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Chemical Education Research

Investigating the Relations between Students' Chemistry Mindset, Self-Efficacy, and Goal Orientation in General and Organic Chemistry Lecture Courses

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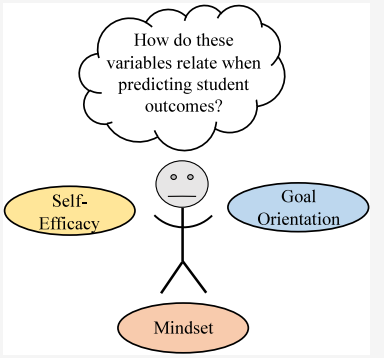
ABSTRACT: Students' view of intelligence (i.e., their mindset beliefs) has been found to be related to their self-efficacy and goal orientations as well as to influence their course outcomes. Comparisons of students' chemistry mindset between different groups found that organic chemistry I students held more of a growth mindset than general chemistry I students at the beginning of a term. Additionally, men tended to hold more growth mindset beliefs than women. Given these differences, structural equation modeling was used to explore the relations between students' mindset, self-efficacy, and goal orientations, along with their relation to achievement outcomes within a course. An indirect effect of mindset on summative achievement was found to be mediated through performance-avoidance goals, whereas the relation between self-efficacy and summative achievement was mediated through performance-approach, mastery-avoidance, and performance-avoidance goal orientations. While mindset was not found to be directly or indirectly related to formative achievement outcomes, self-efficacy was found to have an indirect effect on formative achievement through mastery-approach and mastery-avoidance goal orientations. Additionally, an interaction between mindset and self-efficacy was found to be related to performance-avoidance goals, as has been suggested in prior studies. These results point to the importance of mindset on achievement outcomes while also considering influences from self-efficacy and goal orientations. Future work is encouraged to investigate how these variables are related when they are measured throughout a term.



KEYWORDS: *first-year undergraduate/general, chemical education research*

INTRODUCTION

Students' mindset beliefs (i.e., implicit theories of intelligence) have been found to be related to motivational[1−3] and achievement outcomes,[2,3] as well as how students approach challenges.[3,4] With respect to chemistry courses, how students view their chemistry intelligence may influence their academic outcomes for the course,[5] along with their interest and engagement in STEM.[6] Therefore, this study sought to investigate the relation between students' mindset beliefs, self-efficacy, goal orientations, and achievement outcomes in general and organic chemistry courses.

Mindset Beliefs and Relations to Other Variables

Mindset beliefs are generally categorized into fixed mindsets versus growth mindsets. Students who hold a fixed mindset belief (i.e., entity theory) are thought to view intelligence as something that is unchangeable, whereas students who hold a growth mindset belief (i.e., incremental theory) view intelligence as something that is malleable and that can be improved with appropriate effort.[7]

Mindset beliefs have been found to be related to other affective measures, such as self-efficacy[2,8] and goal orientations.[2,3,7,9,10] Self-efficacy is the belief that students have in their own ability to complete tasks and problems.[11] Higher chemistry-specific self-efficacy has been found to be related to performance outcomes.[12−14] Goal orientations are used to describe students' goals and are split into two types: mastery and performance. Mastery goals are focused on learning and increasing one's understanding whereas performance goals are focused on demonstrating competence in comparison to others.[7,15] In the 2 × 2 framework,[15] mastery and performance goals each have two dimensions: approach and avoidance. Mastery-approach goals center around increasing the understanding of the content, whereas mastery-avoidance goals focus on avoiding a lack of understanding. Performance-approach goals strive toward achieving good grades, while performance-avoidance goals lead students to avoid failing grades.

Students' mindset beliefs and their perceived competence have been found to influence students' goal orientations.[2,7,9] Studies have found that students who hold a fixed mindset are

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more likely to orient to performance-oriented goals.[9] In contrast, students who hold a growth mindset are more likely to favor mastery-oriented goals.[2,9] The approach and avoidance dimensions for mastery and performance goals have been found to influence the association between students' mindset and their goal orientation, with growth mindset students being more negatively associated with performance-avoidance goals versus performance-approach goals and more positively associated with mastery-approach goals versus mastery-avoidance goals.[9] The goal dimension (i.e., approach vs avoidance) has also been found to influence achievement, with approach-oriented goals enhancing achievement and avoidance-oriented goals undermining achievement.[9] Additionally, self-efficacy has also been found to be related to mastery and performance-oriented goals,[8] and an interaction may exist between students' mindset beliefs and self-efficacy on their goal orientations.[2] For example, a student who holds a fixed mindset and has low self-efficacy may be oriented to performance-avoidance goals, while a student with a fixed mindset and high self-efficacy may not align with performance-avoidance goals. Using these proposed relations as a guide, this study explored the influence of mindset and self-efficacy on students' goal orientations, including a possible effect from an interaction between mindset and self-efficacy, and the effect of all of these variables on students' achievement outcomes in chemistry using structural equation modeling with latent variables, such that the influence of measurement error would be reduced.

Mindset in Chemistry Courses

Students' view of mindset is theorized to vary depending on the domain.[4] Recently, a chemistry-specific mindset measure, the Chemistry Mindset Instrument (CheMI), was developed by Santos et al.[5] using student feedback about how they viewed chemistry intelligence and how their perceptions of chemistry intelligence differed from their perceptions of intelligence in general.[16] Thus, this study seeks to begin to fill a gap in the literature related to exploring the relations between variables related to mindset using a measure specific to the domain of interest (i.e., chemistry). Therefore, the CheMI was chosen to investigate the relations between students' chemistry-specific mindset, chemistry self-efficacy, goal orientations, and achievement in chemistry courses.

Previous studies have found that students' mindsets may change as they progress through college courses,[17,18] indicating that mindset may differ between students taking general chemistry and students taking organic chemistry. Differences in the perceived difficulty of a course may also result in a difference in students' self-efficacy between courses,[19,20] and certain goal orientations have been found to be related to retention in chemistry.[21] Additionally, a study in physics courses found mindset beliefs differed between men and women,[22] and studies have also found that how someone views intelligence can be influenced by their culture.[23] Previous studies into students' self-efficacy have also found differences based on gender identity and race/ethnicity.[24] Therefore, in addition to exploring chemistry-specific relations for an aggregated data set, differences in chemistry mindset, self-efficacy, and goal orientation will be explored between groups related to course (i.e., general chemistry vs organic chemistry), gender identity, and race/ethnicity. The full scope of these goals is summarized in the research questions below.

Research Questions

1. How do students' chemistry mindset, self-efficacy, and goal orientation differ between courses and demographic profiles?
2. How does students' chemistry mindset relate to their self-efficacy, goal orientation, and course outcomes?
3. How do the relations between chemistry mindset, self-efficacy, goal orientation, and course outcomes differ between courses?

METHODS

All data collected for this study was approved by the Institutional Review Board (IRB) at Georgia State University, Portland State University, or when required, at the institution where data was collected. Appropriate consent was obtained, as required by the IRB.

Population

Six different institutions were included in this study. Data were collected from first-term general chemistry (GC1) and organic chemistry (OC1) courses from four of the institutions, including institutions that were on a semester (two-term academic year) and quarter (three-term academic year) schedule. The aggregated data set includes responses from students from 15 GC1 classes and 8 OC1 classes, with 13 and 7 instructors, respectively (for details by institution, see Table S1). Demographic breakdowns can be found in the Data Collection and Cleaning section below.

Measures

Chemistry-Specific Mindset. Students' chemistry-specific mindset was assessed using the Chemistry Mindset Instrument (CheMI).[5] The CheMI includes 7 items related to students' perception of their intelligence in chemistry (see Table S3). For example, one item was *My problem-solving ability in chemistry is something...* Students were asked to respond to items on a 10-point semantic differential scale from *I can't change at all* (1) to *I can change a lot* (10).

