M-LoCUS: A Scalable Intervention Enhances Growth Mindset and Internal Locus of Control in Undergraduate Students in STEM[†]

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Student self-beliefs regarding intelligence and ability have been shown to correspond to achievement and persistence in an academic domain. Specifically, previous research has suggested that a growth mindset— or the belief that intelligence is malleable and can increase with effort—is associated with student success. Locus of control is a related but distinct self-belief regarding personal agency over various academic and nonacademic outcomes and has also been associated with study skills and academic persistence. However, academic interventions targeting student mindsets and loci of control have remained relatively underexplored, specifically in the context of undergraduate STEM education. Here, we describe the development and assessment of an intervention encouraging students to adopt a growth mindset and internal locus of control. This five-part intervention is administered entirely online and is therefore independent of individual instructor variability. We administered the intervention in five introductory biology courses and show that the intervention was successful in impacting student mindsets and loci of control across various demographics.

INTRODUCTION

Although the number of students entering college with the intent to major in a STEM field has increased in recent years, fewer than half of these students complete a STEM degree within 5 years (1). Moreover, well-documented gaps in achievement and persistence exist in STEM majors for women, racial minorities, low socioeconomic status students, and first-generation (FG) students, who collectively make up nearly three-quarters of the overall undergraduate population in the United States, leading some to refer to these groups as the "underrepresented majority" (2). The reasons for low persistence rates for these groups are varied and complex; despite much focus on cognitive predictors of student success (e.g., background knowledge and college preparation), evidence continues to accumulate that noncognitive factors, such as student motivation and attitudes toward STEM education, play a key role in student success (3, 4).

At the instructional level, much progress has been made in implementing teaching strategies aimed at addressing disparities in STEM performance and persistence. Although they are still emerging, there has been a widespread increase in the use of inclusive pedagogy strategies shown to enhance student success at the undergraduate level, such as active learning and flipped classrooms (5–8). However, academic strategies to promote the persistence of underrepresented students have thus far been unable to fully address disparities in student engagement, interest, and performance.

Instructors and educational psychologists have increasingly turned to so-called "wise psychological interventions" as adjuvants to alterations in pedagogy to directly target noncognitive factors such as student attitudes and behaviors in the STEM classroom (9). Wise interventions are short, psychologically precise tools aimed at changing a specific psychological process in a real-world setting. Unlike institutional change or wholesale shifts in pedagogy, these interventions aim to produce a positive outcome at the individual student level in a variety of contexts without requiring much in the way of time or financial investment from an instructor or institution. Some examples of wise interventions that have been used with varying levels of success in the STEM classroom include mindset interventions, utility-value interventions, and belonging interventions (10–14).

In this study, we describe the development and implementation of a novel wise intervention administered entirely online in conjunction with introductory biology courses

at a large research university, with the goal of impacting motivation and attitudes toward learning in undergraduate STEM students.

Motivational predictors of student success: mindset and locus of control

Social cognitive career theory (SCCT) provides a useful theoretical framework in understanding students' academic development through connected processes of interest development, decision-making, and performance (15). Based on Bandera's (1986) social cognitive theory, SCCT understands academic success and persistence as an interplay between self-efficacy beliefs, outcome expectations, and interests, influenced by environmental supports (Fig. 1). Moreover, students' self-efficacy develops in the distal environment, while proximal environmental factors influence academic choices. While these environmental factors can be objective (e.g., financial resources), oftentimes perceived environmental factors (e.g., personal ability) play an important role (15). According to this model of student academic and career success, academic interventions are unlikely to promote equity in undergraduate STEM education unless they are paired with strategies aimed at impacting students' beliefs about themselves and their ability to succeed in STEM. Thus,

our intervention targets mindset and locus of control, two related but distinct components of student self-beliefs.

According to constructivist models of human psychology, individuals use implicit assumptions about themselves and the world around them to make sense of complex events and assimilate new information into their existing worldview (16). These assumptions structure the way individuals react to events and outcomes in their daily lives. SCCT would predict that these assumptions contribute to self-efficacy beliefs and outcome expectations, thereby playing a key role in shaping student motivation, behavior, and persistence in STEM majors (Fig. 1) (17).

