry courses will require the development of a robust multidimensional measure to target all relevant aspects and model them alongside motivational and achievement outcomes according to theory.
This work provides sufficient evidence that mindset is highly relevant in chemistry courses and instructional practice can benefit from this understanding. The impact that chemistry instructors have through their course design and talk should be considered in light of how negative mindset-related interpretations of feedback can yield ego threat responses for students activating their fixed mindset knowledge structures (Dweck et al., 1995b). Emphasis on mastery-based outcomes and skill development with the reduction of performance-based comparisons can serve to promote a growth mindset learning environment without explicit mindset intervention or training. Instructional support in the form of study strategy development and multiple attempts for mastery can communicate an emphasis on effort and development rather than evaluation and competition. The ability to probe student mindset is also useful to monitor the effectiveness of teaching practices aimed at improving these aspects of the course environment. We anticipate that the CheMI and the associated theoretical background developed through this study will support efforts in both teaching and chemistry education research moving forward.
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7 APPENDICES

7.1 Appendix A: Supplemental Information for Chapter 2

7.1.1 Appendix A.1 Full codebook definitions table.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>context</td>
<td>definition</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>academic, in class</td>
<td>refers to school subjects and grades, does not acknowledge uses beyond education</td>
</tr>
<tr>
<td>lab</td>
<td>experimenting, testing in the lab, lab skills</td>
</tr>
<tr>
<td>real world, life</td>
<td>job, non-academic career skills, daily life</td>
</tr>
<tr>
<td>street and book smart</td>
<td>mentions both as valuable, explicitly mentions both contexts, all aspects of life</td>
</tr>
<tr>
<td>unspecified</td>
<td>too vague to imply a context</td>
</tr>
<tr>
<td>ability to apply</td>
<td>knowledge, concepts, skills</td>
</tr>
<tr>
<td>abstract thinking, visualization</td>
<td>mention of dimensionality, diagrams, structures</td>
</tr>
<tr>
<td>ambiguous</td>
<td>student did not explain well enough to interpret meaning</td>
</tr>
<tr>
<td>communicate, explain</td>
<td>teaching, explain to others, communicate effectively, speak well about knowledge, sound like you know what you're talking about</td>
</tr>
<tr>
<td>domain-specificity</td>
<td>different kinds of intelligences, multifaceted, better in one area than another</td>
</tr>
<tr>
<td>efficacy for learning</td>
<td>ease of learning, learn quickly, understand quickly, get it better than others, independence in learning</td>
</tr>
<tr>
<td>emotional maturity</td>
<td>adapting to new situations, objectivity, wisdom, good decision making</td>
</tr>
<tr>
<td>knowledge acquisition, retention</td>
<td>memorize, amount of knowledge, depth of knowledge, ability to retain information</td>
</tr>
<tr>
<td>mathematical thinking</td>
<td>math skills, math foundations</td>
</tr>
<tr>
<td>motivation</td>
<td>imposing structure on yourself for your own good, drive, willpower, interest, effort</td>
</tr>
<tr>
<td>performance, achievement</td>
<td>success, grades, performance, do well, test taking, demonstrating proficiency/understanding, competent</td>
</tr>
<tr>
<td>problem solving</td>
<td>critical thinking, analytical skills, logic and reasoning</td>
</tr>
</tbody>
</table>
### psychomotor
- do chemistry, actions, handling chemicals, performing experiments

### subjective
- the definition is subjective, defined by society, societal construct

### understanding
- conceptual understanding, connecting concepts

### unsure
- "I guess", not sure about definition, implying based on combined word definitions

#### origins

<table>
<thead>
<tr>
<th>term</th>
<th>definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>developed, experience</td>
<td>over time it is formed, experiences help to develop, using experience to help exert intelligence/ability</td>
</tr>
<tr>
<td>equality of attainment</td>
<td>everyone/anyone can be/is intelligent</td>
</tr>
<tr>
<td>foundation</td>
<td>having a good foundation, access to resources</td>
</tr>
<tr>
<td>innate</td>
<td>capacity, level, ability, natural attribute, born with it</td>
</tr>
<tr>
<td>malleable</td>
<td>can improve or worsen, changeable</td>
</tr>
<tr>
<td>relatively stable</td>
<td>unchanging, hard to change, fixed trait</td>
</tr>
<tr>
<td>requires effort</td>
<td>explicitly mentions hard work or effort as a cause/necessary for intelligence</td>
</tr>
</tbody>
</table>

#### Appendix A.2 Full separation criteria list for mindset group sorting.

<table>
<thead>
<tr>
<th>Mindset Group</th>
<th>Fixed</th>
<th>Middle</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chemistry intelligence is described as...

