To whom do students believe a growth mindset applies?

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Intelligence mindset has been studied extensively in education research, but domain-specific intelligence mindset research is relatively new in the physics context. Additionally, recent mindset research has uncovered separable factors within the intelligence mindset construct. In this study, we test a model involving four factors (My Ability, My Growth, Others' Ability, and Others' Growth) to pre and post survey data from Physics 1 classes. In particular, we explore how these mindset factors change over time as well as their ability to predict course grade. We find that students are less likely to endorse a growth mindset for themselves and others at the end of their first calculus-based introductory physics course than at the beginning. We also find that decrease in mindset measures are more drastic for female students than male students. Finally, we find that the best predictor of course grades is the My Ability component of the mindset construct, which has implications both for creating equitable and inclusive learning environment and determining how educators implement mindset interventions.

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I. INTRODUCTION

Gender differences in introductory physics performance and persistence have been linked to many factors, such as societal stereotypes and biases about who can succeed in physics [1–3], an unwelcoming climate in physics classrooms for women [1, 2], and gender differences in motivational factors [4–6]. Among the many motivational factors that have been investigated, considerable attention has been placed on the role of intelligence mindsets [7], which describe a person's beliefs about the nature of intelligence. A growth mindset is one in which intelligence is viewed as something that can be cultivated with effort, like a muscle, while a fixed mindset is one in which intelligence is thought to be innate and unchangeable [8]. The mindsets held by learners are thought to shape how students engage in learning. With a fixed mindset, a student is likely to disengage from or avoid difficult tasks [9]. On the other hand, the engagement, propensity to attempt challenging problems, and persistence that often come with growth mindsets have been linked to positive learning outcomes [8, 10], even after controlling for prior academic achievement [11, 12].

Intelligence mindsets may also play a role in shaping learner self-efficacy [13]. As a result, growth mindsets are not only relevant to creating equitable classroom environments, but they also may be an important factor in improving learning outcomes for all students. Growth mindsets have also been linked to greater participation in STEM fields for students in underrepresented groups [14], and can be a useful resource for underrepresented students to combat stereotype threat or anxiety [15]. Fixed mindsets can cause students to withdraw from a subject of interest due to fear of representing their identities (e.g., race or gender) poorly[15], while anxiety can limit working memory [16].

While intelligence mindset was originally conceptualized as a continuum (with fixed and growth mindsets on either end [8, 11], a two-factor model has gained popularity in recent years [17, 18]. In this model, endorsement of fixed and growth mindsets are measured separately. The primary evidence in favor of treating them separately as two dimensions was psychometric evidence in which a two-factor model produced a better fit to the data [17, 18]. Another conceptual divide in mindset research involves beliefs about self versus others. One study [19] found that Australian high-school students conceptualized intelligence mindsets differently for themselves than for others. They also found that intelligence "self-theory" was a stronger predictor of academic performance and motivation than general intelligence mindsets.

Although intelligence mindsets are carried by students into various learning contexts (i.e., have some stability over time and context), they can be malleable through strategic (and relatively brief) interventions with positive results for students' learning outcomes [11, 12], especially if students are at a high risk of failing a class [20]. However, a recent meta-analysis [23] has found that both the methodology and effectiveness of these interventions vary greatly. For example, only 12% of the interventions included in the meta-analysis resulted in significantly greater academic achievement. The varying effectiveness of these interventions may be due in part to procedural details (e.g., whether the intervention needs to be customized to the particular concerns that students have in a particular context). Additionally, the focus of each interventions may account for their effectiveness. For example, did the intervention seek only to address the growth mindset but ignore the ability mindset? Prior interventions may have tried to convince students that people in general can grow their intelligence, leaving relatively untouched the beliefs they have about themselves.

