Developmental Trajectories of Student Self-Perception over a Yearlong Introductory Biology Sequence

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ABSTRACT
Student self-perception is related to persistence in science. Yet how self-perception develops over time is less clear. We examined student self-perception trajectories and their relationship with gender, persons excluded due to ethnicity or race (PEER) status, and first-generation college student (FGCS) status across a yearlong introductory biology sequence. While we found similar rates of change in self-efficacy and science identity for all groups, females and PEER students had lower initial scores that failed to "catch up" to male and non-PEER scores by the end of the year. Students grouped into either high and stable or lower and decreasing trajectories for scientific community values, with first-generation college students overrepresented in the latter group. Additionally, we found no evidence for intersectionality of subgroups. We did find evidence that the relationship between gender and PEER status and science identity is likely mediated via self-efficacy. Taken together, our results suggest that introductory biology students develop self-efficacy and science identity at similar rates regardless of gender, PEER status, or FGCS status and that interventions targeting scientific community values for all students and self-efficacy of female and PEER students may be fruitful areas to pursue to increase persistence of students in the sciences and to reduce score differences between groups.

INTRODUCTION
Student self-perception (sometimes termed "affect" in the biology education literature)—their expectations, values, and attitudes about their education or fields of study—can impact their motivation and achievement (Zimmerman, 2000; Chemers *et al.*, 2011; Trujillo and Tanner, 2014; Byars-Winston *et al.*, 2016; Estrada *et al.*, 2016). In fact, student self-perception is thought to develop in a synergistic manner with cognitive development, each supporting the other. As a result, calls have been made to increase study of student self-perception, particularly regarding potential differences among student groups (National Research Council, 2012). While student self-perception is a broad term, we focus on three major aspects of self-perception that have been studied and linked to long-term outcomes in science, technology, engineering, and mathematics (STEM) students: self-efficacy, science identity, and scientific community values (Chemers *et al.*, 2011; Estrada *et al.*, 2011; Hanauer *et al.*, 2016).

Measures of Student Self-Perception
Self-efficacy is the level of confidence in oneself to achieve desired outcomes (Bandura, 1997). Self-efficacy is domain specific, so a person may have high self-efficacy in one subject and low self-efficacy in another. Four sources have been posited as building self-efficacy: mastery experience (successful experience with similar tasks), emotional/physiological states (emotions experienced with similar tasks), social persuasion (external support such as words of encouragement or praise received from others), and vicarious experience (observed experiences of others; Usher and Pajares, 2008). Students with higher science self-efficacy have been shown to have higher levels of achievement and persistence in the sciences (e.g., Zimmerman, 2000; Flowers and Banda, 2016).

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Identity describes a student's sense of being recognized as a "certain kind of person" in a particular context (Gee, 2000). Students may perceive themselves as having multiple identities. For example, a student might identify as a soccer player, artist, and scientist. Science identity is thought to derive from three factors: recognition (being recognized as a "science person" by oneself or others), competence (cognitive understanding of content knowledge), and performance (practicing science in the public or scientific arenas; Carlone and Johnson, 2007). Science identity is predictive of persistence in the sciences (Hazari *et al.*, 2010; Tate *et al.*, 2014; Frantz *et al.*, 2017; Estrada *et al.*, 2018), and it has been proposed that students who do not persist choose to leave science due to lack of identity with being a scientist rather than lack of skill or competence (Tobias, 1990; Seymour and Hewitt, 1997).

Scientific community values capture students' scientific values orientation—how strongly the students endorse the objectives and acts of science. Internalization of scientific community values also has been tied to persistence in the sciences and career choice (e.g., Hernandez *et al.*, 2013, 2018, 2020; Robnett *et al.*, 2015; Estrada *et al.*, 2018). This influence has been found to hold for undergraduates at least 4 years postdegree as well (Estrada *et al.*, 2018). In a study on biomedical graduate students, personal values, such as academic freedom, wanting to pursue research that would benefit their community, or wanting to help students, were the prime driver of career choice for graduate students actively pursuing careers in academia (Gibbs and Griffin, 2013).