One key implicit assumption that individuals make about themselves pertains to the malleability of personal attributes. For example, a person may believe that a personal attribute such as intelligence is a nonmalleable entity (entity theory), or they may believe that personal attributes may be developed and changed incrementally over time (incremental theory) (16). These diametrically opposed worldviews, often referred to as a fixed mindset and a growth mindset, respectively, impact students' sense of self-efficacy, in turn affecting the way in which individuals set goals and behave within academic environments (Fig. 1, green boxes) (18, 19). Individuals with fixed mindsets are more likely to exhibit a performance goal orientation, meaning that their academic behaviors are driven by a desire to appear competent in a
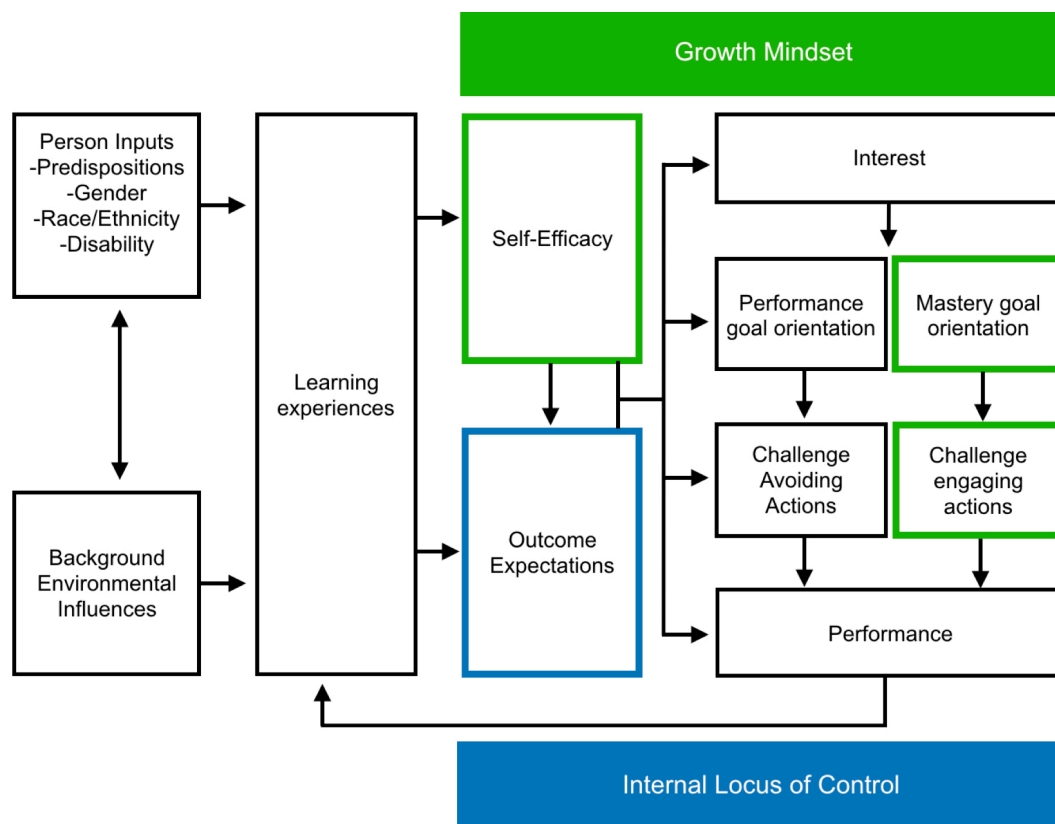

FIGURE 1. Social cognitive career theory model showing connection between student characteristics, learning experiences, interest development, and performance. Nodes predicted to interact with student mindsets and loci of control are outlined in green and blue, respectively.

domain as assessed by normative standards (20). Conversely, individuals with growth mindsets are more likely to exhibit a mastery goal orientation, meaning that their academic motivations are driven by a desire to achieve competence in a domain as defined by self-appointed standards (19). These alternative goal orientations contribute to contrasting academic behaviors; performance goal orientations driven by fixed mindsets elicit behaviors focused on proving competence and avoiding challenges, whereas mastery goal orientations driven by growth mindsets elicit behaviors focused on challenge engaging actions (21). According to SCCT, these goal orientations and actions within academic environments derive from self-efficacy beliefs, outcome expectations, and interests and contribute directly to performance attainments. This interplay leads to a reinforcing feedback loop where academic outcomes contribute to further development of student self-efficacy beliefs.

In addition to behavioral evidence linking a growth mindset to academic success, a growing body of literature has begun to identify neural correlates of growth mindsets (22). For example, growth mindsets are associated with an enhanced error positivity response by EEG, reflecting an increased awareness of and attention to mistakes and leading to increased posterror accuracy (23). Similarly, a functional magnetic resonance imaging analysis of corticostriatal networks important for learning demonstrated that growth mindsets are associated with striatal connectivity with the anterior cingulate cortex, a region of the brain critical for metacognitive processes in learning such as error monitoring and behavioral adaptation (24).

In light of mounting behavioral and neuroscientific evidence that students who exhibit a growth mindset are more likely to monitor their learning, modify behaviors, and persist in the face of academic setbacks, mindset interventions have become increasingly popular among wise interventions in K–12 and some postsecondary education environments (25–27). However, there has been comparatively little investigation into the impacts of mindset interventions on undergraduate students in STEM, where persistent gaps in student achievement driven in part by noncognitive factors provide a promising environment for their deployment (28). Additionally, despite the large body of literature on mindset interventions, particularly in K–12 education, it is unclear whether existing interventions effectively impact participants' mindsets, and whether student attributes affect their response to mindset interventions (29). These limitations necessitate a broader investigation into the proximal impact of mindset interventions in a large and diverse population of undergraduate STEM students.

