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Chemical Education Research

Characterizing Mindset-Related Challenges in Undergraduate Chemistry Courses

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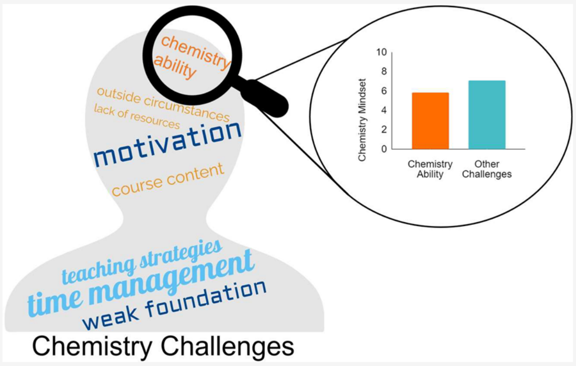
ABSTRACT: Science, technology, engineering, and mathematics (STEM) courses are considered to be challenging for students and may present unique challenges for each domain. This study addresses a gap in the research literature by investigating the challenges students face in general and organic chemistry lecture courses. Students provided information regarding their perceptions of success or failure in the face of challenges. Survey responses were used to examine the types of challenges students commonly face in chemistry. Frequencies of challenge types were compared across groups of students who perceived themselves as either having overcome their challenge or not. A significant difference in performance was observed for these two groups across the semester. One specific challenge, chemistry ability, was identified as relevant to mindset theory, was more prevalent among students who did not overcome their challenges, and showed decreased performance relative to other challenges. Students experience a wide range of challenges in chemistry courses, and these interact with their mindset and impact their performance. Modifications to instruction can address many of these challenges and encourage persistence toward success.



KEYWORDS: *Chemical Education Research, First-Year Undergraduate/General, Second-Year Undergraduate*

■ 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.[1−3] Courses such as these have a high probability of presenting students with academic challenges, which is corroborated by the high failure rates across institutions.[4−6] 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.[7−11] 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.[11,12]

Mindset is described as a context-dependent belief system that can be influenced by a variety of factors,[13] including perceived instructor mindset and cultural STEM stereotypes about who can achieve in these domains.[14,15] Cultural beliefs perpetuated about STEM fields, and specifically chemistry, may influence students[16] to believe that these subjects are suited to those with "natural" science and mathematical abilities[17,18] and as such they 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.[19−21] 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.[12]

If no challenge presents itself, mindset may be less relevant, other than theoretical links to goals of performing well over deep learning.[7,22] 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.[11,22] The type of challenge a student perceives may pose a threat to the self—that will reveal one's low ability or simply signal a need for effort.[7] 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 first characterize the challenges

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commonly encountered by students in these courses and their implications.

■ 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.[23] Individuals can hold various levels of each of these beliefs simultaneously, and these levels can change with context and over time.[13,18,24] 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.[22] 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.[11,22] When operating out of a growth mindset, a student focuses more on improvement, effort and the process of learning.[7,23] 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.[22] 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.[7,11]

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.[7,23] These behaviors are characterized as mastery responses to challenge and yield higher likelihood of successful outcomes.[24] 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[25] or task avoidance so that low effort is the attributable cause for failure.[7] These maladaptive behaviors are characterized as helpless responses to challenge and likely result in relatively poor outcomes.

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.[7] 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.[4] observed that help-seeking behaviors in organic chemistry courses, such as attending office hours or problem-solving help sessions, serve 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.[19] 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[26] 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.[27] 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.[28] 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.[28] 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.

■ 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?

■ METHODS

The work presented here is an exploratory portion within the context of a larger study on the influence of mindset beliefs in the undergraduate chemistry course experience.[29] A goal of this exploratory phase is to understand how challenges may interact with chemistry mindset beliefs and course perform-

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ance. It is 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.

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 U.S. in December 2020 and December 2021. The end of the semester was selected so that students could reflect on their challenge experiences throughout the course and their relative success in overcoming them. During the Fall 2020 semester, all courses at the institution were offered virtually and 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 few 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 nonconsent 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 preprofessional major (87.4%). Approximately half of the sample came from low socioeconomic backgrounds (as indicated by Pell Grant eligibility, 49.3%) and about one-third were first-generation college students (30.8%). The sample was highly diverse academically and demographically, reflective of institutional diversity. A total of 1,375 students participated in the surveys. The breakdown of the student characteristics and participation rates by course is provided in Table 1.