Development of Student Self-Perception

Longitudinal studies have often explored how measures of student self-perception influence long-term student outcomes, such as persistence in STEM and future careers. For example, Robnett *et al.* (2015) found that students' research experiences affected their later science efficacy, which ultimately influenced their science identity. Further, science identity has been shown to be predictive of future persistence in STEM careers (Estrada *et al.*, 2018).

Yet how or when student self-perception changes over time has received relatively less attention. Ainscough *et al.* (2016) and Robinson *et al.* (2019) examined change in self-efficacy and science identity during a single semester for students in introductory biology and introductory chemistry, respectively. Students in introductory biology showed an increase in self-efficacy from the beginning of the semester to the end of the semester (Ainscough *et al.*, 2016). In contrast, in introductory chemistry, change in science identity varied among different subgroups of students (Robinson *et al.*, 2019). One subgroup of students did exhibit an increase in science identity during the semester. However, a different subgroup showed a decline in science identity, and a final subgroup had high levels of science identity at the beginning of the semester that were maintained throughout the semester.

In a study spanning multiple years of undergraduate education, Robinson *et al.* (2018) found different subgroups of students in terms of how science identity changed over the course of their undergraduate careers. Some students had relatively high science identity in the first year that was maintained through graduation. In contrast, other students had high science identity that increased or low science identity that decreased. In addition to developmental trajectories of a particular measure of student self-perception varying among subgroups of students, different measures of student self-perception might change in different ways for the same group of students. For example, in a study of the impact of mentorship and research experiences on underrepresented minority students, self-efficacy increased for students between their junior and senior years, but science identity remained constant (Estrada *et al.*, 2018).

Modeling Self-Perception Developmental Trajectories

Because student self-perception has the potential to influence persistence in STEM, understanding development of different student self-perception measures in introductory courses is particularly important. At many colleges and universities, introductory science courses span at least two semesters. As a result, we were interested in how different measures of student self-perception developed over a two-semester introductory biology sequence (research question [RQ] 1; Table 1). In addition, we examined whether there are multiple developmental trajectories, given previous research that show that change in science identity is not uniform for all students (Robinson *et al.*, 2018, 2019). The simplest approach for statistical modeling of a developmental trajectory is to use a fixed effects linear model with time as a fixed effect. However, this approach estimates the mean intercept and slope for all individuals in a sample. A mixed effects model with individual student identity as the random effect allows for variation among individuals around the mean intercept, mean slope, or both. Yet neither approach considers the possibility of multiple developmental trajectories. Latent class growth analysis (LCGA) and growth mixture modeling allow for multiple classes (i.e., multiple developmental trajectories) and can be thought of as equivalents to fixed effects and mixed effects models, respectively (Jung and Wickrama, 2008; Ram and Grimm, 2009; Curran *et al.*, 2010). Using model comparison approaches (e.g., Bayesian information criterion [BIC]; Nylund *et al.*, 2007) to compare multiple LCGA or growth mixture models, one can determine the number of classes that best explain the data. In these models, the shape of the developmental trajectories being estimated (e.g., linear, quadratic) can be specified. We fit linear models, as at least four time points are recommended for quadratic growth mixture models (Robinson *et al.*, 2019), and we collected data at three time points. Robinson *et al.* (2018, 2019) used a similar analytical approach and explained the approach in detail.

TABLE 1. Summary of research questions on development of student affect in two-semester introductory biology sequence

- RQ1: How does student affect change over a two-semester introductory biology sequence, and are there multiple developmental trajectories?
- RQ2: How do demographic factors (gender, PEER status, FGCS status) influence change in student affect?
- RQ3: Do demographic factors intersect in their influence on student affect?
- RQ4: Are effects of demographic factors on science identity mediated by their effects on self-efficacy?