Although mindset interventions provide a promising avenue toward improving student motivation and performance attainment by impacting self-efficacy beliefs, the SCCT model of student achievement predicts that self-efficacy beliefs alone are not enough to ensure sustained interest and success in STEM for undergraduate students. Another critical factor for educational attainment in a given discipline is a student's expectations about the outcomes associated with their participation in an educational environment within that discipline. Outcome expectations differ from self-efficacy beliefs in that they incorporate a students' sense of personal control over outcomes; they represent a student's measure of the likelihood that their academic behaviors might produce a desired outcome (30). Particularly for URM students, institutional barriers, such as institutionalized racism, may contribute to negative outcome expectations, leading to higher attrition rates in STEM majors (31). Therefore, even with increased self-efficacy beliefs, SCCT would predict that, without a simultaneous increase in outcome expectations, students might not excel academically or persist within their majors.

Outcome expectations are constructed by students in accordance with another implicit assumption they make about themselves, referred to as locus of control (LoC) (32), defined as the degree to which individuals interpret experiences as either within or external to their own agency. Individuals with an external LoC believe that people have little agency over their interactions with the world, whereas individuals with an internal LoC believe that people have the ability to impact these interactions and outcomes (33). Similar to the different adaptation strategies observed in individuals with growth versus fixed mindsets, individuals with high internal LoC are more likely to respond to setbacks by modifying personal behaviors, leading to enhanced educational outcomes (34). Previous research has demonstrated significant positive relationships between internal LoC and study skills, academic achievement, and persistence (35–37). Generational status appears to be a sensitizing factor amplifying the association between LoC and academic outcomes for FG students, making LoC a particularly appealing target for increasing performance and persistence of FG students in STEM majors (38).

Like growth mindset interventions, LoC interventions have been relatively underexplored in undergraduate STEM education. In one study, participation in a freshman study skills and college preparation course was associated with an increase in internal LoC scores for participants that coincided with higher first year GPAs (39). Additional research in the health sciences has shown that interventions aimed at increasing participants' internal LoC can be effective in increasing adherence to pain management regimens (40), decreasing postpartum anxiety and depression (41), and promoting dietary changes and weight loss (42).

Though the constructs of growth versus fixed mindsets and external versus internal LoC appear to share many similarities in the ways they shape student motivation and behavior, they are separated by an important distinction. A growth mindset impacts a student's perceived innate ability to achieve academic success, whereas an internal LoC impacts that student's perception of the situational factors necessary for their academic growth. In other words, a growth mindset would be expected to impact the self-efficacy node of SCCT, whereas an internal LoC would

TABLE 1.
Hypothetical student voices demonstrating different possible combinations of mindset and LoC categories.

Fixed Mindset, External LoC	Growth Mindset, External LoC
"That exam was completely unfair. I'm not some kind of biology whiz who can learn beyond the things we do in class."	"I know that I've been working hard and learning the material very well, but the confusing wording on the exams is the reason I can't get the score I want."
Fixed Mindset, Internal LoC	**Growth Mindset, Internal LoC**
"It's my own fault that I keep getting bad grades on my tests—I'm just not a biology person. It's my job to do better but I feel like I don't have what it takes."	"I haven't mastered the material yet, but I know that if I put in the time and effort and ask for help when I need it, there is no challenge I can't overcome in this course."

improve outcome expectations (Fig. 1, green and blue boxes, respectively). A given student may have any combination of a growth or fixed mindset combined with an internal or external LoC, and each combination would be predicted to produce different patterns of thought associated with variable educational outcomes (Table 1).

With this in mind, we designed and implemented an intervention aimed at fostering a growth mindset and internal LoC in undergraduate STEM students—Mindset and Locus of Control for Undergraduates in STEM (M-LoCUS). We investigated the impact of M-LoCUS in large-enrollment introductory biology courses that students take during their first two years of college. This is a critical time period for students because the factors that contribute to persistence in STEM typically take effect within the first two years of college (43). The intervention consisted of a two-pronged approach targeting both mindset and LoC and was administered entirely online via video-based learning activities to students across the introductory life sciences curriculum at a large research university. In our assessment of the intervention's impacts, we asked two primary questions: 1) Did students demonstrate changes in mindset or LoC over the course of the intervention? 2) Did changes in mindset and/or locus differ between URM versus non-URM students, FG versus non-FG students, and male versus female students?

Development of the M-LoCUS Intervention

A commonly cited barrier for implementing educational interventions based on psychological research is that structural obstacles such as departmental norms, expectations about content coverage, classroom structure, and institutional incentive structures preclude the investment of valuable instructor time and energy into implementing and optimizing materials that do not emphasize course content (44). Additionally, an important barrier to implementation of interventions focused on students' implicit assumptions is the fact that instructors themselves exhibit significant variability in their implicit assumptions about students' abilities, and this variability is associated with differential student outcomes (45). To overcome these obstacles and avoid inherent instructor variability in implementation of M-LoCUS across curricula, we developed M-LoCUS to be implemented entirely online as a series of short videos and reflection assignments throughout the course of an academic term, with no reliance on the availability of in-class time or instructor familiarity with intervention materials.