After removal of nonconsenting or careless respondents (according to aforementioned quality controls), a total of 1,135 participants' data remained for analysis. In Fall 2020 there were 727 participants, and of the 446 participants in Fall 2021, grade data were available for 408.

Table 1. Survey Respondent Rates (Including Careless Responders) and Student Characteristics

characteristic	Fall 2020 N = 806	Fall 2021 N = 569
course level participation rate (%)		
General Chemistry I	17.2	64.8
General Chemistry II	78.3	53.9
Organic Chemistry I	51.8	79.7
Organic Chemistry II	22.7	65.5
major (%)		
chemistry/biochemistry	8.1	7.2
other STEM/preprofessional	85.3	91.3
non-STEM	6.6	1.6
race/ethnicity (%)		
Black/African American	31.5	36.3
Asian	28.0	28.0
White (non-Hispanic origin)	16.6	14.3
Hispanic	9.6	11.7
Other	4.3	7.2
Pell Grant eligibility (%)	47.6	52.2
first-generation status (%)	29.2	33.6

■ 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.,[27] 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" (n = 55) if they indicated they did not face any challenges, "Overcame Challenge" (n = 421) if they indicated that they faced challenges and they overcame them, and "Didn't Overcome Challenge" (n = 250) 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 "Overcame Challenge" group was directed to respond to the prompt, "Please describe these experiences with challenge during this semester of chemistry briefly and what specifically you did to overcome them." The "Didn't Overcome Challenge" group was prompted to respond to the following: "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 survey was designed to build on the findings from the open-ended responses analyzed the previous year (Fall 2020). Students again responded to the two sorting questions to define the challenge level groups. Afterward, they were directed to respond to multiple-choice prompts regarding the type of challenge they faced and how they sought help to overcome them. Students were prompted to provide their primary challenge as well as their second greatest challenge in the course. The multiple-choice prompts (Table 2) were created using the coding themes uncovered in the previous year (Supporting Information). These items provided answer choices that reflected the types of challenges students described facing in the course. An "other" option was provided, but written-in responses fell under previously defined coding categories and were reassigned to the appropriate challenge category. 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).

Measures and Grades

Students' chemistry mindset beliefs were measured using the seven-item Chemistry Mindset Instrument.[30] Responses were measured using a 10-point semantic differential scale across a

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Table 2. Multiple Choice Prompts Used in Fall 2021 Developed from Coding themes

prompts	answer selections	definitions provided to students
Please select (1) the primary challenge and (2) the second greatest challenge you faced in chemistry this semester.	time management	turning things in on time, procrastination, balancing work and schedule, keeping up with content
	motivation	focus, distractions, low importance
	course content	difficulty of the material, large amount of content, lack of understanding
	lack of resources	schedule conflicts, poor communication, no access
	outside circumstances	health, financial, family, etc.
	teaching strategies	poor explanations, bad video quality, lack of feedback
	weak foundation	previous chemistry courses, lack of preparation, weak math skills
	chemistry ability	chemistry is difficult for me, not my strong suit, does not come naturally to me
	no challenges	

range of different abilities specific to studying chemistry (see Table S2 in the Supporting Information). An average CheMI score was computed for each student for use in all analyses. Details of the structure of the CheMI, along with validity and reliability studies of data from the target population in this study, can be found in the publication by Santos et al..[30]

Gradebooks were obtained from instructors in Fall 2021 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.

■ DATA ANALYSIS

The open-ended responses from students regarding challenges and strategies to overcome them were analyzed using an inductive content analysis approach.[31] 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, where 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.[32] 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 κ = 0.79). 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 coding 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 semirandom.

After coding the larger sample, the multiple-choice items provided in Table 2 were created using the common themes (Supporting Information). The data collected using these multiple-choice items in Fall 2021 were analyzed through both qualitative categorization and quantitative comparison methods. All quantitative analyses were conducted using SPSS28. The frequencies of each type of challenge were compared across the two groups who faced challenges using Bonferroni corrected z-tests[33] to determine significant differences in the perceived challenge. Likewise, challenge frequencies reported by students grouped by course sequence were determined and compared using z-tests with Bonferroni corrections. The normality of the chemistry mindset and performance variable distributions was examined using $Q-Q$ plots and histograms, providing evidence that these variables met the assumption of normality. Combined with the sufficiently large sample size, 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.

