

# Engaging in science practices in classrooms predicts increases in undergraduates' STEM motivation, identity, and achievement: A short-term longitudinal study

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## Abstract

Our short-term longitudinal study explored undergraduate students' experiences with performing authentic science practices in the classroom in relation to their science achievement and course grades. In addition, classroom experiences (felt recognition as a scientist and perceived classroom climate) and changes over a 10-week academic term in STEM (science, technology, engineering, and mathematics) identity and motivation were tested as mediators. The sample comprised 1,079 undergraduate students from introductory biology classrooms (65.4% women, 37.6% Asian, 30.2% White, 25.1% Latinx). Using structural equation modeling (SEM), our hypothesized model was confirmed while controlling for class size and GPA. Performing science practices (e.g., hypothesizing or explaining results) positively predicted students' felt recognition as a scientist; and felt recognition positively predicted perceived classroom climate. In turn, felt recognition and classroom climate predicted increases over time in students' STEM motivation (expectancy-value beliefs), STEM identity, and STEM career aspirations. Finally, these factors predicted students' course grade. Both recognition as a scientist and positive classroom climate were more strongly related to outcomes among underrepresented minority (URM) students. Findings have implications for

why large-format courses that emphasize opportunities for students to learn science practices are related to positive STEM outcomes, as well as why they may prove especially helpful for URM students. Practical implications include the importance of recognition as a scientist from professors, teaching assistants, and classmates in addition to curriculum that engages students in the authentic practices of science.

#### KEYWORDS

academic motivation, classroom climate, science education, science identity, science learning, science practices, science processes, scientist recognition

## 1 | INTRODUCTION

In the past decade, there has been a national call in the U.S. to provide college students with more authentic science experiences through direct involvement in research and courses that include the processes of science (e.g., American Association for the Advancement of Science [AAAS], 2011; Association of American Medical Colleges-Howard Hughes Medical Institute [AAMC-HHMI], 2009; National Research Council [NRC], 2011). Involving students in original research under the mentorship of scientists has well-documented impacts on students' opportunities, achievement, and career aspirations in science, technology, engineering, and mathematics (STEM; e.g., Carlone & Johnson, 2007; Chemers et al., 2011; Hunter, Laursen, & Seymour, 2007). However, it is difficult to provide this opportunity to all students. Innovative educators have found ways to bring authentic science experiences into courses and to achieve similar outcomes through course-based undergraduate research experiences (e.g., Clark et al., 2009; Hoskins, Stevens, & Nehm, 2007) and inquiry-based lab courses (e.g., Furtak, Seidel, Iverson, & Briggs, 2012; Minner, Levy, & Century, 2010). An essential feature of all these experiences is that students are engaged in the practices of science (e.g., evaluating a hypothesis, using evidence to explain results) to build new knowledge.

National priorities in the U.S. have also focused on addressing the disparities in STEM degree completion rates among different groups. Though interest in pursuing STEM degrees has steadily increased in the last decade across all ethnic groups, persistence to degree is low and some groups persist at disproportionately lower rates. For example, intent to pursue a STEM major is high among first-year college students across racial-ethnic backgrounds (National Science Board, 2016). However, less than 40% of all students who initially intend to graduate in STEM complete their degree, and graduation rates for students who are ethnically underrepresented in STEM are significantly less than the rates of their majority peers (Higher Education Research Institute [HERI], 2010). These disparities have been the catalyst for a movement to improve STEM education in U.S. colleges and universities nationwide (President's Council of Advisors on Science and Technology [PCAST], 2012).

Providing research experiences to students is widely regarded as a means of advancing more students from underrepresented groups into STEM, and studies have demonstrated success

(e.g., Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013). Some studies have established more concretely that the positive outcomes of research experiences arise from students performing science practices, which led to science self-efficacy, identity, and motivation to pursue a STEM career (Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011; Hernandez et al., 2013; Syed et al., 2018). In addition, laboratory courses that are more reflective of authentic science seem to be particularly beneficial for retaining women (Hazari, Sadler, & Sonnert, 2013) and underrepresented racial-ethnic groups (Dirks & Cunningham, 2006). Opportunities for performing authentic scientific or engineering practices have directly and indirectly been linked to increasing participation of underrepresented groups in STEM.

Few studies have explored the outcomes of incorporating science practices into lecture format courses (with no hands-on laboratory component). Introductory STEM courses are often the gatekeepers to STEM careers. Moreover, for many college students, these will be the only STEM courses they will take. Establishing the benefits of engaging students in science practices in lecture format courses holds tremendous potential for increasing success for all students in STEM. In addition, a better understanding of the processes that connect student performance of science practices to achievement and career aspirations could help educators to more effectively incorporate authentic science experiences into a range of learning contexts and reduce disparities in STEM persistence.

To better understand processes linking students' performance of science practices in the classroom to their STEM achievement and aspirations, we conducted a short-term longitudinal study testing undergraduates' reported performance of science practices in gateway biology courses at the outset of an academic term in relation to subsequent changes over the term in students' STEM motivation and STEM identity. In addition, we considered if these changes predicted the students' course grade. According to expectancy-value theory (Eccles & Wigfield, 1995, 2002) and similar models (see Hulleman, Durik, Schweigert, & Harackiewicz, 2008), individuals are most motivated to achieve in domains in which they expect to succeed (i.e., competence beliefs or self-efficacy) and that they value (i.e., intrinsic interest and perceived importance). Also, research guided by social identity theoretical approaches (e.g., Cohen & Garcia, 2008) has highlighted how identifying with a particular ingroup, such as being a scientist, can bolster students' motivation and achievement.

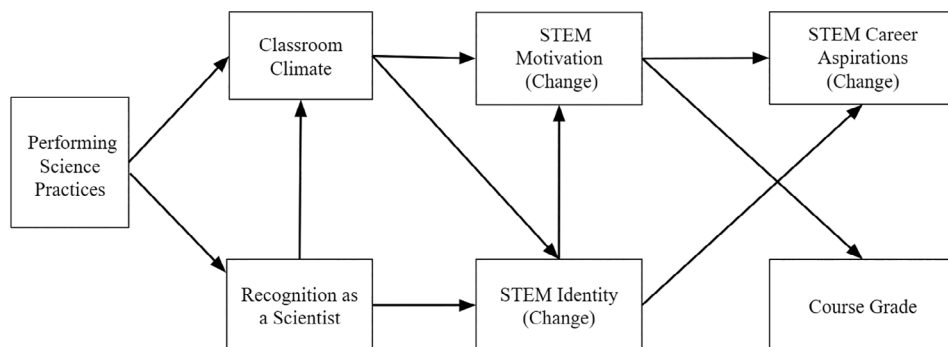
Overall, we hypothesized that students' experiences in the science classroom would predict changes in their STEM motivation and career aspirations. First, we expected that performing science practices in the classroom would positively relate to feeling recognized as a scientist. That is, engaging in science practices (e.g., formulating and testing a hypothesis) can provide opportunities for students to feel acknowledged as a scientist from their classmates, teaching assistant, or instructor. In turn, feeling recognized as a scientist may engender positive perceptions of the classroom climate, whereby students find the learning experience contributed to their interest and confidence in the subject matter. Next, we hypothesized that feeling recognized as a scientist and the perceived classroom climate would predict positive increases in STEM motivation and career aspirations over the course term. In turn, a positive effect on course grade was expected. Given concerns regarding underrepresented ethnic minorities and women in many STEM fields (National Science Foundation, 2017), we additionally tested students' reported status as underrepresented ethnic minorities (URM) and gender as moderators. Our hypothesized model is presented in Figure 1. In the subsequent sections, we review more fully the background for the different components in our hypothesized, beginning with science practices in the classroom.