A third issue might also exist in domain-specificity of intelligence mindsets. Students might believe that intelligence in general can change through hard work but still have fixed mindsets about particular domains. Physics-specific mindset research has just begun in recent years [5, 7]. Early analysis has found that physics-specific mindset is both different than and a better predictor of physics class performance than general intelligence mindsets [5]. There is also evidence that physics intelligence mindset becomes more fixed after taking a physics course, especially for female students [5]. This may be in part due to brilliance beliefs in physics - both the physics community [3] and general public [2] believe that success in physics requires innate talent. Brilliance beliefs are not the same as a fixed mindset, though they work in tandem. If a student thinks raw talent is needed to succeed in a domain (a brilliance belief), and they believe that intelligence is unchangeable (a fixed mindset), then they will see no path to success unless they believe they have innate talent [24]. This combination of brilliance beliefs and a fixed mindset can result in fewer students from underrepresented groups entering physics [3].

Notably, some research supports division of mindset components in the physics context [21, 22] However, since physics-specific mindset is still a very recently explored concept, many fundamental questions about its nature and relationship to gendered performance in physics are still open. Specifically, we address the following questions:

RQ1. Do students have different mindset beliefs about themselves and others, and do they change over time?

RQ2. Do any mindset components predict the course grade?

II. METHODOLOGY

This study took place at a large, public university in the United States. Participants were enrolled in calculus-based Physics 1 over one semester and across four course sections, each taught by a different instructor. The surveys were administered in the first and last week of the required teaching assistant-led recitations. The mindset items were a subset of a larger survey, which took approximately ten minutes to complete. Students received either a participation grade or a small amount of extra credit for completing the survey, depending on the instructor's preference. Survey results were collected, de-identified by an honest broker, and then combined with similarly de-identified demographic information and academic history. In the student sample ($N = 683$), 63% were first-semester engineering students. Female students made up 36% of the sample - only binary data were available for this sample, but we acknowledge that gender is more complex than our data suggest.

The mindset survey was adapted from previously validated surveys [5]. The survey was designed to measure mindsets about self and others, as well as growth and ability mindsets. Therefore, to be able to separately evaluate these different aspects of mindset, additional questions were created and some questions were adapted to make the specific focus more salient. For example, "People can change their intelligence in physics quite a lot by working hard," becomes "I can change my intelligence in physics quite a lot by working hard." After the questions were drafted, we used twenty hours of semi-structured think-aloud interviews to refine the questions and ensure that students interpreted them as intended.

Confirmatory Factor Analysis (CFA) using the R package "lavaan" was used to both provide quantitative validation of the survey items and to test the proposed conceptual division into four components in terms of growth/ability and myself/others. For model fit, we chose the following standards: standardized factor loadings above 0.5 [25], a Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) ≥ 0.95, a Root Mean Square Error of Approximation (RMSEA) ≤ 0.08 , and a Standardized Root Mean Square Residual (SRMR) ≤ 0.06 [26]. In the final model, which can be seen in Table I, the CFI was 0.95, the TLI was 0.95, the RMSEA was 0.073, and the SRMR was 0.052. All fit indices met the chosen cutoffs. To create latent variables, we calculated the average score for the questions in each validated category, and we named the resulting variables "My Ability" (MA), "My Growth" (MG), "Others' Ability" (OA), and "Others' Growth" (OG). All the mindset factors are scored from 1 to 4, and are coded such that a high score corresponds with a growth physics mindset, and a low score corresponds with a fixed mindset. After averaging scores we winsorized each mindset factor so that outliers were set at a cutoff two standard deviations from the mean of each factor (in order to maintain the direction of outliers while eliminating extreme values [27]).

High school Grade Point Average (HS GPA) and Scholastic Achievement Test math (SAT math) scores were used as measures of prior academic preparation. HS GPA was reported using the weighted 0-5 scale, which is based on the standard 0 (Failing) - 4 (A) scale with adjustments for advanced courses. SAT math scores were winsorized using a two standard deviation cutoff to maintain the direction of outliers without introducing extreme values. If only American College Testing (ACT) scores were provided, scores were converted to the SAT equivalent for analysis [28]. Course performance was measured using final grades on a 0 - 4 scale. The suffixes '+' and '-' respectively add or subtract 0.25 grade points (e.g. B- = 2.75 and B+ = 3.25), except for the A+, which is reported as 4. Each instructor determined their own grading scheme and exam content. From examination of syllabi across all sections, course grades were predominantly based upon traditional midterm and final exams, with a smaller portion based on homework, quizzes, and recitation attendance.