Factors Related to Student Self-Perception Measures

Previous research suggests that student self-perception can correlate with a range of demographic factors, including gender, race/ethnicity, and first-generation college student (FGCS) status. Students who identify as female tend to have lower self-efficacy (Adedokun *et al.*, 2013; MacPhee *et al.*, 2013) and science identity (Hazari *et al.*, 2013) than do students who identify as male. In addition, how student self-perception develops over time can be related to gender identity. In their study of how science identity changes over the course of students' undergraduate careers, Robinson *et al.* (2018) found that students who identify as female are more likely to report intermediate levels of science identity that do not change over time, whereas students who identify as male begin with high science identity that increases slightly over time. Interestingly, the factors thought to affect the development of self-efficacy also differ based on gender identity. Vicarious learning experiences (Usher and Pajares, 2008; Trujillo and Tanner, 2014; Flowers and Banda, 2016) seem to be more important for students who identify as female (Sawtelle *et al.*, 2012). In contrast, mastery experiences (Usher and Pajares, 2008; Trujillo and Tanner, 2014; Flowers and Banda, 2016) seem to be more important for students who identify as male (Sawtelle *et al.*, 2012).

Self-efficacy and science identity have been posited to be especially important for persons excluded due to ethnicity or race (PEER; Flowers and Banda, 2016; Asai, 2020a), and several studies have shown these to be important predictors of academic achievement (Hackett et al., 1992), pursuit of scientific careers (National Research Council, 2007; Chemers *et al.*, 2011), and long-term persistence in STEM fields (Byars-Winston *et al.*, 2015, 2016; Estrada *et al.*, 2011, 2018). As a result, correlations between PEER status and developmental trajectories of self-efficacy and science identity are particularly important. Previous studies have shown significant differences in self-efficacy or science identity between ethnic groups (Estrada *et al.*, 2018; Hurtado *et al.*, 2009). In addition, Robinson *et al.*, 2019 found that minority students were more likely to report intermediate levels of science identity that increase slightly over time rather than high levels that remain high over time. Another study found that African-American, Native American, and Hispanic students were twice as likely as other students to report intermediate levels of science identity that decrease over time rather than high levels that transiently increase over time (Robinson *et al.*, 2018).

FGCS status has also been posited as important for student self-perception measures. First-generation college students are students whose parents did not complete baccalaureate degrees. Several studies have shown that first-generation college students have lower levels of achievement in college (Pascarella *et al.*, 2003; Chen, 2005; Engle and Tinto, 2008; Majer, 2009; Martinez *et al.*, 2009) and lower levels of persistence (Kojaku and Nuñez, 1998; Choy, 2001; Ting, 2003; Ward *et al*., 2012). Differences in self-efficacy between FGCS and non-FGCS groups also have been detected (Ramos-Sánchez and Nichols, 2007; Padgett *et al.*, 2012; Wilson *et al.*, 2015) and suggested to underlie achievement and persistence levels (Majer, 2009; DeFreitas and Rinn, 2013; Tate *et al.*, 2014). However, other studies found no difference in self-efficacy of FGCS versus non-FGCS populations in their undergraduate students (Vuong *et al.*, 2010; Martin *et al.*, 2021). One of these studies, Vuong *et al.* (2010), did detect differences in achievement and persistence between these groups, suggesting the need for further research into self-perception trajectories over the first year of college.

Taken together, previous research suggests the importance of demographic factors on student self-perception. As a result, we examined how demographic factors (gender, PEER status, and FGCS status) correlated with change in several measures of student self-perception (research question 2, Table 1).

Intersectionality of Demographic Factors

In addition to the independent effects of gender, PEER status, and FGCS status on student self-perception, these demographic categories have the potential to intersect, leading to "complexities of compoundedness," as theorized in Crenshaw (1989). Thus, students who are from multiple demographic groups that are underrepresented in STEM (e.g., PEER and FGCS) might have unique self-perception trajectories compared with students from a single underrepresented demographic group (e.g., PEER, but not FGCS). For example, students who are both PEER and of lower socioeconomic status had lower self-efficacy than students who were either PEER or of lower socioeconomic status, but not both (MacPhee *et al.*, 2013). Similarly, in a study of PEER students, Byars-Winston *et al.* (2016) found significant intersectionality between race/ethnicity and gender on measures of student self-perception. Specifically, Black males had higher scores on the affective/emotional arousal scale used in the study and Hispanic/Latinx females had higher scores on the science identity scale in comparison to other groups. However, when examining the relationships between learning experiences, measures of student self-perception, and career intentions for different race/ethnicity and gender subgroups, Byars-Winston and Rogers (2019) found largely similar relationships for all subgroups. Yet because of evidence for intersectionality on self-perception measures, we examined whether demographic factors intersect in their relationship to self-efficacy, science identity, and scientific community values (research question 3; Table 1).