## 2 | AUTHENTIC SCIENCE PRACTICES IN THE CLASSROOM

Several recent U.S. federal reports highlight engagement in authentic science practices in the classroom as best practices for the improvement of STEM teaching and for the retention of STEM students (AAAS, 2011; AAMC-HHMI, 2009; NRC, 2011). Moreover, these practices are also seen as an important component of inclusive pedagogy that may be especially helpful in promoting the success of underrepresented minorities and women in STEM (Chang, Sharkness, Hurtado, & Newman, 2014; Dirks & Cunningham, 2006; Hazari et al., 2013). Inquiry or inquiry-based learning has been defined in different ways, but all definitions include learners actively using authentic practices of science in the acquisition of scientific knowledge (e.g., Pedaste et al., 2015). Science practices include constructing scientific explanations, generating hypotheses, and designing experiments, which are all highly valued by the science community and central to scientific literacy (Krajcik & Sutherland, 2010). Though instructors state that they value science practices and want their students to learn to think like a scientist, they rarely include the explicit teaching of science practices in their courses (AAAS, 2011; Coil, Wenderoth, Cunningham, Dirks, & Grossel, 2010).

When students use science practices in classrooms, they are much closer to feeling that they know what it means to do science. In sharing their ideas for an experiment with peers or instructors they have an opportunity to demonstrate their competency with science practices and be recognized for scientific work. This recognition, in turn, may help to strengthen students' identification with the scientific discipline (reviewed later). However, recognition may be more elusive when students encounter biases based on their race/ethnicity or gender (Carlone & Johnson, 2007; Rodriguez, Cunningham, & Jordan, 2017). Furthermore, engaging in science practices appears to strengthen students' self-concepts and motivational outcomes that persist beyond course boundaries (AAAS, 2011; Graham, Frederick, Byars-Winston, Hunter, & Handelsman, 2013; Hunter et al., 2007; Lopatto, 2007; Trujillo & Tanner, 2014).

Prior studies testing links between engagement in scientific practices and STEM achievement commonly focused on one or two potential mediators, and these studies were conducted with samples of students in small research mentorship programs (e.g., Chemers et al., 2011;



**FIGURE 1** Hypothesized path model depicting the associations among the tested variables. Perceived classroom experiences (e.g., classroom climate) are on the left while outcomes predictive of persistence are on the right (e.g., STEM career aspirations). GPA and class size were controlled in the analyses. STEM motivation change, STEM identity change, and STEM career aspirations change refer to changes from Time 1 to Time 2

Robnett, Chemers, & Zurbriggen, 2015) or small active learning classrooms (e.g., Corkin, Horn, & Pattison, 2017; Rogers & Abell, 2008). In this study, we considered multiple mediators utilizing a large and diverse sample of students in undergraduate biology classrooms. These classrooms ranged in size as well as the degree that they incorporated opportunities for students to perform science practices in their curriculum. We tested a path linking the impact of performing science practices in science classrooms to later outcomes. In particular, the key outcome variables in the model were students' grade in the course and changes during the course in their STEM career aspirations. Students' first-year grade point average and the size of the sampled classroom were controlled in the analyses. As reviewed next, we considered classroom experiences that may link the perceived performance of science practices in science classrooms to these outcomes through changes over time in the course in STEM motivation and STEM identity.

### 3 | CLASSROOM EXPERIENCES

Students' reports of performing science practices in the science classroom were hypothesized to predict feeling recognized as scientists and perceiving a positive classroom climate. The significance of the latter two experiences are reviewed next.

#### 3.1 | Recognition as a scientist

Recognition as a scientist has been identified as an important element of developing a science identity that is coupled with science competency and performance (Carlone & Johnson, 2007). A budding scientist must gain meaningful recognition for being a science person. In an introductory science course, instructors and peers are in a position to provide meaningful recognition to students for their competency and the reasoning skills most valued by scientists (e.g., science practices). Prior studies indicate that mentored research experiences that provide opportunities for recognition are highly successful in increasing students' STEM motivation and persistence, especially for those from underrepresented groups (Chemers et al., 2011; Hurtado, Cabrera, Lin, Arellano, & Espinosa, 2009; Lane & Marsteller, 2016; Schultz et al., 2011). In addition, these programs may bolster students' identification with STEM (Hunter et al., 2007; Hurtado et al., 2011; Lane & Marsteller, 2016; Prunuske, Wilson, Walls, & Clarke, 2013). However, bids for recognition as scientists can be undermined due to one's ethnicity or gender (Carlone & Johnson, 2007; Hazari et al., 2013; Johnson, Brown, Carlone, & Cuevas, 2011; Malone & Barabino, 2009; Ong, 2005).

#### 3.2 | Classroom climate

Classroom climate refers to the social characteristics of an educational environment shaped by its classroom practices, structure, and interpersonal relationships (Corkin et al., 2017). A positive classroom climate works to foster a sense of belonging, confidence, and interest (Cohen & Garcia, 2008). Several prior studies have linked positive classroom climate to increases in motivation and science identity (Corkin, Yu, Wolters, & Wiesner, 2014; Corkin et al., 2017; Hazari et al., 2010; Hulleman et al., 2008; Norman & Schmidt, 1992; Sakiz, 2012; Wilson et al., 2015).

For example, Corkin et al. (2017) investigated classroom climate, motivational beliefs, and course grade among a sample of undergraduates in active learning biology courses. They found that active learning classrooms had higher reports of positive classroom climate and motivational beliefs; and these constructs mediated the relationship between active learning classrooms and course grade.

In our hypothesized model, we predicted that when students reported performing science practices in the classroom, it would foster greater feelings of being recognized as a scientist and a more positive classroom climate. We further speculated that feeling recognized as a scientist and perceived classroom climate would be related. That is, feeling recognized may help strengthen students' sense of belonging. In turn, these positive classroom experiences may lead to increased STEM motivation and identity over time, which we review next.

#### 4 | STEM MOTIVATIONAL BELIEFS AND STEM IDENTITY

STEM motivational beliefs (competence and value beliefs) and STEM identity were expected to mediate associations between performing science practices and outcomes (course grade and STEM career aspirations). As posited in the expectancy-value model of achievement motivation and supported in numerous studies, competence and value beliefs are moderately predictive of later achievement and educational choices (Eccles & Wigfield, 2002; Guo, Marsh, Morin, Parker, & Kaur, 2015; Watt, 2010; Wigfield, Cambria, & Eccles, 2012). Additionally, studies have found that expectancy and value beliefs predict career aspirations, along with later career choices (Schoon & Eccles, 2014).

The expectancy-value theoretical model postulates additional factors besides motivational beliefs as influences on achievement-related outcomes (Eccles & Wigfield, 2002). These include individuals' self-concepts or identities. Accordingly, in our own model, we tested the degree that students identified with STEM at the beginning and again the end of the term. In prior studies, students' science identity was positively correlated with their intent to pursue a career in STEM and actual persistence in STEM (Aschbacher, Li, & Roth, 2010; Carlone & Johnson, 2007; Chang et al., 2014; Chemers et al., 2011; Estrada, Woodcock, Hernandez, & Schultz, 2011; Hazari et al., 2013; Hurtado et al., 2009).