Chemistry Self-Efficacy. The self-efficacy measure included 8 items from the self-efficacy subscale of the Motivated Strategies for Learning Questionnaire (MSLQ)[25] (see Table S3). These items measure students' self-efficacy in their current chemistry course and were administered on a six-point Likert-type scale from *strongly disagree* (1) to *strongly agree* (6).

Goal Orientation. Students' goal orientation was measured using slightly modified items from the 2 × 2 Achievement Goal Questionnaire (AGQ)[15] (see Table S3). Items were modified to be specific to students in chemistry courses by changing the original wording of "in this class" to "in chemistry." Each dimension included 3 items, for a total of 12 items related to goal orientation. Items were administered on a six-point Likert-type scale from *strongly disagree* (1) to *strongly agree* (6).

Data Collection and Cleaning. Data were collected through online surveys using Qualtrics. Surveys were administered once at the beginning of the term. This timing allowed students' mindset, self-efficacy, and goal orientations to be measured before receiving any summative feedback about their performance in the course. Although surveys were ideally closed prior to the first exam, the survey for one OC1 class was closed a few days after the first exam due to scheduling constraints. Students were notified of the survey through an announcement posted on their course Learning Management System, which contained a video announcement from a

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Table 1. Number of Cleaned Responses for Demographic Comparisons Collected for the Aggregated Data Set, GC1, and OC1

	Aggregated (n = 1468)			GC1 (n = 733)			OC1 (n = 735)		
	Men	Women	Other	Men	Women	Other	Men	Women	Other
Asian	180	292	5	61	92	2	119	200	3
Black	40	126	0	25	91	0	15	35	0
Hispanic	55	123	0	20	55	0	35	68	0
White	168	271	15	108	174	9	60	97	6
Other[a]	71	117	5	32	61	3	39	56	2

[a]Includes Native American, Pacific Islander, Middle Eastern, two or more identities, and other identities.

researcher, a written announcement, and a link to the Qualtrics survey. The surveys were open for 1 week. All students who completed the survey, regardless of consent, were awarded a minimal amount of extra credit, which was set by their instructor. Grades for all assignments, participation, and exams for consenting students were collected from the instructors at the end of the term and matched to survey responses.

During the survey, students were asked to respond to a selection of "check-items", which asked students to select a specific response. These check-items were included to assist in eliminating responses from students who may not have been reading the items closely before responding. Additionally, a listwise deletion was used to remove any incomplete responses. Students were requested but not required to self-report demographics information, including gender identity and race/ethnicity, at the end of the survey. Some students did not include demographic information; therefore, the total number of responses when considering demographics is lower than the number of responses used when considering only GC1 (n = 740) and OC1 (n = 745) responses. Information about the number of cleaned responses for the aggregated and disaggregated data sets by course is included in Table 1. Demographics information for each institution is included in Table S2.

Data Analysis. Grades for each consenting student were used to create two outcome variables: a summative grade z-score and a formative grade z-score. Z-scores were created for achievement outcomes as data were collected across multiple institutions, courses, and instructors, and grading criteria were not consistent. The summative grade z-score was created by combining students' scores on exams and finals and creating a z-score using the mean and standard deviation of the class for the summative assessments. Formative grade z-scores were created by combining students' scores on formative assignments (i.e., homework, quizzes, and participation) and creating a z-score using the mean and standard deviation of the class. While every class had some type of midterm exam(s) and/or final exam, not every class included the same type of formative assignments. For example, one class included homework assignments and in-class participation, while another class included homework assignments and quizzes.

As prior studies have shown differences in mindset, self-efficacy, and/or goal orientation when considering respondents' gender identity and/or race/ethnicity, we sought to explore these variables by intersectional demographic groups. Therefore, we needed to balance the self-reported demographics used to create each group with the required minimum group size for our data modeling analyses. For gender identity, the groups were designated as men and women. Respondents selecting or reporting any other gender identity represented less than 5% by institution (Table S2). For race/ethnicity, we were not able to retain distinct gender identity × race/ethnicity groupings given the population within our data set. For example, the Hispanic-men and Hispanic-women consist of only 55 and 123 students in the full data set, respectively (Table 1). Therefore, two race/ethnicity groups were created. A racially minoritized (RM) group was created from all students who reported their race/ethnicity to be Black, Hispanic, Native American, Pacific Islander, Middle Eastern, two or more identities, or other identities. A non-RM group was created from respondents who identified as Asian, White, or White and Asian. We grouped students in this way and use the term *racially minoritized* as it signifies "the social construction of underrepresentation and subordination in U.S. social institutions, including colleges and universities."[26] As students identifying as Asian are the majority population at two institutions and >20% in two additional institutions (Table S2), they were not seen as being racially minoritzed and were grouped with the students identifying as White. Therefore, students' responses about gender identity and race/ethnicity resulted in four groups for our analyses: non-RM men, non-RM women, RM men, and RM women.

Confirmatory factor analyses (CFAs), structured means modeling (SMM), and structural equation modeling (SEM) were completed with the statistical program R (version 4.2.2) with the *lavaan* package (version 0.6.15) using maximum likelihood estimation with Satorra-Bentler adjustment and robust standard error to account for any non-normality of the data.[27] Descriptive statistics for all items are included in Table S3.

Validity and Reliability Evidence. CFAs were used to provide evidence of structural validity for the data collected with each measure prior to evaluation of the SEM model. CFA models related to chemistry mindset, chemistry self-efficacy, and goal orientation items were analyzed individually. The chemistry mindset and chemistry self-efficacy data were evaluated by using single-factor models. The goal orientation data were analyzed with a four-factor correlated model with items related to mastery-approach, performance-approach, mastery-avoidance, and performance-avoidance. Data-model fit was evaluated using the suggested recommended cutoffs for good data-model fit from Hu and Bentler:[28] CFI $\geq$ 0.95, TLI $\geq$ 0.95, RMSEA $\leq$ 0.06, and SRMR $\leq$ 0.08. The reliability for each individual scale was assessed using omega.[29]

As group score comparisons were investigated, additional structural validity evidence was gathered through measurement invariance testing. Measurement invariance testing provides support that the structural model is unbiased for each group being evaluated and that any observed differences in scores are due to the latent trait being measured and not due to the model itself. Measurement invariance for comparisons of chemistry mindset, chemistry self-efficacy, and goal orientation were tested through a series of sequential steps. First, the unconstrained factor model for each group was tested