Models of Self-Perception Measures

Theory suggests that measures of student self-perception may be related to one another and may have mediating effects on other student outcomes. Modified models of social cognitive career theory (SCCT) suggest that self-efficacy, science identity, and outcomes expectations are interrelated and in turn affect students' career expectations (Eccles, 2009; Byars-Winston *et al.*, 2016). The tripartite integration model of social influence (TIMSI) suggests that self-efficacy, science identity, and scientific community values, although likely correlated, independently contribute to a student's sense of belonging in the scientific community, thus leading to persistence in science (Estrada *et al.*, 2011, 2018). Empirical research supports the hypothesis that self-efficacy and science identity are related (e.g., Estrada *et al.*, 2018; Byars-Winston and Rogers, 2019). Furthermore, Robnett *et al.* (2015) found that the effect of research experiences on science identity was mediated by the effect of research experiences on self-efficacy, suggesting that factors that influence science identity could be due to their effects on self-efficacy. Therefore, we examined whether the relationships between demographic factors and science identity were mediated by their relationships with self-efficacy (research question 4; Table 1).

Study Summary

In this study, we collected student self-perception measures of science self-efficacy, science identity, and scientific community values from introductory biology undergraduates at the start of the Fall semester, end of the Fall semester, and end of the Spring semester. We analyzed this data set to identify developmental trajectories of student self-perception over a two-semester introductory biology course sequence. We also collected demographic data for study participants of gender, race/ethnicity, and FGCS status, which allowed us to explore how each of these factors may relate to self-perception trajectories. As the potential for intersectionality of demographic factors exists, we also queried our data set to identify any intersectional relationships of gender, ethnicity, or FGCS status. Our data set also allowed us to test whether demographic relationships with science identity are mediated via self-efficacy.

Although previous research has explored student self-perception measures, few studies examine their developmental trajectories or growth over time. As a result, our study fills a gap in understanding changes over an introductory STEM course series in measures of student self-perception that are known to correlate with persistence in STEM. Additionally, studies with high participation rates are needed to determine whether trends observed in past studies with lower response rates are representative of the complete population.

METHODS

Course Context

The study was performed at Emory University, a highly selective research university in the southeast United States. Participants were enrolled in a two-semester sequence of introductory biology lab courses in the 2018–2019 academic year (BIOL 141L Fall 2018 and BIOL 142L Spring 2019). These high-enrollment courses (642 and 489 students in Fall 2018 and Spring 2019, respectively) divided students into small laboratory sections (maximum of 24 students), which were taught by a graduate student or postdoctoral researcher along with an undergraduate lab learning assistant (LA). The labs met weekly for a single 180-minute lab period. The labs consisted of hands-on experiments and analyses, with the first semester focusing on experimental design and the second semester focusing on authentic research projects based on faculty research (Cole *et al.*, 2021).