■ RESULTS AND DISCUSSION

Common Challenges (Research Question 1)

To determine the common challenges students perceive facing 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

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common challenge themes were defined and are listed in the Supporting Information 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 1. The most common challenge students

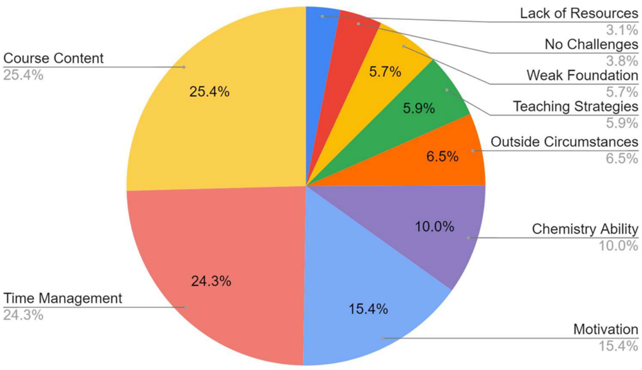

Figure 1. Common challenges students faced across the full sample (Fall 2021).

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 based on their perceived ability level, thus responding to this challenge helplessly. Beyond putting in more effort to understand, it may not be easily 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 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. That is, students may not apply effort if they believe they have a lower amount of ability relative to others.

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, $\alpha_{adjusted} = 0.006$). The frequency comparisons between course sequences are shown in Figure 2. General chemistry students reported facing more challenges with "Teaching Strategies" ($z = 15.860$, $p < 0.001$) and "Chemistry Ability" ($z = 3.983$, $p < 0.001$). 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 evaluation of their ability or 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.

Organic chemistry students reported facing more challenges with "Time Management" ($z = 9.155$, $p < 0.001$), "Motivation" ($z = 2.805$, $p = 0.005$), and "Outside Circumstances" ($z = 3.437$, $p < 0.001$). 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.[34,35] The cognitive demands of organic chemistry are often higher relative to general chemistry with increased problem complexity, such as multiple solutions to a

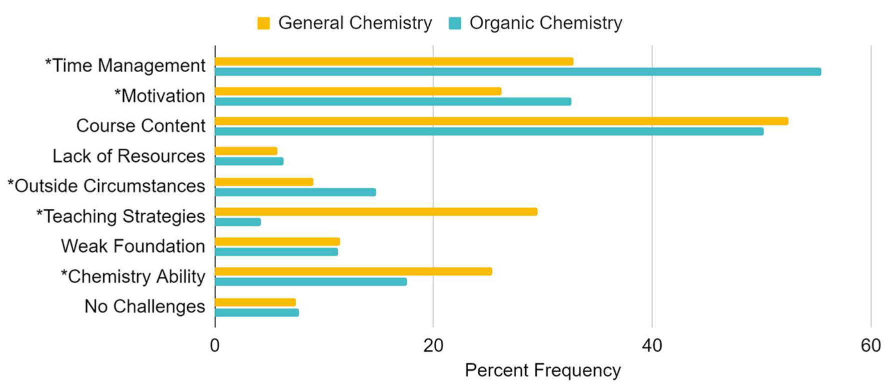

Figure 2. Course sequence comparisons for reported challenge types (*indicates significant paired z-test, $n_{general} = 122$, and $n_{organic} = 286$ for students with grade data available).

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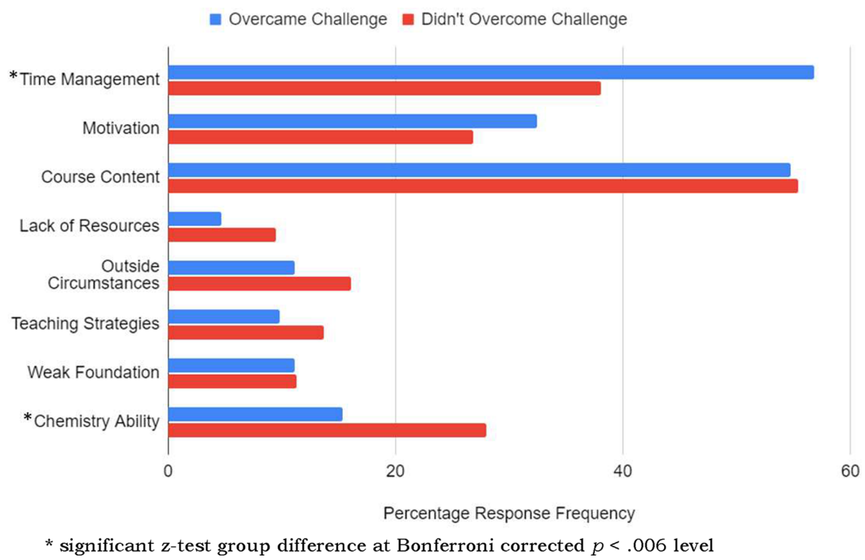