Based on research guided by social-identity theoretical approaches, two facets of STEM identity that we measured are centrality and felt typicality. First, centrality refers to the importance of a social identity (such as belonging to STEM) to the self (e.g., Cameron, 2004). Individuals commonly have multiple social identities, and the centrality of a STEM identity may influence how likely that identity shapes later choices and outcomes (e.g., Settles, 2004). Thus, we predicted that students who consider STEM an important aspect of their identity would score high in STEM centrality. Second, felt typicality is another identity dimension that reflects one's perceived similarity to others who share a social identity (e.g., Wilson & Leaper, 2016). This facet of identity addresses the degree that one feels like they belong. Thus, students who view themselves as similar to other STEM students would score high in STEM typicality. In summary, centrality and typicality reflect the degree that students feel connected to a particular group such as being a person in STEM.

In our study, we tested students' STEM motivation (competence and value beliefs) and STEM identity at the outset and the end of the academic term. We hypothesized that students who demonstrated increases over time in their STEM motivational beliefs and STEM identity would attain higher grades in the course as well as demonstrate increased interest in STEM



careers. Furthermore, as explained in the previous section, we hypothesized that classroom experiences would predict changes over the term in students' STEM motivational beliefs and STEM identity.

## 5 | HYPOTHESES

We tested a path model linking classroom performance of science practices to classroom experiences, and their impact over time on students' STEM motivation, STEM identity, STEM career aspirations, and course grades (see Figure 1). First, we predicted reported experiences in performing science practices would be positively related to feeling recognized as a scientist (Hypothesis 1a) and to perceiving the classroom climate as positive for motivation and belonging (Hypothesis 1b). We hypothesized that recognition as a scientist would predict positive perceptions of classroom climate (Hypothesis 1c); and in turn, classroom climate would predict increases over time in students' STEM motivation (expectancy-value beliefs) and STEM identity (Hypotheses 2a and 2b). Increases in STEM identity were expected to be associated with increases over time in STEM career aspirations (Hypothesis 3); and increases in STEM motivation were hypothesized to predict increases in STEM career aspirations (Hypothesis 4a) and course grade (Hypothesis 4b). Finally, we hypothesized that the model would be more strongly related to the outcome measures for students from underrepresented minority (URM) backgrounds than non-URM students (Hypothesis 5). We additionally tested gender as a potential moderator given potential gender-related variations in STEM motivation and achievement (Cheryan, Ziegler, Montoya, & Jiang, 2017).

## 6 | METHODS

### 6.1 | Participants and courses

#### 6.1.1 | Sampling context

Students were eligible to participate if they were enrolled in a participating biology course at a large public university designated as a R1 Hispanic Serving Institution in the United States. The three gateway courses surveyed were Cell and Molecular Biology (two classrooms with 64 and 356 students each), Development and Physiology (four classrooms with 73–328 students each), and Ecology and Evolution (three classrooms with 72–234 students each). The introductory biology courses included both large lecture (250 students or more) and smaller, active learning versions of the same courses (90 students or less). The active learning versions of the courses were developed as part of an initiative funded by the Howard Hughes Medical Institute (HHMI) to infuse active learning into gateway courses using a model that paired faculty members with postdoctoral teaching fellows. In the active learning courses, instructors significantly reduced lecture time and used class time to engage students in a range of activities that required them to discuss ideas with their peers and instructors and take a more active role in their learning.

A unique aspect of the HHMI project was a collaboration with a campus organization that specializes in professional development focused on teaching science practices. One faculty member and one postdoctoral fellow who taught courses included in our study had participated

in this professional development. Thus, there was variation in the extent to which instructors committed and prepared to incorporate science practices into their curriculum. The integration of science practices into courses occurred in both regular lecture courses and the active learning courses, although this generally occurred to a greater degree in active learning courses because the trained postdoctoral fellow was paired with several faculty members teaching the active learning courses. For the purposes of the present study, the important feature of the sampled courses was they varied in student-reported performance of science practices. The course in which students reported the highest level of performing science practices is further described in the practical implications section of this paper.

### 6.1.2 | Sample selection

Of the 2,070 students enrolled in the nine courses, 63% ( $n = 1,312$ ) completed the full survey both in the first two weeks of the quarter (Time 1) and in the last two weeks of the quarter (Time 2). Of these students, 185 were dropped because they took the survey for two classes, resulting in 1,127 unique student cases. Analysis of the patterns of missing data revealed that less than 1% of all items for all cases were missing, and 99.73% of the items were not missing data for any case. Considering individual cases, 97.57% of participants had no missing data. The most common variable missing was first year GPA (missing in 29 cases). Cases with any missing values were not used in the present study, resulting in 30 cases that were dropped because of missing data.

### 6.1.3 | Final sample

The final sample consisted of 1,079 students (65.4% women,  $n = 706$ ;  $M = 19.7$  years,  $SD = 1.14$ , range 18–37). The majority were either second-year sophomores (52%,  $n = 564$ ) or third-year juniors (31%,  $n = 334$ ), and the rest were either first-year students (10.9%,  $n = 118$ ) or seniors (5.8%,  $n = 63$ ). According to school records, participants were predominantly Asian (37.6%,  $n = 406$ ), White (30.2%,  $n = 326$ ), or Latinx (25.1%,  $n = 271$ ). The remainder had identified to the school as Black (3.7%,  $n = 40$ ), Native American (1%,  $n = 8$ ), Native Hawaiian or Pacific Islander (1%,  $n = 7$ ), or chose not to report their race/ethnicity (2%,  $n = 21$ ). Students were classified as URM if they identified as Latinx, Black, Native American, or Native Hawaiian (29.6%,  $n = 319$ ). Students who identified as Asian, White, or no race reported were classified as non-URM (70.4%,  $n = 760$ ). Additionally, 39.7% ( $n = 428$ ) reported that they were the first in their family to go to a four-year university, and 37.3% ( $n = 402$ ) were eligible for the Pell Grant (which we used as a proxy for low income status). On average students' first-year GPA was 3.24 ( $SD = .42$ , with a range of 1.65–4.0).

## 6.2 | Procedure

Students completed the survey online during their own time both within the first two weeks of the 10-week quarter (Time 1) and within the last two weeks of the quarter (Time 2). Students took the survey for credit in their course. The first page of the survey was an Institutional Review Board (IRB) approved consent form, which explained to the students that it was their



choice to take the survey and that there was an alternative option to write a short paper. The survey took students an average of 22 min, and scales were randomized for each student.

## 6.3 | Measures

The measures used in the present analyses are summarized below. Unless otherwise indicated, we used the assessments from Time 2. See Table S1 for a full list of scale items.

### 6.3.1 | Demographic variables and grades

Demographic variables such as participant age, gender, and URM status were collected from the university's institutional records. In addition, we were provided with each student's first-year grade point average and their course grade in the class from which we sampled.