Survey Instrument

The survey included three student self-perception measures (self-efficacy, science identity, and scientific community values) from the Persistence in the Sciences Survey (Hanauer *et al.*, 2016), which were based, in part, on measures from Estrada *et al.* (2011). Self-efficacy and science identity both used a five-point Likert scale from "strongly agree" to "strongly disagree." Self-efficacy questions asked students to rate the degree to which they agreed or disagreed with a series of statements about various research skills each beginning with "I am confident that I can" (e.g., "design a controlled experiment"). The science identify measure consisted of six questions that asked students to rate the degree to which they agreed or disagreed with statements describing themselves, such as "I have come to think of myself as a scientist." The scientific community values measure consisted of four questions that asked students to select how much the person in the description was like them. These questions began with "A person who" (e.g., "A person who thinks it is valuable to conduct research that builds the world's scientific knowledge") and used a six-point Likert scale ranging from "not at all like me" to "very much like me." Additionally, students were asked to self-identify their gender, race/ethnicity (where they could select multiple answers), and FGCS status. Although students were asked to select the "gender with which they identify," the response options were "female," "male," "nonbinary," and "prefer not to answer." As these options are associated with sex rather than gender, this may have confounded results. However, this likely impacted very few student responses, so we assumed the results represented gender in our analyses. For complete details on the self-perception measure questions, please see Hanauer *et al.* (2016).

Survey Administration

The survey was administered via an online platform and was assigned to students to complete before the first lab and after the last lab period of the Fall 2018 semester and after the last lab period in the Spring 2019 semester (Institutional Review Board approval no. 00106478). Completion of the survey or an alternate writing assignment was included in students' grades as an assignment worth less than 1% of their overall semester scores. Survey responses were anonymous with unique six-digit identifiers used to link responses from individual students across time points. At the end of each survey, students were directed to a separate site where they could enter their names in order to earn credit for completion of the assignment.

Participants

The participant pool consisted of 642 students in the first-semester course and 489 students in the second-semester course. A total of 350 students completed all three surveys for at least one of the self-perception measures. From the self-reported demographic data, 64% were female, 34% were male, and two nonbinary students. Students who self-identified as Black, Native American, Pacific Islander, Hispanic, and/or multiracial/multiethnic, including one of these groups were considered PEER. Although Pacific Islanders are not always included in PEER categories, we included this group in our PEER category to fit with National Institutes of Health guidelines (Asai, 2020b; https://diversity.nih.gov/about-us/population-underrepresented). Participants were 74% non-PEER, 24% PEER, and 3% unknown. There were 21% first-generation college students and 74% non-first-generation college students, with 6% not reported. Demographics of survey respondents in terms of percent females, PEER, and first-generation college students did not change significantly from first- to second-semester data (self-identified females, PEER, and first-generation college students did not change significantly; two-tailed chi-square p-values > 0.05) between end of first- and second-semester respondents (66% and 64%, 26% and 26%, and 26% and 21%, respectively). Additional information on the overlap between demographic groups can be found in Supplemental Table S1. Due to the small number of nonbinary students ($N = 2$) in our data set, we chose not to include this group in our demographic analyses so as to preserve anonymity.

Data Analysis

Data Management. Individual student responses to the survey at the three different time points were linked based on unique anonymous identifiers. Of the 439 students who enrolled in both courses, 350 students participated in all three surveys. Of these, 346 out of 350 (99%) included responses for all three measures at all three time points. Response rates were similar for the surveys at the end of the second semester (480 out of 489) as compared with the beginning (630 out of 642) and the end (604 of 642) of the first semester. Students who only completed one semester of introductory biology or whose responses could not be successfully linked were removed from the study sample. We do note that students who completed all three surveys had significantly higher values with small to medium effect sizes for all three measures of student self-perception at the beginning and the end of the first semester as compared with students who did not complete the survey at the end of the second semester (Supplemental Table S2).

For analysis of the effects of demographics on development of student self-perception (RQ2–RQ4, Supplemental Tables S3–S5), students were grouped based on gender, PEER status, and FGCS status. For all three demographic variables that we considered, students could select "Prefer not to answer" or could skip the question. These cases were coded as missing values for our analysis of demographic factors. However, all cases were included in our first analysis of developmental trajectories of student self-perception (RQ1).

Survey Construct Consistency. Internal consistency of constructs for our student population was examined by calculating Cronbach's alpha for each measure at each time point. Values ranged from 0.86 to 0.96 (Supplemental Table S6). In addition, we used confirmatory factor analysis, using the lavaan package in R (Rosseel, 2012), with all items at each time point separately. Fit measures for the confirmatory factor analysis were acceptable (Ballen and Salehi, 2021; Supplemental Table S7).