M-LoCUS is a five-part intervention (Fig. S1). A meta-cognitive component administered pre- and post-course consists of open-ended questions to elicit students' prior educational experiences and attitudes toward learning (MQ in Table S1). Throughout the academic term, students complete a growth mindset module, a LoC module, and a module focused on the interplay between growth mindset and internal LoC. Each of these modules consists of a content-acquisition phase, in which students watch educational videos or answer content-focused questions to acquire knowledge about implicit assumptions (CQ in Tables S2, S4, S6), and a concept-application phase, in which students reflect on the intersection between implicit assumptions and their own experiences (RQ and case studies in Tables S2–S7).

This intervention was designed with the implicit goal of encouraging students to become metacognitive regarding their educational attitudes and outcomes. Ample evidence suggests that promoting metacognition is an essential component of helping students to develop into self-directed learners, allowing them to internalize and apply ideas about growth versus fixed mindsets and internal versus external LoC to their everyday attitudes and behaviors (46–48). Therefore, while they watch explanatory videos and after watching them, students are given multiple opportunities to reflect on their knowledge and prior and future applications of the concepts to their own lives. After completing videos and associated reflection questions, students complete a series of case studies involving hypothetical peers struggling with a particular component of a course (Tables S3, S5, S7). These case studies were designed using basic principles of cognitive behavioral therapy, which focuses on the connection between negative cognitive distortions (e.g., fixed mindsets and external loci of control) and associated changes in behavior and affect (50, 51). Each case study consists of a hypothetical student undergoing an academic challenge, their thoughts (or cognitive distortions) associated with that academic challenge, and the hypothetical outcome of that student's situation. As a result, students have the opportunity to engage with multiple proposed situations where growth/fixed mindsets and internal/external LoC are directly

associated with an academic outcome for hypothetical students. After reading these case studies, intervention participants are asked to advise the hypothetical students using the information they have learned about growth/fixed mindsets and internal/external loci of control. In doing so, we anticipated that students would be generating advice that would likely be applicable to challenges faced during their own undergraduate experiences.

METHODS

Participants

All courses in a three-part introductory biology series required for life sciences majors and pre-medical students at a large public university were chosen to participate in M-LoCUS during the fall 2018 academic term. At the beginning of the academic term, a member from the research team visited each participating classroom to make an announcement notifying students that their class would be part of a study focused on learning and motivation in the life sciences. During this announcement students were informed that we would be using data from their class for the study and directed them to an Institutional Review Board (IRB)-approved information sheet linked to their class website. M-LoCUS materials were incorporated as a standard component of each course and students were required to complete the modules for a small amount of course credit (10 points out of a total of 716 available points for each course). However, students were advised that the study team would not receive access to students' course materials or data unless they consented. Consent was voluntary and the option to withdraw from the study was provided. The IRB approval covered the collection and analyses of assignments and assessments throughout the course, merged with student demographics from the university registrar's office.

Students consenting to have their data included in this analysis consisted of 1,435 students concurrently enrolled in five different course offerings spanning the three courses in the introductory biology series, each taught by a different instructor. Of these students, 1,208 completed the entire M-LoCUS intervention, and were therefore included in our analysis. Demographics of students completing the M-LoCUS intervention are shown in Table S8.

M-LoCUS modules

M-LoCUS modules were incorporated into the learning management system used by participants for their courses. As described above, each of the five modules contained various combinations of content questions, reflection questions, and instructional videos. To ensure the accessibility of M-LoCUS, we used a library of open-access videos easily accessible on YouTube to teach participants about the concepts of growth mindsets and internal LoC (Table S9).

These videos were chosen in part for their visual appeal to encourage participant engagement and in part for their direct relevance to defining and applying growth mindsets and internal LoC. At various points throughout instructional videos and upon completion of the videos, participants were provided links to answer various content or reflection questions before continuing (Fig. S2A to C). After completing the content-acquisition phase of each module, students were asked to rate their current mindset or LoC on a scale of 1 to 10, with 1 representing a completely growth mindset or internal locus of control, 5 representing a neutral position, and 10 representing a completely fixed mindset or external LoC. After completing all videos and questions, participants were directed to a series of case studies as described above (Fig. S2C). All M-LoCUS components are listed in Tables S1 to S7, and a timeline of M-LoCUS administration is shown in Figure S1.

Statistical Analyses

Statistical analyses were performed using IBM SPSS and R. For all hypothesis tests performed in this study, a p value of 0.05 was considered to be the threshold for statistical significance. Categorical comparisons between groups were performed using one-proportion Z-tests. Between-group comparisons of continuous scale items were performed using two-tailed independent sample t-tests. Between-group comparisons of M-LoCUS effects for different courses in introductory life sciences series (Table S10) were performed using a one-way analysis of variance (ANOVA). Effect sizes were calculated using partial eta-squared. Pearson's correlation coefficients were used to determine significant correlations between outcome measures. Linear regression models were developed in R. Graphs and images were made using Microsoft Excel and ggplot2 in R.