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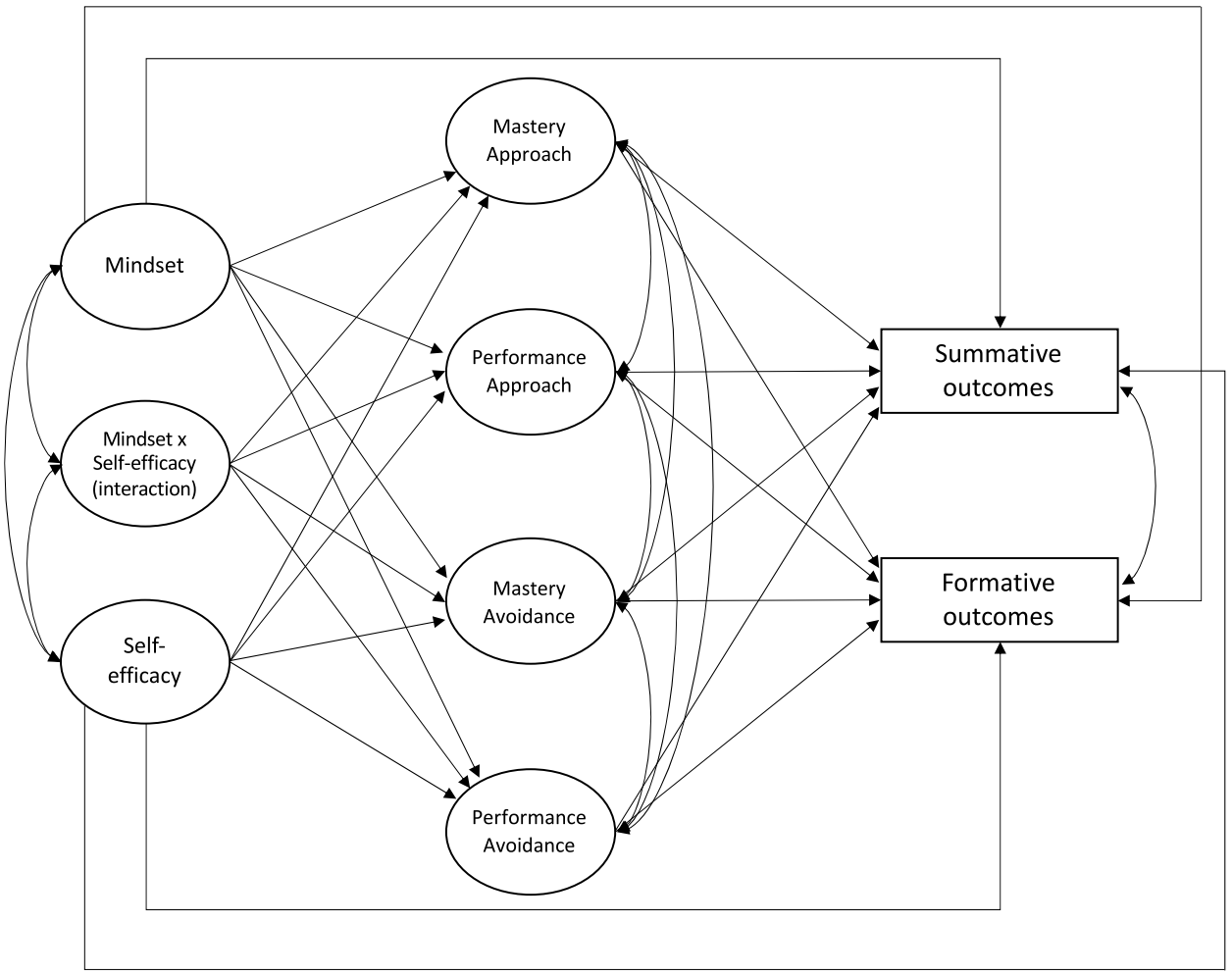

Figure 1. Proposed structural model relating mindset, self-efficacy, goal orientation, and achievement outcomes (formative and summative). An interaction term between mindset and self-efficacy is included, as well as all four goal orientations: mastery-approach, performance-approach, mastery-avoidance, and performance-avoidance. Correlations are included between mindset, self-efficacy, and mindset × self-efficacy, the four goal orientations, and the two achievement outcomes. Individual indicator items for the latent variables are omitted for clarity.

simultaneously to provide evidence of configural invariance. If evidence was found, the factor loadings were constrained across groups, which provided support for metric invariance. Finally, scalar invariance was evaluated by additionally constraining the item intercepts across groups. If evidence of scalar invariance is found, group comparisons using structured means modeling (SMM) and latent means is supported and differences between the groups can be meaningfully compared.[30] Each step of measurement invariance was evaluated using the suggested recommended cutoffs from Chen[31] for changes in data-model fit between subsequent levels: $\Delta CFI \leq 0.010$, $\Delta RMSEA \leq 0.015$, and $\Delta SRMR \leq 0.030$ for metric invariance and ≤ 0.010 for scalar invariance.

Group Comparisons with Structured Means Modeling (SMM). When scalar invariance was supported for a measure, SMM was used to compare group differences by using latent means. For latent mean comparisons, one group is selected as the reference group (i.e., latent mean is set to zero) and the resulting latent mean of the comparison group is the *difference* between the two latent means. For comparisons, by course, GC1 was selected as the reference group. For comparisons by intersectional groups (e.g., non-RM women vs RM women), the analysis was performed multiple times using a different reference group each time to test the significance of each pairwise comparison. The effect size of each analysis was calculated as the absolute difference between latent means divided by the square root of the pooled variance.[32] While similar to Cohen's d, latent means are free from measurement error; thus, the value of the effect size should be larger than the guidelines for measured variables,[32] where 0.2, 0.5, and 0.8 represent small, medium, and large effects, respectively.[33]

Structural Equation Modeling (SEM). The relations between students' chemistry mindset, self-efficacy, goal orientations, and achievement outcomes were explored using structural equation modeling (SEM). Mindset[5,9] and self-efficacy[12−14] have both been shown to relate to achievement outcomes. In addition, goal orientations may mediate the relation between mindset and achievement,[1−3,9] as well as between self-efficacy and achievement.[2] Finally, an interaction between mindset and self-efficacy has been proposed to influence students' goal orientation.[1,2] The structural model included each of these paths (Figure 1). As mindset and self-efficacy are related,[5,8] these factors were correlated, as were all relations between the four goal orientation factors. Additionally, students' summative and formative scores were also correlated, as these were expected to be related.

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Indicators for the latent interaction variable were created using a matched-pair strategy, where product indicators were created from the centered indicator items of the mindset and self-efficacy factors.[34] The items with the highest loadings from each factor found through single-factor CFA were matched in order to the lowest loadings, thereby creating a total of 7 items for the interaction variable (see CFA Results and Table S5 in the Supporting Information). The model was then estimated using the unconstrained approach for the estimation of latent interactions, where loadings and error variances for the product indicators are freely estimated.[34,35] The effect size of significant relations between variables were estimated using Cohen's f^2, where values of 0.02, 0.15, and 0.35 indicate small, medium, and large effect sizes, respectively.[33]

RESULTS AND DISCUSSION

Validity and Reliability Evidence

Before SMM and SEM were completed, evidence for the validity and reliability of the data collected with the measures were evaluated. Details related to internal structure validity and reliability evidence from CFAs with chemistry mindset, self-efficacy, and goal orientation items can be found in Table S4. Data-model fit statistics provided support for the internal structure validity and single administration reliability of the data collected with each measure. Additionally, to support group comparisons, consequential validity evidence was found for data collected with each measure and the structural model through measurement invariance testing (Tables S6−S12). Scalar invariance for all comparisons (i.e., by course and by intersectional group) was found, which provided support for latent means comparisons using SMM.[30]

Latent Means Comparisons

Course Comparisons. SMM was used for latent mean comparisons between students taking first-term general chemistry (GC1) and organic chemistry (OC1) (Table 2).

Table 2. Latent Means Comparisons between Responses from GC1 and OC1 Students on the Chemistry Mindset, Self-Efficacy, and Goal Orientations[a]

Reference Group	Comparison Group	Measure	Latent Mean Difference (Effect Size)
GC1 (n = 740)	OC1 (n = 745)	Chemistry mindset	**0.26** (0.18)
		Self-efficacy	**−0.22** (0.23)
		Mastery-approach	−0.02 (n/a)
		Performance-approach	**0.18** (0.14)
		Mastery-avoidance	0.08 (n/a)
		Performance-avoidance	**−0.13** (0.15)

[a]Bold values are significant at $p < 0.05$.