### 6.3.2 | Performing science practices

To measure students' perception of how often they had engaged in a variety of science practices, a ten-item scale was developed for the present study based on well-established definitions of inquiry (Buck, Bretz, & Towns, 2008; Chinn & Malhotra, 2002; Metevier et al., 2015) and Course-Based Undergraduate Research Experiences (Auchincloss et al., 2014). Participants were asked how often they had engaged in science practices such as “developing and evaluating hypotheses with classmates” and “evaluating the evidence that supports a scientific claim” on a 6-point scale (1 = *never*, 2 = *rarely*, 3 = *some class periods*, 4 = *majority of class periods*, 5 = *almost every class period*, 6 = *every class period*). The measure had excellent internal reliability ( $\alpha = .95$ ).

### 6.3.3 | Recognition as a scientist

For the present study, we created a scale to assess students' experience in gaining recognition for doing science to an introductory science classroom. Nine items were created to reflect opportunities for students to get recognized for their competency and performing science practices (as listed above) by their instructor, teaching assistant, and classmates ( $\alpha = .90$ ). Items included “Assignments allowed me to demonstrate my ability to evaluate evidence to my professor,” “Assignments provided opportunities for me to demonstrate my reasoning abilities to my teaching assistant,” and “My classmates recognized my intellectual contributions to class discussions.” Students answered questions on a scale of 1 = *strongly disagree* to 7 = *strongly agree*. The measure had excellent internal reliability ( $\alpha = .89$ ).

### 6.3.4 | Classroom climate

Classroom climate for STEM was measured using nine items adapted from Stake and Mares (2001) and Robnett and Leaper (2013), which asked students whether their classroom

experiences had increased their interest, confidence, and feelings of belonging in STEM. The three interest related items included questions like “My class experiences have made STEM seem more enjoyable,” while the three confidence items included questions such as “My class experiences have increased my confidence in my ability to do STEM.” Finally, the three belonging questions included items such as “My class experiences have given me an opportunity to make friends with people who like STEM” (1 = *strongly disagree* to 6 = *strongly agree*). The measure had excellent internal reliability ( $\alpha = .95$ ).

### 6.3.5 | STEM identity

To measure a participant's identification with people in STEM, we created a scale that included eight items assessing felt typicality to other students in STEM (e.g., “I feel like I belong with other STEM students” [1 = *Do not belong at all* to 7 = *Very much belong*]) or centrality of STEM to one's identity (“Being a STEM person is part of my self-image” [1 = *Not at all important* to 7 = *Extremely important*]). Whereas prior studies have used these kinds of items to assess gender or racial-ethnic social identities (e.g., Cameron, 2004; Wilson & Leaper, 2016), we adapted them to evaluate STEM identity. The STEM identity measure had good internal reliability ( $\alpha = .75$ ). For the present analyses, we created a measure of STEM identity change from Time 1 to Time 2, by subtracting the Time 1 mean from the Time 2 mean. A paired *t*-test indicated there was no significant change in STEM identity from Time 1 ( $M = 4.05$ ,  $SD = 1.02$ ) to Time 2 ( $M = 4.04$ ,  $SD = 1.01$ ).

### 6.3.6 | STEM motivation

Seven items (Kosovich, Hulleman, Barron, & Getty, 2015) based on Eccles's expectancy-value scale (Eccles & Wigfield, 1995) were used to measure participants' competence beliefs and task value regarding STEM. All items were rated on a 6-point scale. The competence beliefs scale included four items. Sample questions include: “In general, how confident are you in your ability to do well in STEM courses?” (1 = *Not at all confident that I can do well* to 6 = *Definitely confident that I can do well*) and “How successful do you expect to be in your STEM classes?” (1 = *Definitely expect that I will be unsuccessful* to 6 = *Definitely expect that I will be successful*). The value beliefs scale included three questions. Sample questions include: “How important to you are your STEM classes?” (1 = *Not at all important* to 6 = *Extremely important*) and “How useful do you consider your STEM classes?” (1 = *Not useful at all* to 6 = *extremely useful*). For the present analyses, we first created a composite STEM motivation scale by averaging the competence beliefs and task value subscales ( $\alpha = .75$ ); and then we created a measure of STEM motivation change from Time 1 to Time 2, by subtracting the Time 1 mean from the Time 2 mean for each participant. Paired *t*-tests indicated that there was a significant decrease in STEM motivation from Time 1 ( $M = 4.89$ ,  $SD = .64$ ) to Time 2 ( $M = 4.82$ ,  $SD = .66$ );  $t(1078) = -2.73$ ,  $p = .006$ .

### 6.3.7 | STEM career aspirations

The Motivation for a Science Career scale (Stake & Mares, 2001) was used to measure participants' aspirations to go into a STEM career. The four items were adapted by replacing “science” with “STEM.” Example questions include “Having a STEM career would be interesting” and

“I have good feelings about a career in STEM.” Participants answered on a 7-point scale (1 = *Strongly disagree* to 7 = *Strongly agree*). The measure had excellent internal reliability ( $\alpha = .82$ ). For the present analyses, we created a measure of STEM career aspiration change from Time 1 to Time 2 by subtracting the Time 1 mean from the Time 2 mean. Paired *t*-tests indicated that there was a significant decrease in STEM career aspirations from Time 1 ( $M = 5.41$ ,  $SD = .79$ ) to Time 2 ( $M = 5.35$ ,  $SD = .84$ );  $t(1060) = -3.76$ ,  $p < .001$ .

### 6.3.8 | Non-STEM motivation and career aspirations

To test whether the science classroom experiences specifically affected changes in students' STEM motivation and career aspirations, we additionally asked the same questions about motivation (expectancy-value beliefs) and career aspirations regarding non-STEM areas. With the expectancy-value belief items, we substituted “STEM” with “humanities” (e.g., “In general, how confident are you in your ability to do well in humanities courses?”). With the career aspirations questions, we substituted “STEM” with “non-STEM” (e.g., “Having a non-STEM career would be interesting”). To measure change across the term, we created a measure of humanities motivation change and non-STEM career aspirations change from Time 1 to Time 2 by subtracting the Time 1 mean from the Time 2 mean for each set of measures, respectively.

### 6.4 | Preliminary tests for group differences based on URM status

To assess potential group differences among underrepresented-minority students and non-URM students in the sample, ANOVAs with Bonferroni corrected Tukey HSD posthoc *t*-tests were performed. As seen in Table 1, the only significant differences between URM and non-URM students were first-year GPA and biology course grade. Additionally, bivariate correlations were run across the variables (see Table 2). Of particular note, both classroom climate and recognition as a scientist were significantly related to changes in motivational variables over the quarter.

First-year GPA and class size were both controlled for in subsequent analyses, as they were significantly related to key variables. Active and nonactive classrooms significantly differed in science practices and scientist recognition; however, given that class size and active learning classrooms were confounded, and given class size significantly related to more variables than active learning, we chose to control for the former. Independent samples *t*-tests did not find a significant difference in any key variable based on gender, URM status, first generation status, or Pell Grant status. Because of this we did not control for these variables. We additionally broke recognition as a scientist down into recognition from professors, teaching assistants, and classmates; and we correlated them with other key variables to see if source of recognition mattered. We did not find a significant difference based on source of recognition; therefore, the three sources of recognition were grouped together as the recognition as a scientist variable.

Both recognition as a scientist and classroom climate had a significant positive relationship with performing science practices. Additionally, performing science practices was significantly related to majority outcome variables, including two change variables (STEM motivation and STEM identity) as well as end of course grade. Performing science practices was not significantly related to STEM career aspirations (see Table 2).