RESULTS

Participants exhibited an increase in growth mindset and internal locus of control following the intervention

Overall, we found that students were more likely to describe themselves as having a growth mindset and internal LoC following the intervention (Fig. 2). At the beginning of the course, slightly more than half of students (58.0%) self-identified with a growth mindset, and after completing the course with the interventions, this increased to eight out of ten students (81.2%) identifying with a growth mindset (one proportion z-test, p = 6.48e-60) (Fig. 2A and B). Similarly, the proportion of students rating themselves as having an internal LoC increased from 56.1% at the beginning of the course to 78.4% by the end (one proportion z-test, p = 7.90e-55). Across 1,207 students, mean mindset scores were
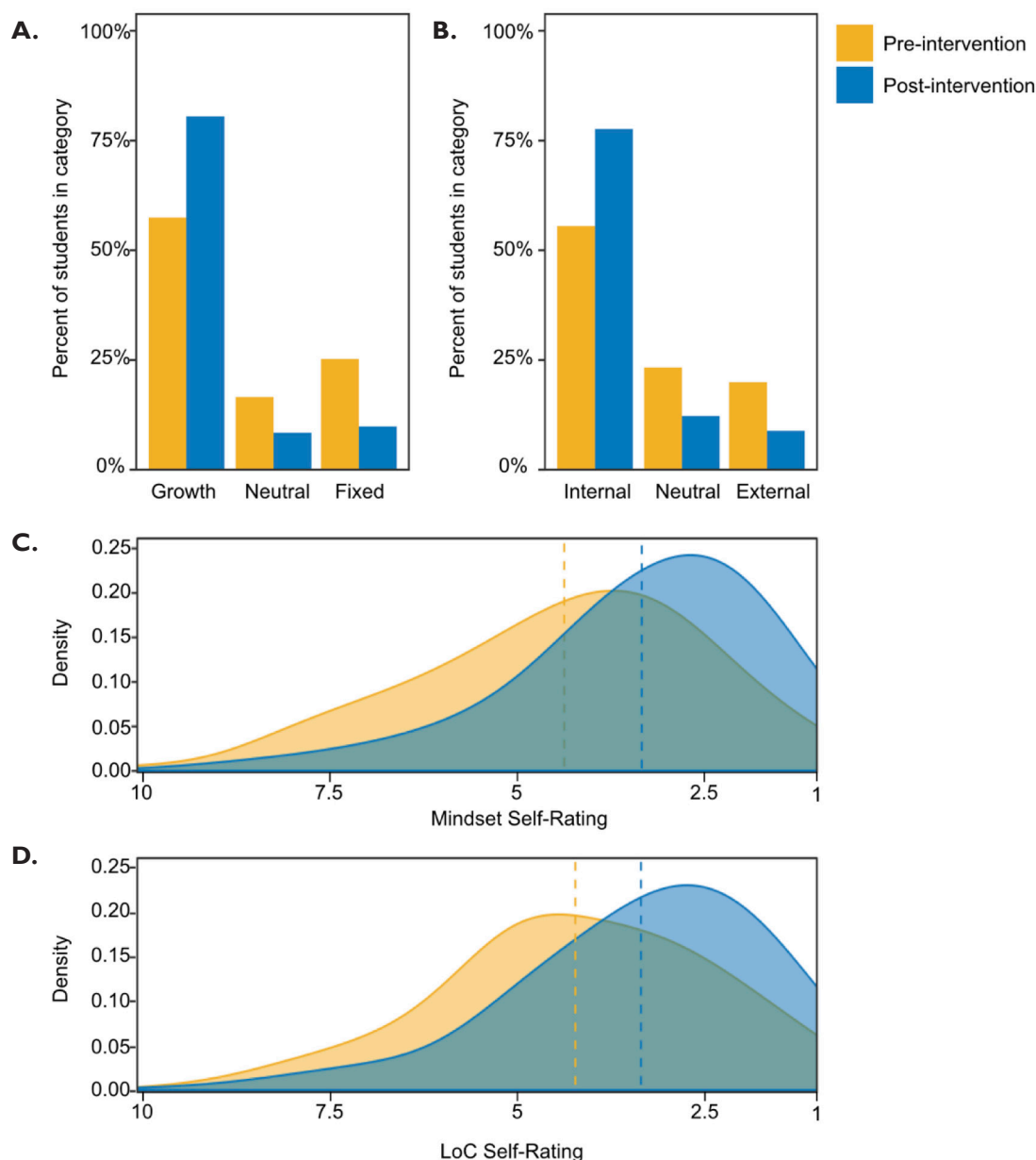
FIGURE 2. A) Percentages of students self-identifying with a growth, neutral, and fixed mindset. B) Percentages of students self-identifying with an internal, neutral, and external LoC. C) Density plot showing the distribution of student mindset self-ratings (on a 10 to 1 scale, with 10 representing a completely fixed mindset and 1 representing a completely growth mindset). D) Density plot showing the distribution of student LoC self-ratings (on a 10 to 1 scale, with 10 representing a completely external LoC and 1 representing a completely internal LoC). Dotted lines represent the median self-rating of all respondents.