When students' chemistry mindset was compared, it was found that students in organic chemistry scored higher on the measure with a small effect size, which meant that organic chemistry students were more likely to orient toward a growth mindset than students in general chemistry at the start of the term. This result contrasts with outcomes in other mindset studies; however, potentially important differences exist. For example, some studies have seen students' incremental (i.e., growth mindset) beliefs decrease throughout a single STEM course[17,18,36] and others have found that students who struggle with a course tend to shift more strongly toward a fixed mindset,[18] which may suggest that students starting organic chemistry would have a more fixed mindset as their mindset may have shifted during general chemistry. However, it is also possible that students in general chemistry who held a fixed mindset and/or struggled may have dropped out or failed the course, which could result in more students entering organic chemistry with a growth mindset. Another study that compared mindset between general and organic chemistry did not find a significant difference between the two groups;[37] however, in that study, mindset was measured at the end of the term, where students' mindset in both general and organic chemistry may have shifted from where it was at the beginning of the term.

When chemistry self-efficacy was compared by course, it was found that organic chemistry students had lower self-efficacy than general chemistry students with a small effect size. As the survey was administered at the beginning of the term, this may be due to differences in students' prior experiences and their ability to evaluate their potential performance before taking chemistry (GC1 group) versus after a year of general chemistry (OC1 group). In one study of organic chemistry students, a reciprocal relation between students' chemistry self-efficacy and performance on exams was found.[12] As students in the OC1 group have already received feedback multiple times during general chemistry, this may have influenced their self-efficacy at the beginning of organic chemistry. The lower self-efficacy of OC1 students may have also been due to differences in the expected difficulty of the courses, as students may have viewed organic chemistry as a more difficult course than general chemistry and judged their abilities based on those perceptions.[19,20]

No differences were found in students' mastery (approach and avoidance) goal orientations between the courses. However, differences were seen in both performance (approach and avoidance) goal orientations, where students in OC1 responded higher on performance-approach and lower on performance-avoidance when compared to GC1 students. Both of these differences were found to represent a small effect. Performance-approach items are related to how students view their performance with respect to the other students in the course. This suggests that OC1 students are more concerned with doing well compared with other students than students in GC1. Performance-avoidance items are related to avoiding doing poorly in the course; thus, GC1 students were found to be more worried about performing poorly than OC1 students. One study found that chemistry students who switched majors or left college reported higher performance-avoidance goal orientation at the beginning of their first term compared to students who were still a chemistry major at the end of their second year.[21] Therefore, the higher performance-avoidance goal orientations found for GC1 students could be due to some of the students leaving the major or university before taking organic chemistry.

Intersectional Grouping Comparisons. SMM was also used to compare students' mindset, self-efficacy, and goal orientations based on intersectional grouping (i.e., gender identity × RM status). Overall, men were found to score higher on the chemistry mindset measure than women with small effects (Figure 2). The latent mean for RM men was 0.51 times higher than non-RM women and 0.58 times higher than RM women. The latent mean for non-RM men was 0.45 higher than non-RM women and 0.52 higher than RM women. All four significant differences represented small effect sizes.

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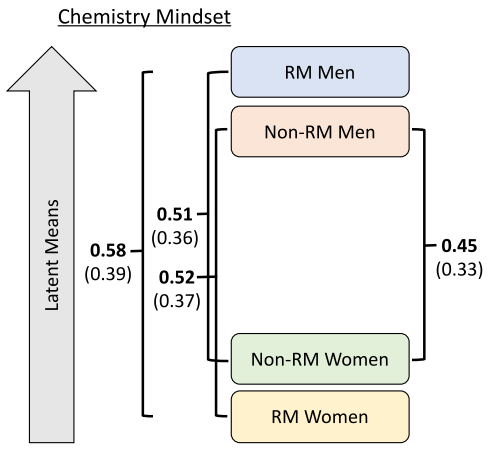

Figure 2. Latent means comparisons of students' chemistry mindset based on demographic profiles. Only differences that were significant at $p < 0.05$ are included. Effect size is included in parentheses.

No significant differences were found related to RM status; therefore, the difference in latent means between RM men and non-RM men was nonsignificant, and the difference in latent means between RM women and non-RM women was also nonsignificant. This suggests that men in general had more of a growth mindset than women at the beginning of the term. Similar findings were discovered when mindset was previously measured in a university physics course.[22]

When self-efficacy was compared, men were found to report higher self-efficacy than women, with small to medium effect sizes. Differences in the self-efficacy of RM and non-RM women were also significant, with a small effect (Figure 3).

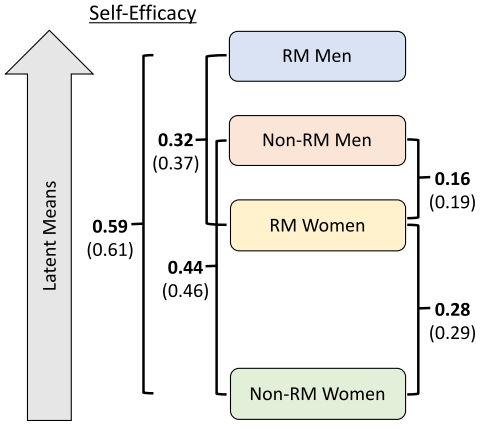

Figure 3. Latent means comparisons of students' self-efficacy based on demographic profiles. Only differences that were significant at $p < 0.05$ are included. Effect size is included in parentheses.

This suggests that, overall, men were more confident in their ability to complete chemistry tasks and problems at the beginning of the term than women and that RM women were generally more confident in their ability than non-RM women. Similar trends have been seen in other studies of students' chemistry self-efficacy. One study found that students who identified as Asian or Hispanic had higher self-efficacy than White students, with intersectional effects of gender for those groups.[24] Another study found no differences in preterm self-efficacy between men and women, but it did find that non-RM students had higher preterm self-efficacy than RM students;[38] however, intersectional race/ethnicity × gender differences were not explored.

Students' goal orientations were also compared based on the intersectional group (Figure 4). Overall, RM women were found to report the highest mastery-approach, mastery-avoidance, and performance-avoidance goal orientations, but the lowest performance-approach goal orientation. In contrast, non-RM men generally reported the lowest, or second lowest, scores for mastery-approach, mastery-avoidance, and performance-avoidance, while reporting the highest scores for performance-approach. All differences represented small to medium effects. These results suggest that RM women were more likely to orient toward goals related to understanding (mastery-approach), while also being more worried about not being able to understand the content (mastery-avoidance) and performing poorly (performance-avoidance), whereas non-RM men were more likely to orient toward goals related to doing better than other students (performance-approach). RM men and non-RM women generally reported alignment to goal orientations in between what was reported for RM women and non-RM men, with the exception of mastery-avoidance. In the case of mastery-avoidance, non-RM men reported higher, but nonsignificant, scores compared to RM men. RM men and non-RM women generally reported similar goal orientations (i.e., nonsignificant differences), except for mastery-avoidance, where non-RM women were found to be more likely to be worried about their understanding than RM men.

Structural Equation Modeling (SEM)

The relations among mindset, self-efficacy, goal orientations, and achievement outcomes were explored using a structural equation model. When analyzing the aggregated data set, the model (Figure 5) showed evidence of good data-model fit (see Table S12). Overall, chemistry mindset was found to be positively related to mastery-approach goals (coefficient = 0.196, Cohen's $f^2 = 0.03$) and negatively related to performance-avoidance goals (coefficient = −0.117, Cohen's $f^2 = 0.01$), with small effect sizes. This suggests that students with more of a growth mindset were more likely to have goals related to understanding and less likely to have goals related to avoiding doing poorly. This relation between mindset and mastery-approach has been found in other studies.[2,5,9,10] A prior study on chemistry students did not find a significant correlational relation between chemistry mindset and performance goals;[5] however, other studies have reported a negative relation between mindset and performance-avoidance.[9,10] Chemistry mindset was also found to directly and positively predict summative achievement outcomes (coefficient = 0.149, Cohen's $f^2 = 0.01$) with a small effect size but was not found to be directly related to formative achievement outcomes. A previous study found mindset to be correlated with both summative and formative outcomes.[5] Since this study used a mediational model to analyze the impact of mindset on achievement, it is possible that the influence of another pathway affected the relation between mindset and formative outcomes.