TABLE I: Mindset survey questions.

	My Growth ($\alpha = 0.84$)
1	I can become even better at solving physics problems through hard work.
2	I am capable of really understanding physics if I work hard.
3	I can change my intelligence in physics quite a lot by working hard.
	My Ability ($\alpha = 0.84$)
4	Even if I were to spend a lot of time working on difficult physics problems, I cannot develop my intelligence in physics further.
5	I won't get better at physics if I try harder.
6	I could never excel in physics because I do not have what it takes to be a physics person.
7	I could never become really good at physics even if I were to work hard because I don't have natural ability.
	Others' Growth ($\alpha = 0.84$)
8	People can change their intelligence in physics quite a lot by working hard.
9	If people were to spend a lot of time working on difficult physics problems, they could develop their intelligence in physics quite a bit.
10	People can become good at solving physics problems through hard work.
	Others' Ability ($\alpha = 0.68$)
11	Only a few specially qualified people are capable of really understanding physics.
12	To really excel in physics, people need to have a natural ability in physics.
13	If a student were to often make mistakes on physics assignments and exams, I would think that maybe they are just not smart enough to excel in physics.

To characterize change in mean attitudes over time, and differences by gender in mean attitudes at pre and post as well as grades, we used Cohen's d to describe the size of the mean differences and t-tests to evaluate the statistical robustness of the differences. Cohen's d can be considered small if $d \sim 0.2$, medium if $d \sim 0.5$, and large if $d \sim 0.8$ [29]. Pre-post differences were conducted using a paired t-test and gender differences were conducted with unpaired t-tests. We used a significance level of 0.05 in the t-tests and later regression models as a balance between Type I and Type II errors [29].

Multiple linear regression analysis was used to find partial correlations between mindset factors and grades controlling for gender and prior preparation. Multiple models were tested in order to find which was the best predictor of learning outcomes and show robustness of relationships across model specification. A baseline model predicted grade using only gender, HS GPA, and SAT math scores. Next, we added the mindset variables with the strongest correlation to grade one-by-one until all mindset variables were present. All models with significant mindset variables were kept, along with the final model with all variables induced as a robustness test. The regression analyses were conducted with the scores from the pre-survey, then from the average of pre- and post-survey scores. The average group included only students who took the survey both times. Average scores were used as a proxy for students' mindset during the semester, when they were taking the course, rather than after the class. Using average rather than only pre is particularly important given the sizeable changes from pre to post that were observed in several of the attitudinal variables.

III. RESULTS AND DISCUSSION

Do students have different mindset beliefs about themselves and others, and do these change over time? In validation, survey items separated along both myself/others and ability/effort dimensions, resulting in four factors: My Ability (MA), My Growth (MG), Others' Ability (OA), and Others' Growth (OG). This is consistent with previous work [19], which found the same division of mindset factors in Australian high school students. Our results also agree with other studies that find a divide along the ability/effort dimensions [17, 18]. Table II shows descriptive statistics for each measure by gender at pre and post. On the pre-surveys, men and women have nearly identical scores for both OA and OG. Men and women also have similar scores for MG pre. This means that at the beginning of the semester, most students have growth rather than fixed mindsets, particularly when considering others. The only pre-survey category with a significant gender difference is My Ability. In this category men had higher scores than women, with a medium effect size ($d = 0.37$, $p < 0.001$). This means women were more likely than men to believe that natural ability is important for themselves to succeed in physics.