**TABLE 1** Descriptive statistics and *T*-tests ( $N = 1,079$ )

	Scale alpha	Scale range	Non-URM ( $n = 760$ ) <i>M (SD)</i>	URM ( $n = 319$ ) <i>M (SD)</i>	<i>t(df)</i>	<i>d</i>
Performing science practices	.95	1–6	3.28 (1.13)	3.25 (1.22)	−.32 (1077)	−0.02
Recognition as a scientist	.90	1–6	3.83 (1.00)	3.69 (1.14)	1.95 (1077)	0.13
Classroom climate	.95	1–6	4.30 (1.04)	4.41 (1.06)	−1.46 (1077)	−0.09
STEM identity change	.75	−5–5	−.01 (.80)	−.02 (.87)	.12 (1077)	−.01
STEM motivation change	.75	−5–5	−.08 (.53)	−.06 (.59)	−.64 (1077)	−0.04
STEM career aspirations change	.82	−5–5	−.07 (.72)	−.03 (.78)	−.87 (1077)	−0.05
Course grade	n/a	0–4	2.79 (.88)	2.51 (.83)	4.82 (1077)***	0.29
First year GPA	n/a	1–4	3.28 (.41)	3.13 (.40)	5.61 (1077)***	0.34
Class size	n/a	64–376	278.10 (91.26)	272.23 (95.98)	.95 (1077)	0.06

Note: STEM motivation (expectancy-value beliefs) change, STEM identity change, and STEM career aspirations change were derived by the difference between Time 1 and Time 2 scores for these measures.

Abbreviations: Class size, number of people enrolled in the course; URM, underrepresented minority status.

\* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

**TABLE 2** Bivariate correlations ( $N = 1,079$ )

	1	2	3	4	5	6	7	8
1. Performing science practices								
2. Recognition as a scientist	.49***							
3. Classroom climate	.30***	.47***						
4. STEM identity change	.11***	.17***	.20***					
5. STEM motivation change	.07*	.11***	.18***	.12***				
6. STEM career aspirations change	.04	.08**	.18***	.16***	.21***			
7. Course grade	.09**	.15***	.23***	.02	.16***	.09**		
8. First year GPA	.02	.07*	.11***	−.01	.04	.08**	.56***	
9. Class size	−.26***	−.21***	−.11***	−.03	−.02	.00	−.12***	.05

Note: STEM motivation (expectancy-value beliefs) change, STEM identity change, and STEM career aspirations change were derived by the difference between Time 1 and Time 2 scores for these measures.

Abbreviations: Class size, number of people enrolled in the course; URM, underrepresented minority status.

\* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

## 6.5 | FACTOR ANALYSIS OF SCALES

To examine the psychometrics of our measures, we conducted an ordinal item factor analysis (IFA) for each scale. IFA is based on classical test theory (CTT), within the SEM family, and it is similar to confirmatory factor analysis (Brown, 2006). CTT uses factor analysis to determine that all items of a scale satisfactorily measure their underlying construct, and the measure is calculated by averaging the items on the scale. It is appropriate for assessing attitudes and

beliefs, where items in a scale are similar (DeVellis, 2012). Conversely, IRT is typically used for items that can be hierarchically ordered based on correctness or excellence, such as PISA test scores (DeVellis, 2012). Studies have found that IRT and CTT have similar results in samples over 100 (e.g., Beaujean, 2014). For additional information on why we selected to use an IFA, please see the additional results in Supporting Information.

For the IFAs, model fit was tested using multiple goodness of fit indicators (e.g., TLI) and standardized factor loadings were examined to determine if any questions were not sufficiently loading onto the scale (see Supporting Information for more detail, including full scales and item factor loadings in Table S1). Results of the measurement model demonstrated that the indicator variables loaded significantly onto their constructs for all scales ( $p < .001$ ). However, standardized factor loadings and goodness of fit indicators suggested the removal of 1–2 items for the recognition as a scientist scale, STEM identity scale, and STEM motivation scale (see Supporting Information for more detail about items removed). These adjusted scales were used for the remainder of analyses.

The final scale factor loadings are as follows: performing science practices (10 items; factor loadings range: .75–.91); classroom climate (9 items; factor loadings range: .77–.92); recognition as a scientist (7 items, factor loadings range: .64–.86); STEM identity (6 items, factor loadings range: .55–.61); STEM motivation (6 items, factor loadings range: .55–.72).

## 7 | RESULTS

### 7.1 | Path model overview

The *R* SEM package lavaan was employed to test our hypotheses regarding the relationships among performing science practices, recognition as a scientist, and change in STEM identity, change in STEM motivation, and change in career aspirations and end of course grade. A two-step modeling process was followed (e.g., Tabachnick & Fidell, 2013). First, the initial theoretical model was tested. Then modification indices were examined to identify potentially significant paths omitted from the model. These paths were then added, so that all significant paths were included in the model.

Model fit was tested using multiple indicators. First, the chi-square test of model fit was examined. Additionally, the Tucker–Lewis Index (TLI), the Comparative Fit Index (CFI), and the Root Mean Square Error of Approximation (RMSEA) were examined. For both the TLI and CFI, a value  $\geq .95$  indicates a good model fit, and values  $\geq .90$  indicate an acceptable fit (Hu & Bentler, 1999). For RMSEA, values  $\leq .06$  indicate a good model fit and values  $\leq .08$  indicate acceptable fit (McDonald & Ho, 2002).

### 7.2 | General path model

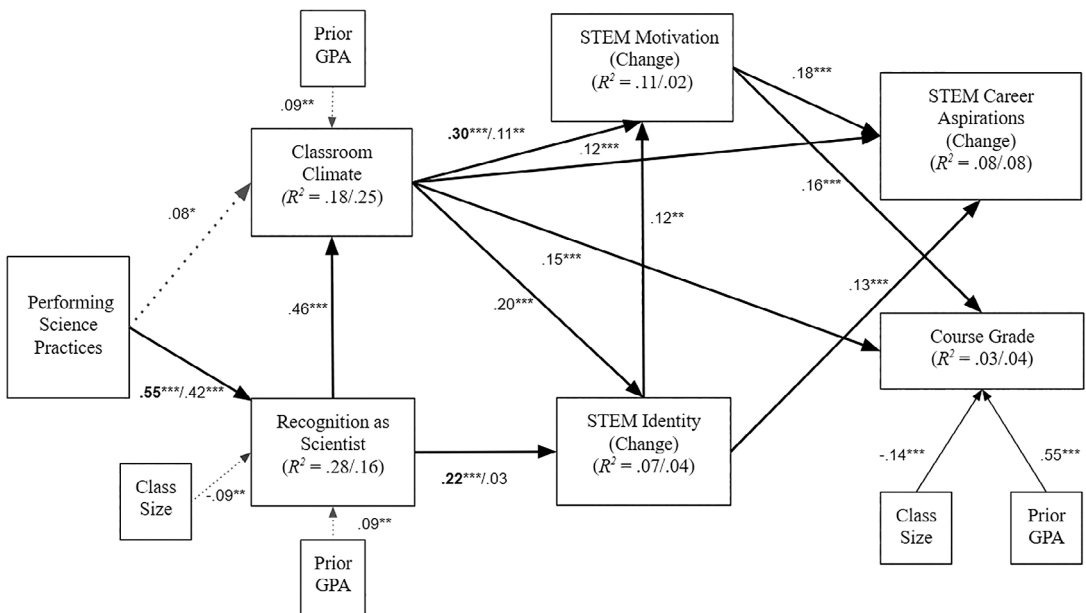
For the present model (see Figure 1), we hypothesized that performing science practices would have a significant positive relationship to recognition as a scientist as well as positive classroom climate (Hypotheses 1a and 1b), and that recognition as a scientist would be significantly positively linked to classroom climate (Hypothesis 1c). We additionally predicted that classroom climate would have a significant positive relationship with STEM motivation change and STEM identity change (Hypotheses 2a and 2b). Finally, we predicted that STEM identity change would be positively

related to increases in STEM career aspirations (Hypothesis 3), and that STEM motivation change would positively predict increases in STEM career aspirations and course grade (Hypotheses 4a and 4b). We controlled for both first-year GPA and number of students in the course.