Students' chemistry self-efficacy was found to be positively related to both mastery-approach (coefficient = 0.371, Cohen's $f^2 = 0.12$) and performance-approach goals (coefficient = 0.213, Cohen's $f^2 = 0.03$) with a medium and small effect, respectively. Students' chemistry self-efficacy was found to be negatively related to both mastery-avoidance (coefficient = −0.165, Cohen's $f^2 = 0.02$) and performance-avoidance

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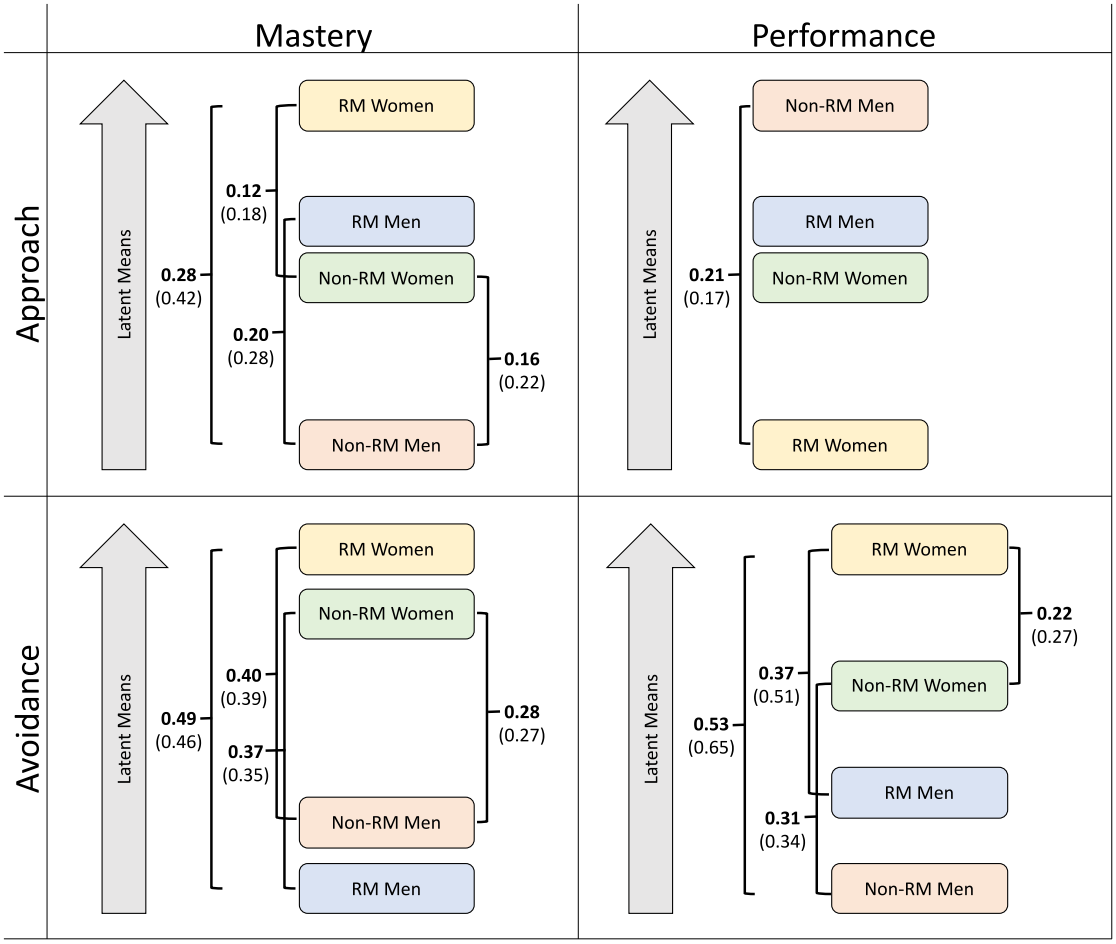

Figure 4. Latent means comparisons of students' mastery-approach, performance-approach, mastery-avoidance, and performance-avoidance goal orientations based on the intersectional group. Only differences that were significant at $p < 0.05$ are included. Effect size is included in parentheses.

(coefficient = −0.097, Cohen's f^2 = 0.01) goals with small effect sizes. This suggests that students with a higher self-efficacy are more likely to orient to goals related to understanding and performing well, whereas they are less likely to orient to goals related to being worried about not understanding or performing poorly. A positive relation between self-efficacy and approach-oriented goals has been found in other studies.[2,39] Higher chemistry self-efficacy was also found to positively predict summative achievement outcomes (coefficient = 0.090, Cohen's f^2 = 0.00) with a small effect size but not formative achievement outcomes. Previous studies have found students' self-efficacy at the end of a term to predict final exam scores[13] and final course grades (i.e., a combination of summative and formative scores).[14]

An interaction between mindset and self-efficacy has been hypothesized to influence students' goal orientations.[2] When the interaction between mindset and self-efficacy was explored, the interaction term was found to be significantly related to performance-avoidance goals (coefficient = −0.076, Cohen's f^2 = 0.01) with a small effect size. When simple slopes were analyzed at 1 standard deviation (SD) above and below the mean self-efficacy score, it was found that the relation between mindset and performance-avoidance became more positively related for lower values of self-efficacy (standardized regression coefficient at −1SD = −0.041) and more negatively related for higher values of self-efficacy (standardized regression coefficient at +1SD = −0.193) when compared to the value of the standardized regression coefficient between mindset and performance-avoidance at the mean self-efficacy value of −0.117 (Figure 6). This steeper regression slope (purple in Figure 6) suggests that students' mindset has a larger influence on performance-avoidance goal orientation when students have higher levels of self-efficacy and less of an influence when students have lower levels of self-efficacy. For example, students with a growth mindset but low self-efficacy (i.e., green slope in Figure 6) would be expected to align less negatively toward performance-avoidance goals than students with a growth mindset and high self-efficacy.

With respect to goal orientations, students' summative outcomes were found to be influenced by their performance-approach (coefficient = 0.165, Cohen's f^2 = 0.03), mastery-avoidance (coefficient = −0.160, Cohen's f^2 = 0.02), and performance-avoidance (coefficient = −0.147, Cohen's f^2 = 0.02) goals with small effect sizes. Students who focused on performing better than others were found to perform better on summative assessments. In contrast, students who were focused on being worried about their understanding or performance in the course were found to score less on summative assessments. Students' formative achievement scores were found to be related to mastery-approach (coefficient = 0.092, Cohen's f^2 = 0.01) and mastery-avoidance (coefficient = −0.091, Cohen's f^2 = 0.01) goals with small effect sizes, where students who were focused on goals related to understanding performed better on formative assignments