By the end of the semester, all students saw declines in MA and MG, and women also saw declines in OA and OG. The declines in all four categories were larger for women than for men. This suggests that classroom experiences that influenced student mindsets affected men and women differently. The larger declines in MA and MG than OA and OG suggest that intelligence mindset "self-theory" [19] may be more malleable than general physics mindset. This also suggests that the classroom environment led to students becoming more fixed mindset away from growth mindset in the physics context. Trends were similar across instructors, though some results were non-significant when calculated for individual instructors' classes, due to low sample size.

Further, following their first university-level experience, women became more likely than men (for MA post $d = 0.50$, $p < 0.001$) to believe that natural ability is important to succeed in physics for both themselves and others. This suggests that classroom experiences that influenced student mindsets affected men and women differently. These results mirror other studies that have shown that female students have lower

TABLE II: Means (M) and standard deviations (SD) of students' academic and mindset factors. 164 women and 264 men took the pre-survey; 70 women and 147 men took the post-survey. Cohen's *d* is negative if scores decreased from pre to post. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001.

	Women			Men		
Variable	M	SD	*d*	M	SD	*d*
MG Pre	3.59	0.46		3.62	0.48	
MG Post	3.12	0.58	-0.96***	3.48	0.54	-0.31**
MA Pre	3.32	0.46		3.49	0.46	
MA Post	2.98	0.59	-0.71***	3.28	0.62	-0.40***
OG Pre	3.48	0.49		3.50	0.49	
OG Post	3.17	0.44	-0.66***	3.45	0.54	-0.15
OA Pre	3.15	0.53		3.16	0.55	
OA Post	2.91	0.49	-0.49***	3.08	0.61	-0.14
SAT Math	695	64		712	60	
HS GPA	4.25	0.35		4.09	0.42	
Grade	2.49	0.90		2.76	0.98	

average motivational characteristics, such as self-efficacy and sense of belonging, then male students [4–6]. In physics, and other fields in which success is viewed as a result of brilliance [3], students become less engaged and more likely to avoid attempting difficult problems if they don't believe they have the necessary talent to succeed [9]. Female students generally receive few messages that they are brilliant and can thus succeed in physics. Women also make up less than a third of students who take advanced high school physics (Physics 2 or AP Physics C), so they are also likely to be less experienced in physics than their male peers [30]. If the student believes that ability is static, then a student attributing early difficulty to lack of ability instead of experience can discourage the engagement needed to master content.

Do any mindset components predict course grade? We conducted multiple regression analysis to find which mindset factors best predicted course grade (see Tables III and IV). Models 1-3 used only pre-survey results, while Models 4-6 used the mean of pre- and post-survey mindset scores (because of the large changes in mindset across the semester). In Model 1, only gender, SAT math scores, and HS GPA are included as predictors and all three were statistically significant. This model shows that women have lower Physics 1 grades than men when controlling for prior academic preparation, formally establishing that other factors are needed to account for gender differences in course performance. Model 2 includes My Ability (MA) as a fourth predictor. MA was chosen because it is the single strongest correlate of grades. Here pre-survey MA is a significant predictor beyond academic preparation. Its addition weakens the relationship between gender and grade, though gender remains significant. Model 3 adds the remaining pre-survey mindset factors: MG, OA, and OG. None of the newly-added factors are statistically

TABLE III: Standardized β coefficients of models predicting course grade using pre-survey results. For the gender variable, Women = 1 and Men = 0. $N = 497$.

	Model 1		Model 2		Model 3	
Predictor:	β	p	β	p	β	p
Gender	**-0.13**	<0.001	**-0.12**	<0.001	**-0.11**	0.003
SAT Math	**0.39**	<0.001	**0.38**	<0.001	**0.38**	<0.001
HS GPA	**0.32**	<0.001	**0.32**	<0.001	**0.32**	<0.001
MG Pre					0.03	0.515
MA Pre			**0.09**	0.016	**0.10**	0.038
OG Pre					-0.01	0.910
OA Pre					-0.05	0.212
R^2	0.32		0.33		0.33	

significant, and their addition leaves fully intact or slightly strengthens the predictive power of the other predictors, suggesting robust relationship estimates. The predictive power of gender decreases slightly. Importantly, using pre-survey results, MA is the mindset variable with the most predictive power and the variable with the largest gender difference.