- something natural, an inclination, or superior ease of learning
- indicated that people have different levels
- an unchangeable quality about someone
- refers to being “smarter” than others or something only some people have
- multifaceted
- discussed personal growth
- inclusive beyond the educational sphere
- interest and motivation were mentioned as causes
- both growth and fixed statements together
- subjective/societal definition
- attributed to teaching/learning styles
- effort is necessary to develop it
- explicitly discussed improving intelligence
- anyone can achieve despite how they were born
- discussed overcoming challenges in chemistry
- learned over time, can increase, learning from cumulative experience

7.2 Appendix B: Supplemental Information for Chapter 3

7.2.1 Appendix B.1. Item level descriptives across CheMI versions

<table>
<thead>
<tr>
<th>CheMI Version</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version 1 (6-point Likert scale), Fall 2020 Pretest, N = 851</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Incremental Items**

1. No matter who I am, I can change my chemistry intelligence level. 4.85 1.13
2. I can always change my chemistry intelligence. 4.90 1.02
3. No matter how much chemistry intelligence I have, I can change it quite a bit. 4.74 1.00
4. I can change my chemistry intelligence level significantly. 4.73 1.12

**Entity Items**

1. I have a certain amount of chemistry intelligence, and I really can’t do much to change it. 2.22 1.08
2. My chemistry intelligence is something about me that I can’t change very much. 2.20 1.13
3. To be honest, I can’t really change my chemistry intelligence. 1.97 1.04
### Incremental Items

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>I can learn new things, but I cannot really change my level of chemistry intelligence.</td>
<td>2.34</td>
</tr>
</tbody>
</table>

Version 2 (6-point Likert scale), Fall 2020 Postest, N = 292 (randomly assigned 50%)

**Incremental Items**

1. I can change my problem-solving ability in chemistry. 4.96 0.92
2. My ability to understand concepts in chemistry is something I can improve. 4.96 0.94
3. My ability to apply chemistry knowledge is something I can change. 4.96 0.90
4. My ability to master chemistry content is something I can improve. 4.98 0.94
5. I can improve my ability to visualize chemical structures and processes in chemistry. 4.76 1.08
6. My ability to use mathematical and logical reasoning in chemistry is something I can change. 4.77 1.06
7. My overall chemistry intelligence is something I can change. 4.93 0.99

**Entity Items**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I can’t really change my problem-solving ability in chemistry.</td>
<td>2.21</td>
</tr>
</tbody>
</table>
2. | I can’t change my ability to understand concepts in chemistry much. | 2.27 | 1.05 |
3. | My ability to apply chemistry knowledge is something I can’t really improve. | 2.27 | 1.08 |
4. | My ability to master chemistry content is something I can’t improve much. | 2.14 | 1.05 |
5. | I can’t really improve my ability to visualize chemical structures and processes in chemistry. | 2.37 | 1.09 |
6. | My ability to use mathematical and logical reasoning in chemistry is something I can’t change very much. | 2.48 | 1.17 |
7. | My overall chemistry intelligence is something I can’t change. | 2.25 | 1.16 |

Version 3 (6-point Semantic Differential), Spring 2021 Pretest, N = 289 (randomly assigned 50%)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1.</td>
<td>My problem-solving ability in chemistry is something...</td>
<td>4.49</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
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</tr>
<tr>
<td>2.</td>
<td>My ability to understand concepts in chemistry is something...</td>
<td>4.64</td>
</tr>
<tr>
<td>3.</td>
<td>My ability to apply chemistry knowledge is something...</td>
<td>4.44</td>
</tr>
<tr>
<td>4.</td>
<td>My ability to master chemistry content is something...</td>
<td>4.46</td>
</tr>
<tr>
<td>5.</td>
<td>My ability to visualize chemical structures and processes is something…</td>
<td>4.22</td>
</tr>
<tr>
<td>6.</td>
<td>My ability to use mathematical and logical reasoning in chemistry is something...</td>
<td>4.46</td>
</tr>
<tr>
<td>7.</td>
<td>My overall chemistry intelligence is something…</td>
<td>4.55</td>
</tr>
</tbody>
</table>