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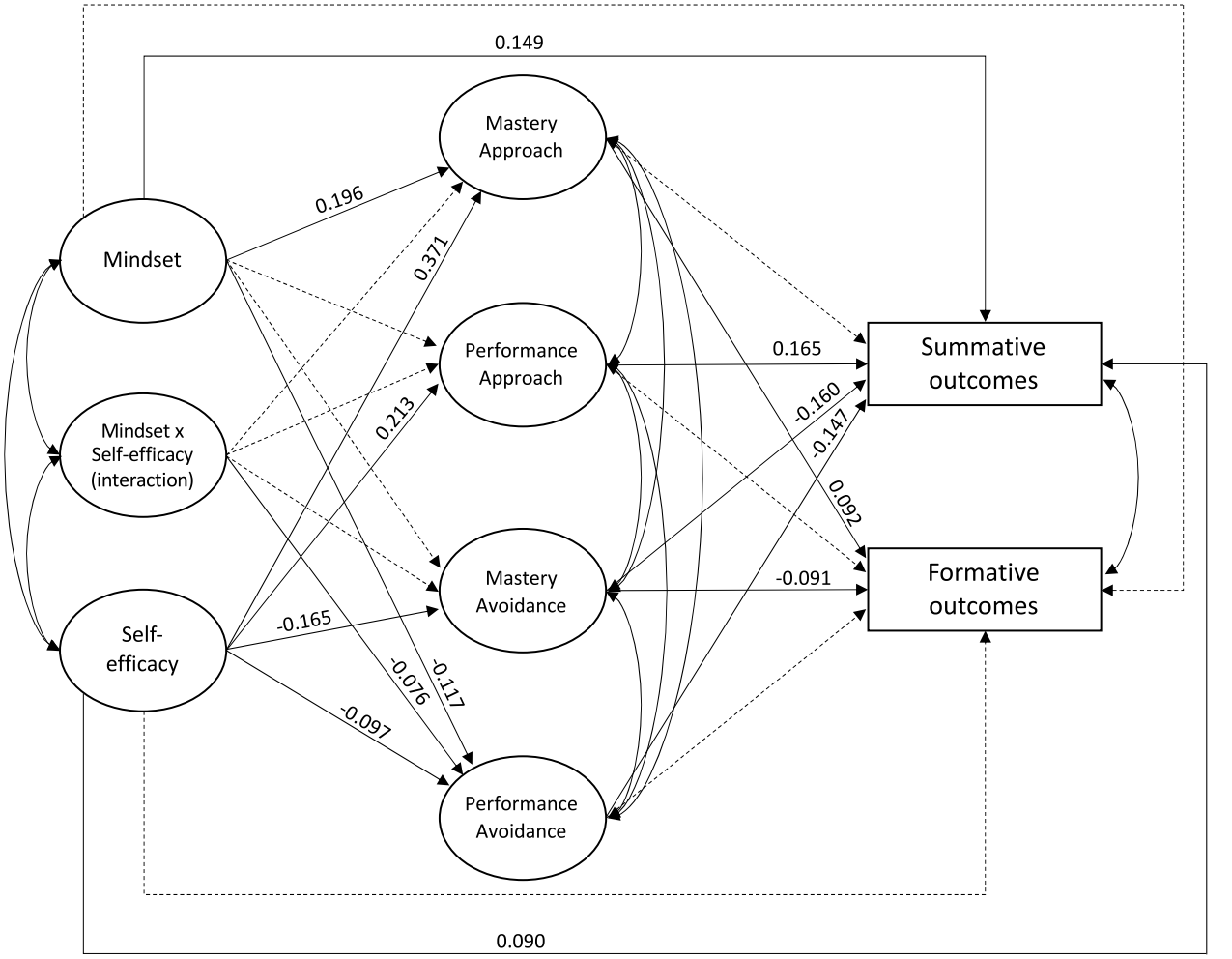

Figure 5. Results of structural analysis with the aggregated data set. Standardized regression coefficients are included for all significant paths ($p < 0.05$). Nonsignificant paths are denoted with dotted arrows. Correlational values can be found in Table S13.

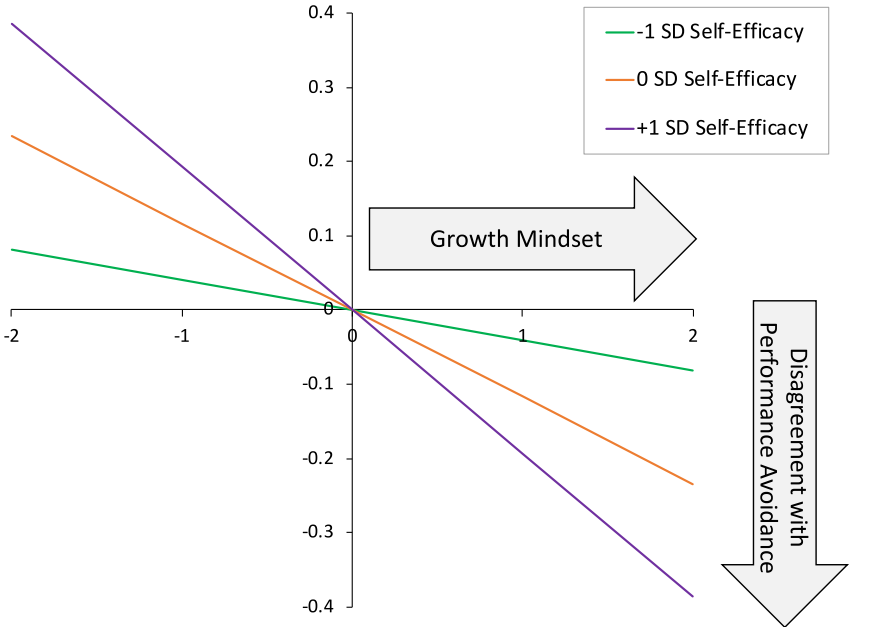

Figure 6. Standardized simple slopes for the relation between mindset (x-axis) and performance-avoidance goal orientation (y-axis) at −1 (green), 0 (orange), and +1 (purple) standard deviations from the mean of self-efficacy.

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and students who focused on avoiding not being able to understand the material performed worse on formative assignments. It has been suggested that approach-oriented goals positively influence achievement, whereas avoidant-oriented goals negatively influence achievement.[9] A previous study with general chemistry students found that students who had overall low goal orientations related to mastery and performance did worse on exams than students with average or high goal orientations.[40] Another study found that only students' performance-approach goal orientations were correlated to formative and summative outcomes;[5] however, a study of high school students found that mastery-approach, performance-approach, and performance-avoidance goal orientations (mastery-avoidance was not tested) were all related to academic achievement (i.e., GPA).[2]

Indirect paths were tested for significance with the aggregated data set (Table 3). In addition to the direct relation between mindset and summative scores, an indirect effect mediated through performance-avoidance was also found. Additionally, the relation between self-efficacy and summative scores was also found to be partially mediated through performance-approach, mastery-avoidance, and performance-avoidance goal orientations. Neither mindset nor self-efficacy were found to be directly related to formative outcomes; however, indirect effects for the relation between self-efficacy and formative scores mediated through mastery-approach and mastery-avoidance goals were found to be significant. Therefore, performance goal orientation and mastery-avoidance orientation were found to be significant partial mediators between mindset and self-efficacy and summative scores, whereas both mastery-approach and avoidance were found to completely mediate the relation between self-efficacy and formative scores. One prior study found an indirect effect between mindset and academic achievement through mastery-approach and intrinsic motivation mediators but did not see a significant indirect effect with performance-avoidance as a mediator (mastery-avoidance and performance-approach pathways were not tested).[10] Other studies have found indirect relations between self-efficacy and academic achievement by evaluating the indirect effect between self-efficacy and motivation through mastery and performance-approach goals (mastery-avoidance and performance-avoidance pathways were not tested).[2]

Table 3. Estimates for Significant Indirect Effects for the Aggregated Data Set (n = 1485)[a]

Indirect Effect	Standardized Estimate [95% CI]
M → PAv → Sum	0.017[b] [0.003, 0.018]
SE → PAp → Sum	0.032[c] [0.017, 0.050]
SE → MAv → Sum	0.024[b] [0.010, 0.041]
SE → PAv → Sum	0.013[b] [0.002, 0.025]
SE → MAp → Form	0.026[b] [0.001, 0.055]
SE → MAv → Form	0.012[b] [0.001, 0.024]
MxSE → PAv → Sum	0.011[b] [0.001, 0.010]

[a]Indirect effects that were nonsignificant were omitted. Note: M = mindset; SE = self-efficacy; MxSE = mindset × self-efficacy interaction; MAp = mastery-approach; PAp = performance-approach; MAv = mastery-avoidance; PAv = performance-avoidance; Sum = summative outcomes; Form = formative outcomes. [b]$p < 0.05$. [c]$p < 0.001$.