Models 4-6 (in Table IV) are focused on the sample that completed both pre and post. Model 4 is identical to Model 1, but now provides the baseline model for the reduced sample set. The parameter values are similar to Model 1, although the SAT estimate is smaller and the gender estimate is larger. Model 5 adds average MA as a predictor. Average MA has more than twice the predictive power of pre-MA, and the gender estimate decreases in size by 38%. Model 6 introduces the remaining average mindset factors, none of which are statically significant predictors (similar to the findings of Model 3). There are no major changes in the predictive power of MA, HS GPA, or SAT math from Model 5 to Model 6, again suggesting robust relationship estimates and that MA in particular was the most likely mediator of gender differences in grades among the mindset factors. When performing regressions, MG, OA and OG do not predict course grade, while both pre- and average-MA do.

Physics self-mindset is a predictor of Physics 1 grade, so increasing MA beliefs may increase all students' performance as well as mitigate gendered grade differences. In this population (primarily engineering students), women are more likely to leave the major due to concerns about low grades than men are, even when they have an A or B average [1], so enhancing students' MA beliefs may increase retention. Importantly, average-MA is a stronger predictor of course grade than pre-MA. Educators have an opportunity to intervene and potentially improve grades and cultivate growth mindsets, since self-mindset appears to be simultaneously more malleable and have a stronger correlation to learning outcomes. Prior research suggests that mindset interventions in this context should focus on students' individual experiences or the experiences of people they can relate to [31–33], rather than focusing on teaching students about the brain's ability to change and grow [11, 12]. The latter approach appears to be well-suited to students who hold a general fixed mindset. However, it may not be useful to students who endorse a general growth mindset but a fixed self-mindset. In addition to showing students that changing one's intelligence is possible, we must show them that they can change their own intelligence.

Moreover, the mindset of the instructors can predict the motivation and achievement of students in their class [34]. Instructors with fixed mindsets tend to have low expectations of students they believe lack natural talent [35]. Instructors with growth mindsets encourage students to embrace mistakes and failures as a part of a normal learning process, congratulate persistence, and praise effort rather than intelligence when students succeed [32, 35]. Students in classes taught by professors with a growth mindset report that the instructors "motivated them to do their best work" and "emphasized learning and development" [34]. Thee studies suggest that, even in courses that may not have the time or resources to conduct a mindset intervention, some benefits of a growth mindset can be brought about via instructor-level changes.

IV. FUTURE DIRECTIONS

Our results are most likely to translate directly to other large universities. However, results in different contexts, such as liberal arts and community colleges, would be valuable to examine and compare to our findings. Further, due to low sample size, we were unable to study whether mindset beliefs differ or predict grades differently for students of different racial/ethnic backgrounds. We plan to do this in future years once we have an adequate number of students for this type of analysis. We also note that the relationship between mindset and grades is correlational in our study. Other work has suggested a causal relationship [36] but this relationship needs to be further explored. We believe that the decrease in growth mindset and growing gender disparity over the semester is a solvable problem. Thus, future work must focus on development and implementation of teaching methods and interventions to cultivate a growth mindset in all students.

TABLE IV: Standardized β coefficients of models predicting course grade using averaged survey results. For the gender variable, Women = 1 and Men = 0. $N = 197$.

	Model 4		Model 5		Model 6	
Predictor:	β	p	β	p	β	p
Gender	**-0.15**	0.019	-0.09	0.152	-0.09	0.179
SAT Math	**0.34**	<0.001	**0.31**	<0.001	**0.31**	<0.001
HS GPA	**0.28**	<0.001	**0.28**	<0.001	**0.28**	<0.001
MG Avg					0.07	0.485
MA Avg			**0.25**	<0.001	**0.24**	<0.001
OG Avg					-0.02	0.791
OA Avg					-0.06	0.426
R^2	0.27		0.33		0.32	

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