Figure 3. Comparison of "Overcame" and "Didn't Overcome" challenge-type response frequencies.

single problem.[36] 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 to escape feelings of inadequacy. Studies on STEM mindset have consistently observed declines in STEM-related mindset throughout STEM coursework,[19,21,27,37] suggesting that organic chemistry students may have lower 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 ($F_{1,434} = 1.96$, $p = 0.162$). 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 3 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 (eight total comparisons, $\alpha_{\text{adjusted}} = 0.006$). The largest group difference was observed for "Time Management" ($z = 3.759$, $p < 0.001$), 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" ($z = 3.188$, $p = 0.001$). 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.

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,[1] 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. Additionally, students with lower socioeconomic status may not have equal access to resources such as 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 ($z = 1.898$, $p = 0.057$). Additionally, the challenge regarding the

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instructor's teaching strategies and course content did not reach significance between groups.

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 portion of their 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.

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 3. Both main effects of primary and secondary challenges yielded significant differences in chemistry mindset, indicating that challenges do relate to mindset.

Table 3. ANOVA Results for Interaction and Main Effects of Challenge Types on Chemistry Mindset

ANOVA factor	effect type	F	p	partial η^2
primary × secondary	interaction effect	1.45	0.042	0.147
primary challenge	main effect	5.73	<0.001	0.104
secondary challenge	main effect	5.05	<0.001	0.093
chemistry ability dichotomous	N/A[a]	35.79	<0.001	0.082

[a]N/A, not applicable.

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 3 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 = < 0.001, partial η^2 = 0.082) 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 = 0.019, partial η^2 = 0.015; summative: F = 13.73, p = < 0.001, partial η^2 = 0.036). However, the effect sizes were fairly small.[38] 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 4a 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 (x = 5.64). Students who reported this primary challenge had significantly lower mindset scores relative to students who reported challenges with "Time Management" (x = 7.34), "Outside Circumstances" (x = 7.56),

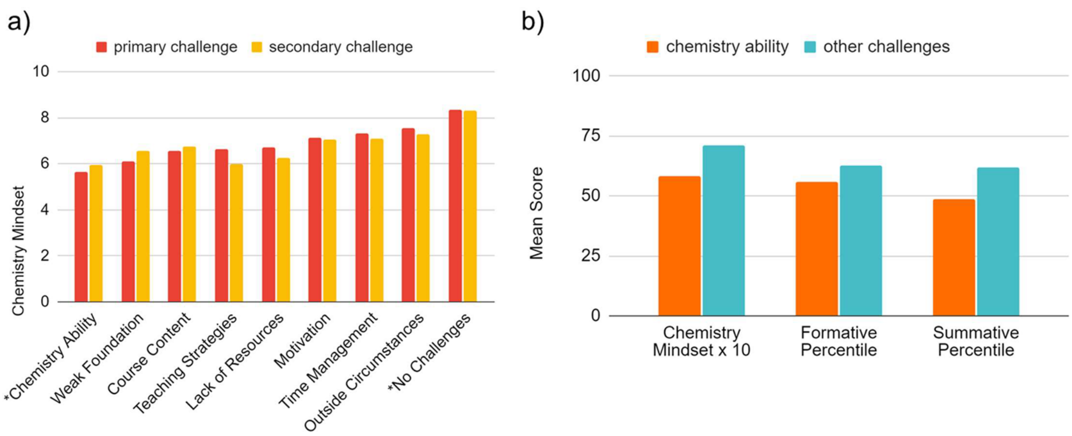

Figure 4. (a) Challenge type relates to chemistry mindset (*indicates significant score differences). (b) Chemistry ability versus other challenges as a predictor for course outcomes and mindset beliefs (chemistry mindset 10-point scale average multiplied by 10 to place on same scale).