Potential differences in significant pathways between GC1 and OC1 students were explored by analyzing the disaggregated data using a structural model (Figure 7). A few differences between the GC1 and OC1 results were noted; these are labeled as paths A−D in Figure 7. First, path A, from mindset to performance-approach, was found to be significant for GC1. However, path B, from self-efficacy to performance-avoidance, as well as the direct path (C) from self-efficacy to summative outcomes were not found to be significant for GC1. For OC1, path D from mastery-avoidance to formative outcomes was not significant. It is possible that differences may be due to students' past experiences (or lack thereof) in a chemistry course. Students in general chemistry with a growth mindset may be less likely to orient to goals related to striving for higher performance than other students (i.e., performance-approach orientation), whereas students with a fixed mindset would more likely be oriented to such goals; however, in OC1, students may already have a sense of where they stand in the course, which may make any relation between mindset and performance-approach nonsignificant. Related to students' self-efficacy, students in GC1 might not have any past experience with chemistry, which could reduce any potential influence between their beliefs in their ability and their academic performance. A prior study found that, in a first-term general chemistry course, self-efficacy at the beginning of the term only weakly predicted final course grade, whereas self-efficacy at the end of the term was a better predictor of course grade.[14]

When course-specific results were compared to those of the aggregated data set, two differences were noted. Whereas path E, from the mindset × self-efficacy interaction term to performance-avoidance, and path F, from mastery-approach to formative outcomes, were significant for the aggregated data set, these paths were not found to be significant for either the GC1 or OC1 data sets. This is likely due to an inability to detect significant differences when the data was disaggregated due to the lower sample sizes.

CONCLUSIONS

Individual Measures

Overall, differences in latent means for chemistry mindset, chemistry self-efficacy, and goal orientations were found based on course (i.e., GC1 versus OC1) and intersectional group (i.e., racially minoritized (RM) status × gender identity). Students beginning first-term organic chemistry were found to have a greater growth mindset, higher self-efficacy, higher performance-approach goal orientation, and lower performance-avoidance goal orientation than students beginning first-term general chemistry. Men tended to report more of a growth mindset and higher self-efficacy than women at the beginning of the term. Additionally, RM women were found to respond higher on mastery-approach, mastery-avoidance, and performance-avoidance goal orientations than non-RM and RM men and non-RM women but responded the lowest on the performance-approach goal orientation. In contrast, non-RM men responded with one of the lower scores for mastery-approach, mastery-avoidance, and performance-avoidance goal orientations but responded the highest on the performance-approach goal orientation.

Relations Among Measures and Course Outcomes

Both mindset and self-efficacy were found to predict summative achievement outcomes but not formative outcomes. Additionally, mindset was positively related to mastery-

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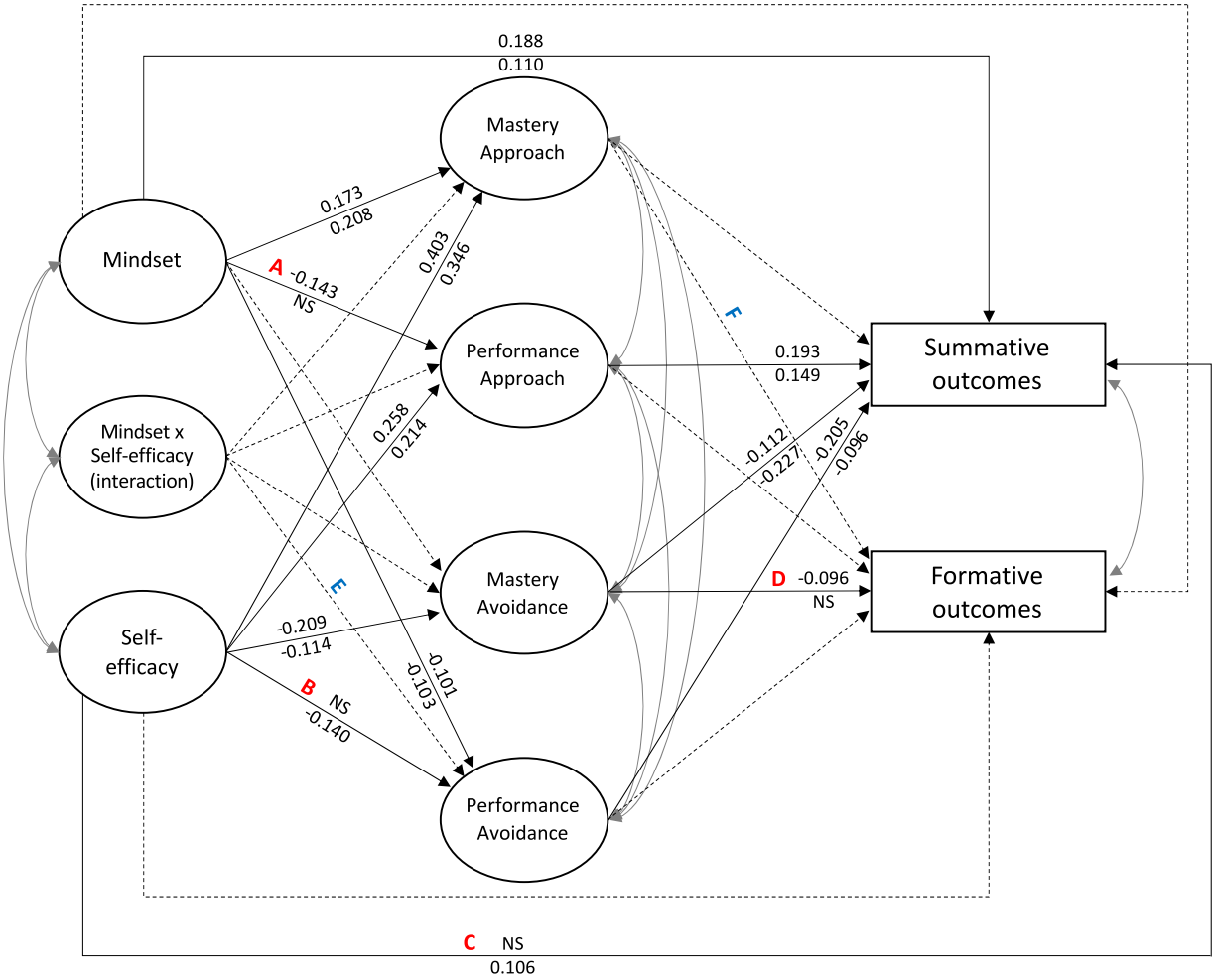

Figure 7. Structural analysis comparison from responses from students in GC1 (top values) vs OC1 (bottom values). Standardized regression coefficients are included for all significant paths ($p < 0.05$). Nonsignificant paths for both groups are denoted with dotted arrows. Correlations are indicated in gray, and values can be found in Table S13. Red letters (A−D) indicate paths that differed in significance between GC1 and OC1 data sets, whereas blue letters (E, F) indicate paths that differed in significance between the aggregated data set and both GC1 and OC1 data sets.

approach and negatively related to performance-avoidance goal orientations, while self-efficacy was found to be positively related to both approach orientations and negatively related to both avoidance orientations. The interaction between mindset and self-efficacy was found to be related to performance-avoidance goals. An indirect effect from mindset to summative outcomes was found to be mediated through performance-avoidance, whereas self-efficacy was found to indirectly affect summative outcomes through mastery-avoidance, performance-approach, and performance-avoidance goals. The relation between self-efficacy and formative outcomes was found to be completely mediated through mastery-approach and avoidance goals. Mindset was not found to predict formative scores directly or indirectly through goal orientations.