4.34 pre-intervention, and 3.30 post-intervention (on a 1 to 10 scale; scores are scaled such that lower scores represent greater *growth*-mindset orientation and *internal* LoC); mean LoC scores, pre- and post-intervention, were 4.21 and 3.32, respectively (Fig. 2C and D). Mindset and LoC scores exhibited a strong positive correlation before the intervention (r = 0.437, *p* < 0.001), and this correlation strengthened following the intervention (r = 0.565, *p* < 0.001). Neither shifts in mindset nor shifts in LoC were dependent upon students' prior completion of courses in the introductory life sciences series, indicating that observed shifts were not dependent on the level of experience students had with introductory biology courses (Table S10). These data suggest that the intervention was successful in impacting students' beliefs about their mindsets and LoC.

Demographic characteristics did not predict post-intervention outcome scores

Previous literature has suggested that outcomes of wise psychological interventions might be sensitive to demographic characteristics of participants (10, 51). Therefore,

TABLE 2.
Pre- and post-intervention mean outcome of mindset self-ratings, by demographic group (*n*=1,207).

Demographic Group (*n*)	Pre	Post	Difference	SD	Effect Size (Cohen's *d*)
All students	4.35	3.30*	1.05	1.51	0.70
Sex					
Male (285)	4.11	3.15*	0.96	1.40	0.69
Female (782)	4.42	3.36*	1.06	1.58	0.67
URM Status					
Non-URM (568)	4.23	3.37*	0.86	1.39	0.62
URM (473)	4.48	3.36*	1.12	1.70	0.66
FG Status					
Non-FG (822)	4.22	3.25*	0.97	1.42	0.68
FG (228)	4.70	3.46*	1.24	1.84	0.67

Lower scores indicate a shift toward growth mindset. Significant differences between pre- and post-intervention self-ratings were determined using an independent samples *t*-test (* *p* < 0.05).

TABLE 3.
Pre- and post-intervention mean outcome of LoC self-ratings, by demographic group (*n*=1,207).

Demographic Group (*n*)	Pre	Post	Difference	SD	Effect Size (Cohen's *d*)
All students	4.20	3.33*	0.87	1.52	0.57
Sex					
Male (285)	4.04	3.24*	0.80	1.40	0.57
Female (782)	4.26	3.36*	0.90	1.58	0.57
URM Status					
Non-URM (568)	4.21	3.40*	0.81	1.49	0.54
URM (473)	4.19	3.25*	0.95	1.59	0.59
FG Status					
Non-FG (822)	4.18	3.36*	0.82	1.47	0.56
FG (228)	4.31	3.24*	1.07	1.78	0.60

Lower scores indicate a shift toward internal LoC. Significant differences between pre- and post-intervention self-ratings were determined using an independent samples *t*-test (* *p* < 0.05).

we sought to determine whether the omnibus shifts we observed toward a growth mindset and internal locus of control were consistent between different demographic groups among our participants. Statistically significant differences between pre- and post-intervention scores were observed regardless of student sex, race (URM vs. non-URM), or generational status (Tables 2 and 3). Pre-intervention ratings for women, URM, and FG students indicated that all of these groups had more of a fixed mindset and that FG students had more of an external LoC prior to the intervention. These disparities were no longer significant following the intervention. Regression analyses confirmed that, after controlling for pre-intervention scores, sex, URM status, and FG status do not significantly predict post-intervention scores for either outcome (Tables 4 and 5), indicating that the intervention was effective in impacting students' per-

ceptions of their own implicit assumptions regardless of demographic group.

Students on the margins of fixed mindsets and external loci of control exhibited the greatest magnitudes of shifts

The majority of students who self-identified as having marginally fixed mindsets before the intervention shifted either two (37.4%) or three or more (39.1%) places along the scale over the course of the intervention. Accordingly, students who rated themselves with marginally fixed mindsets (a self-rating of 6 or 7 on the 10-point scale) prior to the intervention were the most likely to shift mindset categories (i.e., fixed to neutral or growth mindset) (Fig. 3A). We observed similar results for students who rated their LoC

TABLE 4.
Standard multiple regression results for pre-intervention mindset rating and demographic
characteristics predicting magnitude of shifts in mindset self-rating from pre- to post-intervention.

Coefficient	B	SE-b	Beta	t	p value
Constant	0.911	0.124		7.356	**<0.001**
Mindset pre	−0.443	0.022	−0.533	−19.976	**<0.001**
Sex	0.020	0.093	0.006	0.216	0.829
URM status	−0.041	0.087	−0.013	−0.477	0.633
FG status	−0.067	0.105	−0.018	−0.644	0.519

Boldface indicates $p<0.001$.
B = unstandardized coefficients; SE-b = standard error of the regression coefficient;
Beta = standardized coefficients.