Analytical Approaches. First, we examined the developmental trajectory for each measure of student self-perception across the two-semester introductory biology sequence (RQ1). We began by estimating an intercept-only model as a null model. Then we estimated a series of growth mixture models with between one and nine classes. The growth mixture models differed in whether only intercepts were random or both intercepts and slopes were random and how random effect and residual variances were specified. All models were estimated using the flexmix package in R (Leisch, 2004). Various estimates of model fit were calculated (see Supplemental Tables S8–S10). The best model for each measure was determined by comparing sample size–adjusted BIC (SABIC) values, due to low sample sizes ($N < 400$; Tofighi and Enders, 2008). The model with the lowest SABIC was considered the best model. Using BIC values, as suggested by Nylund *et al.* (2007), resulted in the same best model.

Second, to examine the relation of demographics to developmental trajectories of student self-perception (RQ2), we used two different approaches. For our first approach, we determined whether grouping into a particular cluster based on the best growth mixture model for a particular measure differed based on demographics using Fisher's exact tests. For example, did the frequencies of students who identify as female and are grouped into cluster 1 versus cluster 2 for scientific community values differ from those frequencies for students who identify as male in each of those clusters? Our second approach examined the relationship between demographic factors and measures of student self-perception within a particular cluster based on the best growth mixture model. For each cluster for each dependent variable, we included the three demographic variables (gender, PEER status, FGCS status) along with time as fixed effects in a linear mixed effects model with random effects specified in the same way as in the best growth mixture model. To determine whether the slope of developmental trajectories differed based on demographics, we included the two-way interactions between demographic variables and time (Beck and Bliwise, 2014), as well as the main effects of demographic variables and time. If interaction terms were not significant, we removed the interaction effects and re-estimated the model with just the main effects. Linear mixed effects models were estimated with the lme4 package in R (Bates *et al.*, 2015). p values for the fixed effects were estimated with Type III Wald χ^2 tests using the car package in R (Fox and Weisberg, 2019).

Third, we explored the potential for intersectionality to relate to developmental trajectories (RQ3), as demographic categories have the potential to interact (e.g., Hazari *et al.*, 2013; Byars-Winston and Rogers, 2019). Again, for each cluster for each dependent variable, we added demographic covariates to a linear mixed effects model. Tests for intersectionality were included by adding two-way interaction terms between demographic variables (e.g., gender × PEER status) in addition to the main effects of demographic variables and time as fixed effects. A significant two-way interaction effect would suggest an intersection between two demographic categories on student self-perceptions. An alternative approach for testing for intersectionality would be to create a dummy variable with particular combinations of demographic variables that then could be included as a fixed effect. However, because we considered three different demographic variables, this would result in 12 pairwise combinations, making the results of such an analysis difficult to interpret.

Finally, theory and previous research suggest that changes in science identity might be mediated by changes in self-efficacy (Robnett *et al.*, 2015; Byars-Winston *et al.*, 2016; Byars-Winston and Rogers, 2019). As a result, we examined whether relationships between demographic variables and science identity might be due to the relationships between these demographic variables and self-efficacy (RQ4). We added self-efficacy as a covariate along with demographic variables as fixed factors in a linear mixed effects model with science identity as the dependent variable. Although some research has suggested a time lag between gains in self-efficacy and gains in science identity (e.g., Robnett *et al.*, 2015; Hernandez *et al.*, 2020), correlations between self-efficacy and science identity were higher within a time point as compared with across time points (Supplemental Table S8). Therefore, we structured our data with self-efficacy at each time point as a covariate of science identity at the same time point. If demographic variables that were significantly related to science identity (RQ2) are no longer significantly related to science identity after the inclusion of self-efficacy as a covariate, this would suggest that the

TABLE 2. Class sizes and parameter values for the best growth mixture models for three measures of student affect

Measure	Class	Class size	Intercept	Slope
Self-efficacy	1	26	3.05	0.20
	2	322	3.69	0.24
Science identity	1	23	3.43	–0.34
	2	327	3.64	0.15
Scientific community values	1	118	4.91	–0.12
	2	230	5.51	0.03

relationship between demographic variables and science identity was mediated by the relationship between demographic variables and self-efficacy.