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and "No Challenges" (x = 8.35). Likewise, upon examining Tukey's test results for the main effect of secondary challenges, "Chemistry Ability" yielded significantly lower mindset scores (x = 5.97) relative to "No Challenges" (x = 8.31). Other challenges that consistently yielded significantly lower mindset scores relative to "No Challenges" were "Weak Foundation" (x_1 = 6.10, x_2 = 6.57), "Course Content" (x_1 = 6.56, x_2 = 6.74), and "Teaching Strategies" (x_1 = 6.63, x_2 = 5.98).

Challenge Impacts on 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 4. 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 4. One-Way ANOVA Results for Challenge Level Group Comparisons on Performance and Chemistry Mindset Scores

variable	F	p	partial η^2
challenge group on formative performance	33.78	<0.001	0.154
challenge group on summative performance	52.93	<0.001	0.222
challenge group on chemistry mindset	46.88	<0.001	0.190

The results of the challenge-level group comparisons regarding performance and chemistry mindset scores can be observed in Figure 5. 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.[7] 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.[27] 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.

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

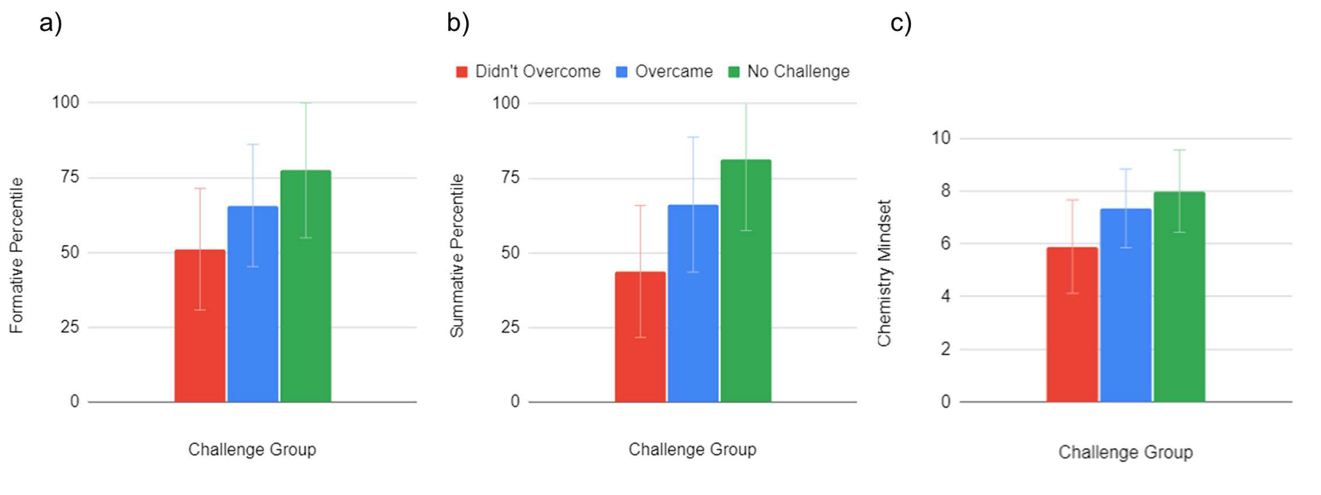

Figure 5. Challenge group trends for (a) formative performance scores, (b) summative performance scores, and (c) chemistry mindset scores.

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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.

■ CONCLUSION

Eight challenge types were derived from characterization of open-ended descriptions from students in general and organic chemistry courses and were used to assess relationships with performance, challenge perceptions, and chemistry mindset. The most common challenges students reported facing 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 other factors as a defense mechanism. It is also possible that students experienced lower-quality instruction. The "Overcame" group was significantly more likely to attribute their challenge to "Time Management", a factor that may be perceived as easier to 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, that 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.[7]

■ 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.[39] 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,[40,41] 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.

■ 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. Additionally, all data presented here were collected at the end of the semester, limiting conclusions about causality between mindset and challenge perceptions in light of performance feedback. They do seem to be related, yet it is unclear whether mindset predicts challenge perceptions or challenge perceptions are due to performance feedback, thereby shifting mindset beliefs. Further studies could investigate causality with appropriate time precedence.

In the qualitative analysis stage, 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 was reached with the existing codes. Interpretive bias is always present to some degree, although it is minimized through the quality control process of checking for inter-rater reliability among multiple researchers. Although the sample investigated in this work represented a diverse range of backgrounds, the data were 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.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00270.

Challenge-type coding themes, Chemistry Mindset Instrument (CHEMI) items, and normality analysis (PDF, DOCX)

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Notes

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