Version 4 (10-point Semantic Differential) Fall 2021 Posttest, N = 436

<p>| | | | | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>My problem-solving ability in chemistry is something...</td>
<td>6.93</td>
<td>2.06</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>My ability to understand concepts in chemistry is something...</td>
<td>7.08</td>
<td>2.05</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>My ability to apply chemistry knowledge is something...</td>
<td>6.77</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>My ability to master chemistry content is something...</td>
<td>6.83</td>
<td>2.28</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>My ability to visualize chemical structures and processes is something…</td>
<td>6.48</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>My ability to use mathematical and logical reasoning in chemistry is something...</td>
<td>6.91</td>
<td>2.03</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>My overall chemistry intelligence is something…</td>
<td>7.00</td>
<td>2.15</td>
<td></td>
</tr>
</tbody>
</table>

7.2.2 Appendix B.2. Modified measures used in Fall 2021 pretest survey

<table>
<thead>
<tr>
<th>Measure / Construct</th>
<th>Original Subscale</th>
<th>Modified Subscale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achievement Goal Questionnaire / Performance-Approach</td>
<td>1. It is important for me to do better in this class than other students. 2. It is important for me to do well compared to others in this class. 3. My goal in this class is to get a better grade than most of the other students.</td>
<td>1. It is important for me to do better in chemistry than other students. 2. It is important for me to do well compared to others in chemistry. 3. My goal in chemistry is to get a better grade than most of the other students.</td>
</tr>
<tr>
<td><strong>Achievement Goal Questionnaire / Mastery-Avoidance</strong></td>
<td>4. I worry that I may not learn all that I possibly could in this class.</td>
<td>4. I worry that I may not learn all that I possibly could in chemistry.</td>
</tr>
<tr>
<td></td>
<td>5. Sometimes I'm afraid that I may not understand the content of this class as thoroughly as I'd like.</td>
<td>5. Sometimes I'm afraid that I may not understand chemistry content as thoroughly as I'd like.</td>
</tr>
<tr>
<td></td>
<td>6. I am often concerned that I may not learn all that there is to learn in this class.</td>
<td>6. I am often concerned that I may not learn all that there is to learn in chemistry.</td>
</tr>
<tr>
<td><strong>Achievement Goal Questionnaire / Mastery-Approach</strong></td>
<td>7. I want to learn as much as possible from this class.</td>
<td>7. I want to learn as much as possible from this chemistry class.</td>
</tr>
<tr>
<td></td>
<td>8. It is important for me to understand the content of this course as thoroughly as possible.</td>
<td>8. It is important for me to understand chemistry content as thoroughly as possible.</td>
</tr>
<tr>
<td></td>
<td>9. I desire to completely master the material presented in this class.</td>
<td>9. I desire to completely master the material presented in chemistry.</td>
</tr>
<tr>
<td><strong>Achievement Goal Questionnaire / Performance-Avoidance</strong></td>
<td>10. I just want to avoid doing poorly in this class.</td>
<td>10. I just want to avoid doing poorly in chemistry.</td>
</tr>
<tr>
<td></td>
<td>11. My goal in this class is to avoid performing poorly.</td>
<td>11. My goal in this chemistry class is to avoid performing poorly.</td>
</tr>
<tr>
<td></td>
<td>12. My fear of performing poorly in this class is often what motivates me.</td>
<td>12. My fear of performing poorly in chemistry is often what motivates me.</td>
</tr>
<tr>
<td><strong>Motivated Strategies for Learning Questionnaire / Self-Efficacy</strong></td>
<td>1. I believe I will receive an excellent grade in this class.</td>
<td>1. I believe I will receive an excellent grade in this class.</td>
</tr>
<tr>
<td></td>
<td>2. I'm certain I can understand the most difficult material presented in the readings for this course.</td>
<td>2. I'm confident I can understand the basic concepts taught in this course.</td>
</tr>
<tr>
<td></td>
<td>3. I'm confident I can understand the basic concepts taught in this course.</td>
<td>3. I'm confident I can do an excellent job on the assignments and tests in this course.</td>
</tr>
<tr>
<td></td>
<td>4. I'm confident I can understand the most complex material presented by the instructor in this course.</td>
<td>4. I expect to do well in this class.</td>
</tr>
<tr>
<td></td>
<td>5. I'm confident I can do an excellent job on the</td>
<td>5. I'm certain I can master the skills being taught in this class.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Considering the difficulty of this course, the teacher, and my</td>
</tr>
</tbody>
</table>
assignments and tests in this course.
6. I expect to do well in this class.
7. I'm certain I can master the skills being taught in this class.
8. Considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class.