Lavaan modification indices recommended that two new paths be added: one between classroom climate and STEM career aspirations change, and one between classroom climate and end of quarter grade. See Figure 2 for the adjusted model with added pathways and standardized betas, broken down by URM status when appropriate. Additionally, the indices recommended removing the path between STEM identity change and course grade. Following these changes, the model was an excellent fit according to the following indicators;  $\chi^2(30, N = 1,079) = 22.55, p = .83, TLI = 1.01, CFI = 1.00, RMSEA = .000, 95\% CI [0.00, 0.02]$ . Thus, the hypothesized model was supported.

### 7.3 | Recognition as a scientist and classroom climate as mediators

In order to test the prediction that recognition as a scientist and classroom climate would both be mediators between performing science practices and outcome variables (i.e., STEM motivation change and STEM identity change) we employed the PROCESS macro for SPSS (Hayes, 2017) to test for mediation effects. The PROCESS bootstrapping procedure creates 5,000



**FIGURE 2** Observed path model reflecting the associations among the tested variables ( $N = 1,079$ ). Perceived classroom experiences (e.g., classroom climate) are on the left while outcomes predictive of persistence are on the right (e.g., STEM career aspirations). GPA and class size were controlled in the analyses; the  $R^2$  presented for each variable does not include variance due to class size or GPA. STEM motivation change, STEM identity change, and STEM career aspirations change refer to changes from Time 1 to Time 2. Grey dotted line indicates paths that are significant but negligible (beta = .09 or lower). SEM model statistics: CFI = 1, TLI = 1.01, RMSEA = .000, 95% CI [.00, .02],  $\chi^2(45) = 38.88, p = .73$ ; thus, there was excellent fit. When different beta weights are indicated for a particular pathway, the first is for URM students and the second is for non-URM students

bootstrapped samples of randomly selected observations from the data, drawn with replacement (Hayes, 2017). Model paths were then estimated for each bootstrap sample, and results from these samples were then used to construct estimates and confidence intervals for each model path. Class size and GPA were controlled for. Direct, indirect, and total effects with 95% confidence intervals were calculated using the PROCESS macro (Hayes, 2017). Results indicated that recognition as a scientist was a significant mediator between both performing science practices and STEM identity change, and between performing science practices and classroom climate. In turn, classroom climate mediated the relationship between recognition as a scientist and STEM motivation change over time. Direct, indirect, and total effects for scientist recognition and classroom climate as mediators are presented in Table 4. As expected, direct effects of performing science practices on the outcome variables of classroom climate, STEM identity change, and STEM motivation change were small. However, the indirect effects of performing science practices on the outcome variables through the two mediator variables were significant, indicating a mediation effect.

## 7.4 | Testing an alternative model

Our hypothesized model is premised on the assumption that experiences in science classrooms specifically affect students' science motivation and aspirations. To examine this premise, we tested the same model again substituting STEM motivation with humanities motivation and STEM career aspirations with non-STEM career aspirations (see Section 6 for description of measures). Consistent with our theoretical model, when using non-STEM specific outcome variables, the model fit was poor;  $\chi^2(53 N = 1,079) = 911.13, p < .001, TLI = .38, CFI = .58, RMSEA = .175, 95\% CI [0.17, 0.19]$ .

## 7.5 | Testing possible moderators

In the final set of analyses, we tested three dichotomous factors as possible moderators of our hypothesized model. First, we tested our hypothesis that the classroom variables might be more strongly related to the outcome measures among underrepresented-minority (URM) students than non-URM student (Hypothesis 5). Second, for exploratory purposes, we tested first-generation (vs. continuing) college status as a potential moderator. We noted substantial overlap between first-generation college status and URM status (URM:  $n = 202$  first-generation,  $n = 117$  continuing-generation; Non-URM:  $n = 226$  first-generation,  $n = 534$  continuing-generation);  $\chi^2(1, N = 1,079) = 105.91, p < .001$ . Thus, we sought to explore which of the two variables might better account for any variations in the hypothesized model. Finally, given potential gender-related variations in STEM motivation and achievement, we tested gender as a moderator to consider whether classroom variables were more strongly related to women's than men's outcomes.

### 7.5.1 | Underrepresented-minority (URM) status as a potential moderator

We hypothesized the classroom experience variables (i.e., performing science practices, recognition as a scientist, and classroom climate) would be more important for URM students



compared to non-URM students (Hypothesis 5). To test this hypothesis, we performed multi-group analysis to detect any group differences in pathways. After testing for significant differences, we set all nonsignificant paths to be equal.

We found three pathways of interest were significantly different among URM and non-URM students. First, the path between performing science practices and recognition as a scientist was significantly different between groups ( $z = 2.72, p = .006$ ), with a somewhat stronger positive association between the constructs for URM students ( $B = .55, SE = .04$ ) than for non-URM students ( $B = .42, SE = .03$ ).

Second, we expected a stronger link between recognition as a scientist and increases over time in STEM identity for URM students than non-URM students. Consistent with our hypothesis, we found the two paths were significantly different ( $z = 2.71, p = .007$ ), and the path between scientist recognition and STEM identity was significant among URM students ( $B = .22, SE = .06$ ) but not among non-URM students ( $B = .03, SE = .04$ ).

Third, the path between perceived classroom climate and expectancy-value change over time significantly differed between groups ( $z = 3.18, p = .001$ ). The positive relationship between classroom climate and changes in motivation was significantly stronger among URM students ( $B = .30, SE = .05$ ) than non-URM students ( $B = .11, SE = .04$ ).

Finally, we were able to explain a larger percentage of variance for related constructs among URM groups in comparison to non-URM students (see Table 3). After controlling for class size, performing science practices explained 28% of variance in recognition as a scientist for URM students (vs. 16% for non-URM). Recognition as a scientist and classroom climate explained 7% of increases in STEM identity among URM students (vs. 4% among non-URM students). Finally, classroom climate and STEM identity change explained 11% of the variance in students' change in STEM motivation over time among URM students (vs. 2% in non-URM students).

In summary, the path model significantly predicted outcomes for URM and non-URM students. However, consistent with our hypothesis, it accounted for a greater amount of variance in outcomes for URM students.

**TABLE 3** Percent of variance ( $R^2$ ) explained for each construct ( $N = 1,079$ )

Construct	$R^2$ underrepresented minority group	$R^2$ nonunderrepresented minority group
Recognition as a scientist	.28***	.16***
Classroom climate	.18***	.25***
STEM motivation (change)	.11***	.02**
STEM identity (change)	.07***	.04***
STEM career aspirations (change)	.08***	.08***
Course grade	.03**	.04***

*Note.* STEM motivation (expectancy-value beliefs) change, STEM identity change, and STEM career aspirations change were derived by the difference between Time 1 and Time 2 scores for these measures. Class size and first year GPA are controlled for  $R^2$  includes all variables (excluding control variables) that are connected to the construct in Figure 2.  $R^2$  calculated using hierarchical regression analysis.

\* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

**TABLE 4** Mediation analysis effects for scientist recognition and classroom climate ( $N = 1,079$ )

<i>Mediator (outcome)</i>	Total effect	Direct effect	Indirect effect	95% CI's for indirect effect	
				Lower bound	Upper bound
Recognition as a scientist					
Classroom climate	.19***	.08**	.18***	.15	.20
STEM identity change	.08**	.02	.08**	.03	.08
Classroom climate					
Expectancy-value change	.06**	.01	.08**	.05	.11

Note: Effects are from PROCESS macro for SPSS, with 5,000 bootstrapped samples. Class size and first-year GPA are controlled. \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ .

### 7.5.2 | First-generation college status as a potential moderator

Given the overlap between URM status and first-generation college status explained earlier, we tested our hypothesized model replacing URM status with first-generation status. The overall model fit using first-generation status as a moderator was excellent (e.g., CFI = 1.00, TLI = 1.01). There were two significant group differences. First, the link between performing science practices and perceived classroom climate significantly differed based on first-generation status ( $z = -2.16$ ,  $p = .031$ ). Whereas the association was significant and positive for first-generation students ( $B = .18$ ,  $SE = .05$ ,  $p < .001$ ), it was nonsignificant for continuing-generation students ( $B = .03$ ,  $SE = .04$ ,  $n. s.$ ). Second, the association between recognition as a scientist and classroom climate differed for the two groups ( $z = 3.34$ ,  $p = .001$ ). It was significant and positive for both groups, but it was somewhat stronger for continuing-generation students ( $B = .49$ ,  $SE = .04$ ,  $p < .001$ ) than first-generation students ( $B = .31$ ,  $SE = .05$ ,  $p < .001$ ). In comparison to URM status, first-generation college status accounted for fewer differences in the hypothesized model.

### 7.5.3 | Gender as a potential moderator

Next, we tested the model again using participant gender as a moderator, and the model worked well (e.g., CFI = 1.00, TLI = 1.01). However, we found two significant path differences between women and men. First, the path between STEM motivation change and STEM career aspiration change was significantly different between groups ( $z = -2.48$ ,  $p = .013$ ). The relationship between the two constructs was significant and positive among women ( $B = .25$ ,  $SE = .04$ ,  $p < .001$ ), but it was nonsignificant among men ( $B = .07$ ,  $SE = .05$ ,  $n. s.$ ). Additionally, the path between classroom climate and STEM identity change was significantly different between groups ( $z = 2.28$ ,  $p = .023$ ). Although it was significant and positive for both groups, the association was stronger for men ( $B = .23$ ,  $SE = .06$ ,  $p < .001$ ) compared to women ( $B = .11$ ,  $SE = .04$ ,  $p = .01$ ).

## 8 | DISCUSSION

We investigated U.S. students' experiences in performing science practices in the classroom and felt recognition as a scientist in relation to changes in student's STEM identity, motivation (expectancy-value beliefs), career aspirations, and end-of-course grade. We additionally

considered whether students' status as underrepresented minorities (URM) moderated the hypothesized model. Our research yields insights to the processes connecting the incorporation of sciences practices into classroom experiences, and to important variables related to STEM persistence. We additionally observe how science practices in the classroom and felt recognition as a scientist may be especially beneficial for students who are underrepresented in STEM fields.

## **8.1 | Performing science practices: an important driver of change in motivation and identity**

Science practices are the reasoning skills that scientists use and highly value. Our model begins with science practices in the classroom. Instructors of the courses in our survey incorporated science practices into their courses to varying degrees. When students reported that they had opportunities to perform science practices they were more likely to feel recognized as scientists by their teachers, teaching assistants, and classmates. We observed this association even after taking into account class size. Thus, the meaningful incorporation of science practices into curriculum can be achieved even in large lecture style classrooms (e.g., our largest course had 356 students enrolled).

Our finding that the inclusion of science practices into students' learning experience predicted increases over time in STEM motivation and identity is similar to what others observed when students were engaged in research (Chemers et al., 2011; Hazari et al., 2013; Syed et al., 2018). For example, Chemers et al. (2011) demonstrated that the research experience component of science-support programs has a positive effect on student commitment to a science career, which is mediated by science self-efficacy and identity as a scientist. Their survey instrument defined "research experience" as a set of science practices and suggests that the positive effects came from opportunities the student had to learn and use science practices, which is similar to our own measure.

Our study differs from this earlier investigation in that we sampled students who were enrolled in lecture classrooms rather than undergraduate research programs. The benefits of engaging students in authentic research are widely known, but they are very difficult to provide to all students. Our results suggest that science practices can be emphasized in a lecture course—and, through similar mechanisms as in research, these experiences can increase students' science motivation and identity may follow (e.g., Clark et al., 2009; Hoskins et al., 2007). Our results indicate that the essential features of undergraduate research experiences—such as learning to think like a scientist and engaging in the cognitive practices of science—can still be realized in other instructional settings with more students, including introductory courses. (However, engaging students in science practices in large lectures is not necessarily equivalent in its effect on motivation, identity, and other important outcomes.)

## **8.2 | Feeling recognized as a scientist mediated course outcomes**

Recognition as a scientist and classroom climate served as significant mediators between performing science practices and changes in science identity and motivation over the course of the class. Both were particularly important for URM students. Previous studies have utilized a science identity framework developed by Carlone and Johnson (2007) to examine the importance

of recognition for URM success (Hurtado et al., 2009; Hurtado et al., 2011) to students' science identity development (Cribbs, Hazari, Sonnert, & Sadler, 2015; Godwin, Potvin, Hazari, & Lock, 2016). The latter studies also used path modeling to understand how recognition was correlated with various STEM identities (e.g., math). These researchers found that recognition and performing science practices were each critical to STEM identity development. Performance and competence were often combined in these quantitative studies, and they were defined by grades as well as ability in STEM content and practice. However, in our model, science performance was captured in the students' self-reported opportunities for performance of science practices.

The relationship between students' perceptions of engagement in science practices and their motivation and identity were mediated by recognition as a scientist. Engaging students in science practices may thereby create opportunities for students to be recognized for doing science. Curricular strategies that engage students in science practices that create opportunities to get recognized as a scientist will be more successful in building students' science motivation and identity. For example, an instructor in a large lecture hall might have students individually evaluate two possible scientific claims using evidence, and then ask students to explain to a peer which claim is strongest and why.

To our knowledge, no prior study has longitudinally investigated recognition as a mediator connecting performing science practices to course outcomes such as science motivation and identity in a nonlab, classroom setting. Our findings indicate that science practices in the classroom may provide opportunity for genuine scientist recognition based on performance. This related to a positive classroom climate as well as increases in STEM motivation and identity—especially among URM students. In turn, these increases predicted higher STEM career aspirations and course grade.