TABLE 5.
Standard multiple regression results for pre-intervention LoC rating and demographic
characteristics predicting magnitude of shifts in LoC self-rating from pre- to post-intervention.

Coefficient	B	SE-b	Beta	t	p
Constant	1.054	0.127		8.312	**<0.001**
Locus pre	−0.440	0.023	−0.521	−19.505	**<0.001**
Sex	0.013	0.094	0.004	0.134	0.893
URM status	−0.111	0.088	−0.036	−1.266	0.206
FG status	−0.158	0.106	−0.042	−1.494	0.136

Boldface indicates $p<0.001$.
B = unstandardized coefficients; SE-b = standard error of the regression coefficient; Beta = standardized
coefficients.

TABLE 6.
Pearson correlation coefficients between post-intervention mindset and LoC self-rating and
additional socio-cognitive outcomes associated with student motivation and success.

Basis of Self-Belief	Career Motivation	Self-Efficacy	Academic Self-Confidence
Growth mindset	0.18*	0.30*	0.28*
Internal LoC	0.15*	0.21*	0.17*

*$p<0.01$

as being marginally external at the beginning of the course (Fig. 3B). After the intervention, most of those students shifted two (34.6%) or three or more (30.2%) places along the scale, resulting in neutral or marginally internal LoC perspectives post-course.

Post-intervention mindsets and loci of control predicted other socio-cognitive outcomes associated with student learning and academic success

Previous studies have suggested that growth mindsets and internal loci of control are associated with other socio-cognitive outcomes associated with student learning and academic success (18, 36). Therefore, we sought to test whether student beliefs about their mindsets and loci of control as measured by student self-ratings in our analysis correlated with other predictors of student success. Indeed, post-intervention mindset and locus of control exhibited strong positive correlations with career motivation, self-efficacy, and academic self-confidence, suggesting that self-reported mindset and locus of control measures may be a reliable predictor of motivational factors associated with student success in STEM (Table 6).
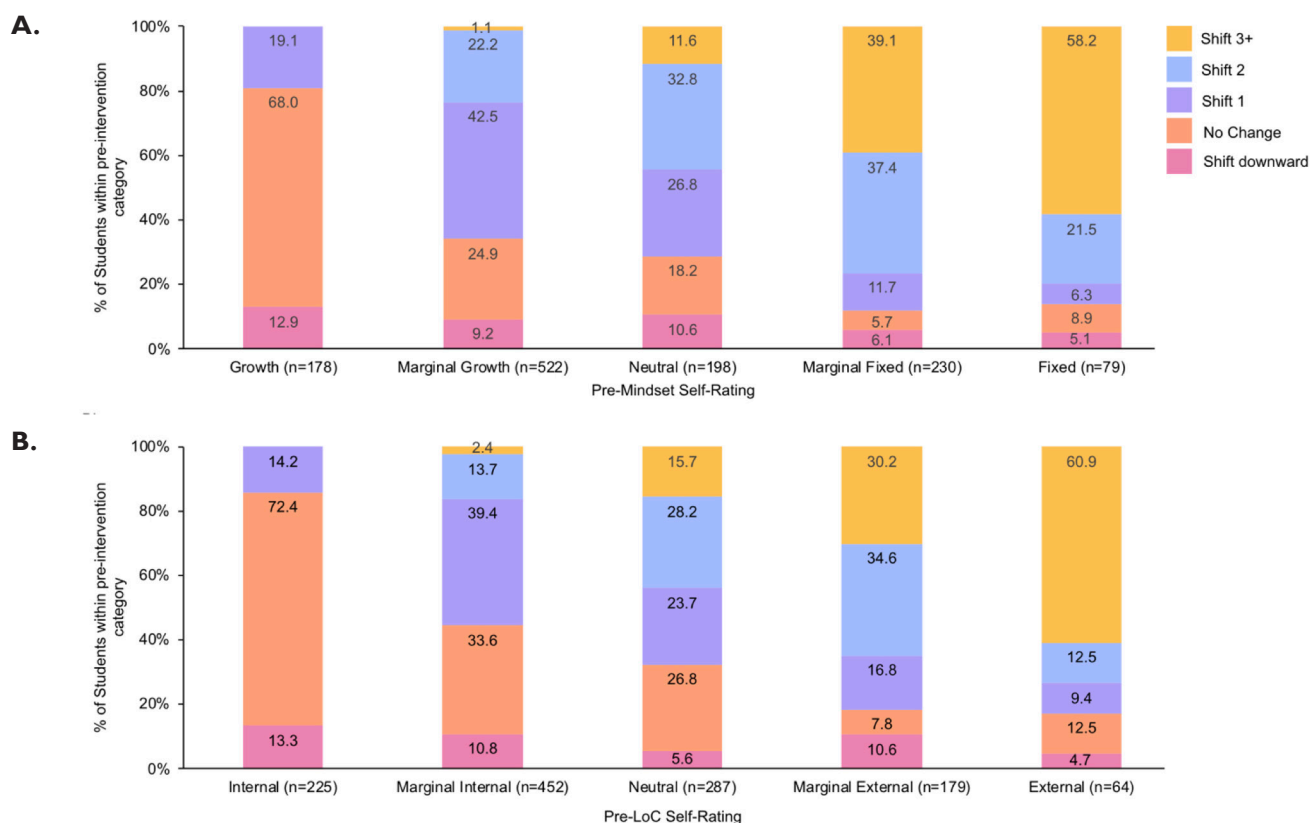
FIGURE 3. Magnitude of shifts in mindset (A) and LoC (B) over the course of the intervention, by pre-intervention self-ratings. Colored bars indicate percentages of students who started in a given mindset or LoC category (x-axis) and shifted 3 or more points toward a growth mindset or internal LoC (yellow), 2 points toward a growth mindset or internal LoC (blue), 1 point toward a growth mindset or internal LoC (purple), did not shift (orange), or shifted toward a fixed mindset or external LoC (pink).