- Elliot and McGregor (2001) A 2×2 achievement goal framework.

### 7.2.3 Appendix B.3. Cognitive interview protocol used in Spring 2021

#### Spring 2021 Cognitive Interview Protocol: Chemistry Mindset Instrument

1. Student reads and signs the consent form before beginning the interview.
2. Researcher thanks student for participating and initiates with a few questions about their experience in the course.
3. Researcher instructs student to complete a series of several activities using the WebEx drawing tools and has the student project the activity documents on the screen as they work.
4. The student circles or crosses out items based on whether they correspond to their own beliefs about chemistry intelligence or behaviors in challenging chemistry scenarios.
5. After the student has responded to all items, the researcher will ask further questions and prompt for the next part of the activity, such as sorting remaining items into categories.
6. The researcher will ask the student questions about why they categorized items in this way.
7. The researcher will then show the student responses they gave in their survey earlier in the semester and ask about why they selected those answer choices (do they actually believe this or what other reason might they have chosen it?). Any discrepancies between responses on the survey and during the previous activities can be discussed.
8. The researcher will then ask the student to draw several graphs based on their own beliefs and discuss them in terms of comparing and contrasting their graphs/shapes.
9. The researcher will ask final open-ended questions to conclude the interview.
10. The student will acknowledge receipt of the gift card for participation.

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

**Phase 1: Beginning questions to practice talking**
• Personal challenge, effort, and engagement in chemistry - previous and present experience?
• Personal interest in chemistry, reason for taking it, and career goals?
• Meaning of natural ability?
• Interest and natural - can you have something naturally that doesn’t interest you? Is interest natural or developed?
• Comes easily vs natural - are different things natural for different people?

Phase 2: Chemistry abilities sorting task
Provide instructions to the student that they should dictate aloud how they wish to sort the abilities into categories. They can create any number of categories as they wish.

Sort the below abilities into categories

- problem solving in chemistry
- applying knowledge in chemistry
- mastering chemistry content
- visualizing in chemistry
- mathematical and logical reasoning in chemistry
- understanding chemistry concepts
- overall chemistry intelligence

Appendix B Figure 1. Aspects of chemistry intelligence sorting task

• Ask students to label or name each category
• Ask for definitions of each term in chemistry

Phase 3: Chemistry mindset items
• Give Likert scale version first (Version 1). Ask student to respond to all aloud. Are they still reading each one?
• Ask how they would respond on a 10 point semantic scale (Version 4)
• Ask why they would choose that value, what does that number mean in words?
• Ask to compare 10 and 6 point scale (Version 3)
• Ask to compare Likert scale version (Version 2) - how would you respond and why?
How does the format impact your answer or understanding of the item?

Items:
1. My problem solving ability in chemistry is something...
   1 I can't change at all   2 3 4 5   6 I can change a lot
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…

Phase 4: Final questions
Where do you think your chemistry intelligence comes from? Is this true for others?
Do you believe your chemistry intelligence can change and what led you to believe that?