Notably, our survey asked students about recognition from faculty, teaching assistants, and peers. We found no difference in which of these groups that students felt recognized in relation to the other outcomes. Thus, when students recognize one another as scientists, they can forge a positive classroom climate. This finding aligns with other literature showing the importance of peer recognition for the development of student identity (Cribbs et al., 2015; Godwin et al., 2016; Lane & Marsteller, 2016; Robnett & Leaper, 2013; Rodriguez et al., 2017), while negative peer interactions can have the opposite effect (Hurtado et al., 2009; Hurtado et al., 2011; Leaper & Starr, 2019).

Another important mediator in the model was classroom climate—that is, students' perceptions of whether classroom experiences contributed to their confidence, interest, and belonging. Feeling recognized as a scientist significantly contributed to these experiences, and classroom climate in turn predicted increases in student's motivation. These patterns are consistent with prior studies highlighting the potential impact of classroom belonging to college students' science success (e.g., Lewis et al., 2017; Wilson et al., 2015). Moreover, we observed that the link between classroom climate and increases in STEM motivation was especially strong for URM students. Attaining a sense of belonging in academic contexts can be a greater challenge for many URM than non-URM students (e.g., Cohen & Garcia, 2008; Mallett et al., 2011). A supportive classroom climate may strengthen URM students' sense of belonging and academic achievement (e.g., Murphy & Zirkel, 2015).

### **8.3 | The importance of recognition as a scientist for underrepresented-minority students**

Although our model had a good fit with all students, several pathways were particularly strong among URM students, particularly in regards to performing science practices and recognition.

Thus, providing opportunities for engaging in science practices and gaining recognition may especially benefit URM students that have historically been marginalized in STEM.

Our findings align with prior studies comparing the impact of research experiences on URM and non-URM students' identity (e.g., Hernandez et al., 2013; Robnett et al., 2015). For instance, Robnett et al. (2015) longitudinally investigated whether science self-efficacy mediated the association between research experiences and identity as a scientist. Research experiences were measured by asking students the degree to which they had been active in science-related activities, outside of regular coursework (e.g., identifying relevant data and planning to collect it), generating research questions, and relating research results and explanations to the work of others (similar to our measure of science practices). They found that science self-efficacy mediated the relationship between research experiences and science identity. However, their model explained less variance in science identity for URM participants compared to non-URMs. In contrast, our results showed a significant difference as a function of URM status in how engagement in science practices was associated with science identity. A distinctive feature of our study was that we tested recognition as a scientist and perceived classroom climate as mediators for science practices and science identity. Thus, recognition as a scientist may an influential facet of science learning environments that can enhance positive perceptions of classroom climate as well as the development of a positive STEM identity. As Carlone and Johnson (2007) noted, URM students' bids for recognition as a scientist can be ignored or overlooked based on their ethnicity or gender.

## 8.4 | Practical implications

Overall, our findings suggest that: (a) science practices can be incorporated into large classes that do not have hands-on lab components; (b) performing science practices fosters felt recognition as a scientist; (c) at the introductory course level, recognition from classmates and instructors may each be important; (d) science practices and felt recognition as a scientist can lead to many positive outcomes in students' motivation and achievement; and (e) gaining recognition as a scientist may be especially helpful for students from URM backgrounds. Because there can be more barriers for URM students to gain meaningful recognition in the science classroom (Carlone & Johnson, 2007), instructors must plan and create opportunities for *all* students to engage in science practices and to be recognized as scientists for their performance.

The extent and manner in which science practices are integrated, communicated, valued, and recognized can vary across science classrooms and contribute to disparate outcomes among students. To help illustrate, we can describe how science practices were implemented by instructors whose students in our study reported high levels of performing science practices. In one course, students' generation of scientific explanations was a thematic element infused throughout the course. Students had opportunities to learn about explanations, which included making a claim, using evidence, and linking the evidence to the claim. These instructors scaffolded students' learning by providing structure early on that was gradually pulled back as students gained proficiency, confidence, and comfort with scientific explanations. Over the term, students additionally reviewed published journal articles to identify components of explanations from practicing scientists, and as a culminating experience reported their version of the explanation through posters in which the authors were present (publications of local authors were used). The intent was for students to talk science with scientists and to begin seeing themselves as scientists. Students were assessed, given feedback, and assessed again at multiple times

in the course; this process may have conveyed to students that learning how to create an explanation was valued.

Several of our study's classroom instructors had participated in professional development, which assisted them in designing the course. Instructors were attentive to social dynamics and employed many small instructional moves to create an inclusive environment. For example, these instructors intervened to make sure all students working in a group were making meaningful contributions and getting credit for their ideas (rather than leaving to the student best able to convey an idea). In these ways, instructors sought to incorporate science practices in the classroom in ways that could lead to students to feel recognized as scientists.

## 9 | FUTURE DIRECTIONS AND LIMITATIONS

There are limitations to our study that correspondingly point to future research directions. First, although a strength of our study is its longitudinal design, we only followed students over a 10-week course. Future studies might explore whether findings extend to the end of the year or beyond. Additionally, we only surveyed students currently enrolled in introductory biology classrooms. Although these courses tend to be gateway courses for many STEM majors, biology is one of the more diverse STEM majors, with higher enrollment of URM students in comparison to other majors such as engineering (National Science Foundation, 2017). Researchers might explore a similar model in other STEM classroom contexts. Many of our scales were developed for the present study in consultation with biology instructors. Future studies might explore the measures in these other classroom contexts.

Another strength of this study was that it was diverse in terms of Asian, Latinx, and White student representation. However, there were fewer participants who identified as Black or Native. Given that Black and Native individuals are also underrepresented in STEM, future studies might explore the current study model among students in these groups. Additionally, many other social groups are underrepresented in STEM, such as women, students who are the first generation in their families to attend college, and low-income students.

Although we did not have background income data on our students, we did explore whether first-generation college status or gender moderated any of the pathways in the model. With first-generation status, we detected a couple of paths in the model that were stronger for first-generation than continuing-generation college students. With gender, there were few significant differences model pathways. This was unsurprising given our sample comprised students in gateway biology courses. The biological sciences are among STEM fields in which women are not underrepresented as college majors (Cheryan et al., 2017). However, we would like to see a similar analysis conducted with students in majors in which women remain underrepresented, such as the physical sciences and engineering (Cheryan et al., 2017). Analogous to the difference between URM and non-URM students in the present findings, perhaps felt recognition as a scientist while performing science practices in these subjects would be more strongly related to changes in STEM motivation and identity for women than men.

Finally, we hope to see researchers to conduct long-term longitudinal studies to identify if and how classroom practices and students' experiences over time predict persistence in STEM. For example, such studies might consider outcomes such as declaration of a STEM major,



graduation from a STEM major, and obtaining a job or advanced degree in STEM. Prior studies have found motivational beliefs, such as expectancy and value, were linked to persistence in a subject or a major (see Wigfield, Cambria, & Eccles, 2012).

## 10 | CONCLUSION

Our short-term longitudinal study points to recognition as a scientist and positive classroom climate as important mediators between science practices and outcomes related to persistence. These mediators were especially important for URM students. Notably, when students reported performing science practices, it was effective regardless of class size and it did not matter if recognition as a scientist came from professors, teaching assistants, or classmates. Findings demonstrate that performing science practices may lead to opportunities for authentic recognition and a positive classroom climate, and that these experiences in turn may lead to increases in outcomes. Practical implications include supporting pedagogy that provides opportunities for students to perform science practices and to get recognition for performing those practices from instructors and peers.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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