When considering the relations between variables for general chemistry and organic chemistry students, the relation between mindset and performance-approach goals was found to be significant for general chemistry students only; however, the relations between self-efficacy and performance-avoidance, as well as between self-efficacy and summative outcomes, were not found to be significant for general chemistry students. Additionally, the relation between mastery-avoidance and formative outcomes was not significant for organic chemistry students. However, due to the complexity of the model and the sample size of the disaggregated data sets, differences between the significant paths found for general and organic chemistry students should be interpreted with caution.

■ LIMITATIONS

All affective measures were collected at the beginning of the term, which may have influenced the relations between variables. For example, self-efficacy has generally been seen to increase throughout the term[38] and larger associations between self-efficacy and achievement have been reported when self-efficacy was measured at the end of the term.[14] Additionally, although the model included causal pathways between mindset, self-efficacy, and goal orientations, we cannot say with certainty the directionality of these relations, although other studies have theorized similar relations between mindset, self-efficacy, and goal orientations.[2]

As only three items were associated with each goal orientation factor, individual CFAs to confirm the unidimensionality of the data could not be completed; thus, there was a lack of support to evaluate the single administration reliability of the data collected with this measure. Additionally, a ceiling effect was seen with some goal orientation items, especially ones related to mastery-approach and performance-avoidance. This has also been reported in other studies that

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measured students' goal orientations in chemistry.[5,40] Therefore, results related to students' goal orientations should be interpreted with caution.

Due to sample size limitations, we were unable to disaggregate the student population by individual race/ethnicity groupings or nonbinary gender identity for statistical analyses. This undermined our ability to fully understand these data in the context of the students' lived experiences within these courses/institutions. We further acknowledge that the racial category of Asian, used within our data collection, represents a broad range of ethnicities and cultures and that including them in the nonracially minoritized group may mask the difficulties faced by some students who selected this label.

Lastly, when the structural model was evaluated by course (GC1 vs OC1), some significant paths found with the aggregated data set were found to be nonsignificant for both groups. However, the sample size of the aggregated data set compared to the number of estimated model parameters was around 10:1, which is suggested as a minimum ratio when evaluating SEMs.[41] Therefore, the nonsignificant paths found with the disaggregated data sets may be due to a lack of power to detect differences and should be interpreted with caution, especially ones found to be significant with the aggregated data set. Further, we were unable to analyze the model with the disaggregated intersectional groups due to an insufficient sample size for each group.

IMPLICATIONS FOR RESEARCH

This study only focused on how students' chemistry mindset, chemistry self-efficacy, and goal orientations at the beginning of a course affected student performance. Future research could consider exploring a model where pre- and postmeasures are collected and evaluated with respect to achievement. How mindset relates to self-efficacy and goal orientation has been found to depend on setbacks or challenges that students face throughout the term.[9,42] Additionally, struggling through a course may lead to a shift toward fixed mindset beliefs[18] and students who reported challenges related to chemistry ability in general and organic chemistry courses were found to be more likely to hold a fixed mindset and have lower performance outcomes than students who reported other challenges.[37] A recent study found that the relation between students' chemistry mindset and summative achievement was completely mediated through chemistry-related challenges.[43] Therefore, exploring students' mindset and academic achievement throughout the term may provide valuable information about a potential relation between failing or succeeding in a course and students' mindset throughout. As mindset and summative outcomes were only found to be related through the indirect effect of performance-avoidance goals, future research may consider focusing on how students' performance-avoidance goals may influence changes in this relation. Additionally, other studies have found self-efficacy and goal orientations to change throughout a term.[39,44] In our study, we found self-efficacy to be directly related to summative outcomes as well as indirectly related through all goal orientations except mastery-approach. Self-efficacy was also found to be indirectly related to formative outcomes through both mastery-oriented goals. Therefore, future studies interested in the influence of a students' self-efficacy throughout a term on their formative and summative achievement outcomes may want to focus on all four goal orientations. Ultimately, investigating how these variables change and relate to each other throughout a term as students face challenges and receive feedback on their performance would provide additional information about the relation between mindset and performance and may also provide more guidance on the influence of mindset interventions.

IMPLICATIONS FOR TEACHING

The results of this study highlight some relevant areas for instructors to focus on to improve student outcomes in their classrooms. Overall, both mindset and self-efficacy were positively related to summative achievement outcomes, which suggests that students who hold a growth mindset and have more confidence in their chemistry abilities performed better on exams. Additionally, mindset was found to be positively related to mastery-approach goal orientation and negatively related to performance-avoidance goal orientation. One study found that including metacognitive growth mindset interventions in the classroom led students to put more emphasis on learning versus performance and to better achievement outcomes.[45] Therefore, encouraging a growth mindset in the classroom may encourage students to adopt more mastery goals versus performance goals and lead to improved achievement outcomes. This may be especially important for students who enter the course with a lower mindset and self-efficacy beliefs. Achievement gaps for RM students have been found to be larger in courses where instructors hold fixed mindset beliefs themselves.[46] Moreover, this study found that women reported less of a growth mindset and lower self-efficacy than men at the beginning of the term. Gender research in physics proposes that women are more likely to tie their grades to their views about their academic self-concept (similar to self-efficacy) and are less likely to receive positive comments from instructors.[47] Canning et al.[46] found that women in STEM who perceived that a professor had a fixed mindset had decreased feelings of belonging in a course when compared to men, and as a result, women's grades suffered more than men. These results further emphasize the importance of what faculty say and do on the course outcomes for women. Thus, instructors should also be mindful of their own mindset beliefs and strive to present a growth mindset to students in their course through positive messages about success, providing opportunities for feedback and practice, responding to students' struggles with strategies for improvement, and placing value on student improvements and development.[48]

Another finding of this study is that general chemistry students had a more fixed mindset than organic chemistry students. One study in physics suggests that first-year students who are new to college may be unfamiliar with exams that account for a significant portion of their grade. As such, general chemistry students may struggle with implementing successful strategies. The implementation of more frequent, low-stakes assessments for first-year students can provide them with more opportunities to learn from their mistakes and improve their study skills.[49] These frequent low-stakes assessments can also give students an increased sense of mastery, which can lead to increased self-efficacy and growth mindset beliefs. Other authors have noted that this type of formative feedback may increase self-efficacy[49] and that interventions that involve increased feedback can increase mastery-approach goal orientation. An additional consideration for instructors is an increased emphasis on alternative assessment practices, such as specification grading, that emphasize mastery of learning

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outcomes. One study in biology found that specifications grading increased student growth mindset beliefs and self-efficacy over the course of a semester.[50] Specifications grading and similar practices provide students with clear learning outcomes that help them focus on mastery over performance goals.

In summary, the findings of this study suggest that interventions should focus on increasing growth mindset and self-efficacy, which also impact approach goal orientations. The results of this study suggest that both student- and instructor-facing interventions are needed. In addition, since mindset and self-efficacy were positively related to summative and not formative outcomes, an evaluation of interventions meant to impact growth mindset or self-efficacy may need to consider summative and formative outcomes separately rather than just the final course grade.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00929.

Institutional information, descriptive statistics, CFA results, measurement invariance, and additional values for tested models (PDF; DOCX)

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Notes

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