DISCUSSION

The M-LoCUS intervention described above is a novel wise intervention that targets multiple nodes predicted by SCCT to impact undergraduate student success and retention in STEM majors. Taken together, our data provide compelling evidence that M-LoCUS is a promising avenue for a scalable, low-resource intervention that effectively targets undergraduate students' implicit assumptions about their ability to succeed in STEM majors. Students who participated in M-LoCUS exhibited significant increases in self-ratings of growth mindset and internal LoC over the course of the intervention, and these increases were associated with other socio-cognitive factors previously shown to impact student success and retention within STEM majors, such as career motivation, self-efficacy, and academic self-confidence. Because M-LoCUS is administered entirely online, with minimal effort required from course instructors, it averts some of the major barriers typically faced by interventions targeting noncognitive factors impacting student success, including class time constraints and instructor variability. Therefore, M-LoCUS offers an improvement over existing resource-intensive unidimensional interventions and has the potential to become an important high-impact addition to

the existing toolkit used by STEM instructors to improve student outcomes.

The present study focused on the development of M-LoCUS based on an SCCT framework, as well as its initial implementation across the introductory biology curriculum at a large research university. Critically, we demonstrated a significant shift in self-reported student mindset and LoC, the absence of which has been a persistent shortcoming of mindset interventions. This manipulation check, combined with data demonstrating efficacy across demographic groups and correlational indications that self-reported mindset and LoC are associated with other socio-cognitive predictors of student motivation and success, comprises an important first step in assessing the impact of M-LoCUS on a broad scale. Student grades within individual courses were not a target outcome of this study, as our theoretical framework would predict that having a growth mindset and internal LoC would have complex and long-term impacts that would not be captured by a crude analysis of course grades. Future longitudinal studies will be needed to assess these secondary outcomes. While we predict that the entirely online format of M-LoCUS and its theoretical grounding in SCCT will translate to efficacy across a broad range of undergraduate STEM student populations, future work will

be needed to test the impacts of this intervention in different educational settings. Additionally, future studies will benefit from additional investigation of student attitudes about learning and performance concomitant with their participation in M-LoCUS to paint a more detailed picture of the impact of M-LoCUS on various noncognitive predictors of student success.

One area that we did not investigate in our initial development of M-LoCUS was the impact of mindsets and LoC on student responses to academic setbacks. While SCCT provides a useful framework for conceptualizing student achievement and persistence as a complex interconnected positive or negative feedback loop, it does not explicitly provide for alternative student responses to academic setbacks. Recent work has begun to incorporate student implicit assumptions into models of student failure coping mechanisms (19). According to the failure mindset coping model, student mindsets impact their attributions of failure. Students with a fixed mindset are likely to attribute failures to stable or uncontrollable factors (e.g., their innate ability to succeed), leading to maladaptive coping mechanisms such as escape and helplessness, and ultimately leading to negative long-term outcomes. On the other hand, students with a growth mindset are more likely to attribute failures to unstable or controllable factors (e.g., the effort they put in and study strategies they used), leading to adaptive coping mechanisms such as support seeking and cognitive reframing, and ultimately leading to positive long-term outcomes and resilience. Therefore, it is likely that the impacts of M-LoCUS on student mindsets and LoC may extend beyond initial experiences of academic success and additionally predict student responses to academic setbacks.

Overall, M-LoCUS provides a unique intervention grounded in SCCT and targeting multiple nodes of student implicit assumptions to impact motivational predictors of student success. Its format as a low-resource wise intervention administered entirely over a course learning management system should facilitate the widespread application of a much-needed intervention in undergraduate STEM education to promote the success and persistence of all students.

SUPPLEMENTAL MATERIALS

Appendix 1: Tables S1 to S10 and Figs. S1 and S2

ACKNOWLEDGMENTS

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