### 7.3 Appendix C: Supplemental Information for Chapter 5

#### 7.3.1 Appendix C.1. Survey measures and open-ended items associated with multiple-case analysis

<table>
<thead>
<tr>
<th>Survey Measures/Scale</th>
<th>Items</th>
<th>Scale Mean</th>
<th>SD</th>
<th>Terciles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry Mindset (self)/10-point semantic differential</td>
<td>1. My problem solving ability in chemistry is something...</td>
<td>6.93</td>
<td>1.68</td>
<td>&gt;7.57</td>
</tr>
<tr>
<td></td>
<td>2. My ability to understand concepts in chemistry is something...</td>
<td></td>
<td></td>
<td>7.57-6.29</td>
</tr>
<tr>
<td></td>
<td>3. My ability to apply chemistry knowledge is something...</td>
<td></td>
<td></td>
<td>&lt;6.29</td>
</tr>
<tr>
<td></td>
<td>4. My ability to master chemistry content is something...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. My ability to visualize chemical structures and processes is something...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. My ability to use mathematical and logical reasoning in chemistry is something...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. My overall chemistry intelligence is something...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature of Chemistry Intelligence (others)/6-point Likert</td>
<td>1. Some people naturally understand chemistry more easily.</td>
<td>4.15</td>
<td>0.91</td>
<td>&gt;4.50</td>
</tr>
<tr>
<td></td>
<td>2. Some people are just smarter in chemistry and can do well without much effort.</td>
<td></td>
<td></td>
<td>4.50-3.75</td>
</tr>
<tr>
<td></td>
<td>3. If you have to work harder than others in chemistry, it doesn’t come naturally to you.</td>
<td></td>
<td></td>
<td>&lt;3.75</td>
</tr>
<tr>
<td></td>
<td>4. Students who pick up on chemistry concepts faster are gifted.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incremental Behaviors/6-point Likert</td>
<td>1. I prefer challenging chemistry work that I'll learn from, even if I make a lot of mistakes.</td>
<td>4.03</td>
<td>0.92</td>
<td>&gt;4.50</td>
</tr>
<tr>
<td></td>
<td>2. When something in chemistry is hard, it just makes me want to work more on it, not less.</td>
<td></td>
<td></td>
<td>4.50-3.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;3.75</td>
</tr>
</tbody>
</table>
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.

| Entity Behaviors/6-point Likert | 1. I prefer chemistry homework that I can do perfectly without any mistakes. | 3.53 |
|                                | 2. When I have to work hard in chemistry, it makes me feel as though I'm not very smart. | 1.11 |
|                                | 3. I often question whether I can actually improve my ability in chemistry. | >4.00 |
|                                | 4. When I experience failure at a learning task in chemistry, such as getting homework problems wrong, I feel less motivated to continue trying. | 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. |

7.3.2 **Appendix C.2. Initial in-depth semi-structured interview protocol with tasks**

**Fall 2020 Semi-Structured Interview Protocol**

1. Student reads and signs the consent form before beginning the interview.
2. Researcher thanks student for participating and initiates with a few questions about their experience in the course.
3. Researcher instructs student to complete a series of several activities using the WebEx drawing tools and has the student project the activity documents on the screen as they work.
4. The student circles or crosses out items based on whether they correspond to their own beliefs about chemistry intelligence or behaviors in challenging chemistry scenarios.
5. After the student has responded to all items, the researcher will ask further questions and prompt for the next part of the activity, such as sorting remaining items into categories.
6. The researcher will ask the student questions about why they categorized items in this way.
7. The researcher will then show the student responses they gave in their survey earlier in the semester and ask about why they selected those answer choices (do they actually
believe this or what other reason might they have chosen it?). Any discrepancies between responses on the survey and during the previous activities can be discussed.

8. The researcher will then ask the student to draw several graphs based on their own beliefs and discuss them in terms of comparing and contrasting their graphs/shapes.

9. The researcher will ask final open ended questions to conclude the interview.

10. The student will acknowledge receipt of the gift card for participation.

**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?)
- STAR item: 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**
- 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 C Figure 1. Entity behavior item task**
Appendix C Figure 2. Incremental behavior item task

Phase 3a: Beliefs about cognitive abilities important to chemistry intelligence selection activity

- 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 C Figure 3. Chemistry intelligence aspects task

Phase 3b: Beliefs about chemistry intelligence cognitive abilities origins sorting activity

- 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 C Figure 4. Natural and developed chemistry intelligence aspects sorting task

Phase 3c: Beliefs about chemistry intelligence cognitive abilities malleability within origin sorting activity

- 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 C 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

- 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 C 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?

7.3.3 Appendix C.3. Follow-up semi-structured interview protocol

Fall 2021 Follow-up Interview Protocol: Multiple Case Study

1. Student reads and signs the consent form before beginning the interview.
2. Researcher thanks student for participating and initiates with a few questions about their experience in the course.
3. The researcher asks student a series of questions which were not fully addressed in previous interview to gain further insight into the student’s beliefs and behaviors.
4. After the student has responded to all questions, the researcher will show the previously completed activities from the prior interview and ask questions about why they gave certain responses and whether they still agree with them.
5. The researcher will then show the student responses they gave in their survey earlier in the semester and ask about why they selected those answer choices (do they actually believe this or what other reason might they have chosen it?). Any discrepancies between responses on the survey and during the previous activities can be discussed.
6. The researcher will ask final open-ended questions to conclude the interview.
7. The student will acknowledge receipt of the gift card for participation.

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?