RESULTS

RQ1: How Does Student Self-Perception Change over a Two-Semester Introductory Biology Sequence, and Are There Multiple Developmental Trajectories?

Based on growth mixture models, the best model for all three measures of student self-perception had two classes or clusters (i.e., two groups of students with different developmental trajectories; Supplemental Tables S8–10). For self-efficacy, the main cluster had a higher starting self-efficacy and increased over time, and the smaller cluster had an intermediate starting value and increased over time (Table 2, Supplemental Figure S1). In contrast, for science identity, the main cluster showed an increase over time, and the smaller cluster showed a decrease over time (Table 2, Supplemental Figure S1). For both self-efficacy and science identity, the smaller cluster was less than 10% of the sample (Table 2). For scientific community values, one cluster showed higher overall values with no change over time, as indicated by a low slope value, whereas the other cluster showed lower overall values with a decrease over time (Table 2, Supplemental Figure S1).

RQ2: How Do Demographic Factors (Gender, PEER Status, FGCS Status) Relate to Change in Student Self-Perception?

First, we examined whether students in particular demographic groups were overrepresented in particular classes determined by the growth mixture models. Representation in a particular growth mixture model class did not differ between demographic groups for self-efficacy and science identity (Table 3; Fisher's exact tests, $p > 0.05$ in all cases). In contrast, first-generation students (Fisher's exact test, $p = 0.046$) were overrepresented in the community values class that began lower and decreased over time (Table 3). Representation in community values classes did not differ based on gender or PEER status (Table 3; Fisher's exact text, $p > 0.2$).

Next, we used linear mixed models with demographic factors as main effects for each cluster for each measure of

TABLE 3. Frequency of students in each growth mixture model class based on demographic categories

Measure	Class	Female	Male	Nonbinary
Self-efficacy	1	19	5	1
	2	204	113	1
Science identity	1	14	6	1
	2	209	113	1
Scientific community values	1	67	44	2
	2	154	75	0
	Class	**Not PEER**	**PEER**	
Self-efficacy	1	18	6	
	2	239	77	
Science identity	1	16	4	
	2	242	79	
Scientific community values	1	85	28	
	2	171	55	
	Class	**Not FGCS**	**FGCS**	
Self-efficacy	1	18	5	
	2	239	66	
Science identity	1	17	4	
	2	240	69	
Scientific community values	1	75	31	
	2	180	42	

TABLE 4 Effects of demographic factors on measures of student affect based on mixed effects models[a]

Self-efficacy Cluster 1 ($N = 22$)

	Estimate	SE	*df*	χ^2	*p*
Intercept	2.90	0.46	39.36	1	<0.001
Time	0.26	0.20	1.67	1	0.20
PEER	−0.48	0.41	1.42	1	0.23
Female/male	−0.15	0.40	0.15	1	0.70
FGCS	0.21	0.43	0.25	1	0.62

Cluster 2 ($N = 297$)

	Estimate	SE	*df*	χ^2	*p*
Intercept	**3.69**	**0.05**	**5453.98**	**1**	**<0.001**
Time	**0.25**	**0.02**	**190.33**	**1**	**<0.001**
PEER	**−0.18**	**0.06**	**9.12**	**1**	**0.003**
Female/male	**0.13**	**0.05**	**6.45**	**1**	**0.01**
FGCS	−0.01	0.06	0.01	1	0.91

Science identity Cluster 1 ($N = 19$)

	Estimate	SE	*df*	χ^2	*p*
Intercept	**3.32**	**0.26**	**1**	**165.91**	**<0.001**
Time	**−0.43**	**0.09**	**1**	**20.95**	**<0.001**
PEER	−0.28	0.45	1	0.39	0.53
Female/male	0.34	0.29	1	1.35	0.25
FGCS	0.16	0.43	1	0.14	0.71

Cluster 2 ($N= 301$)

	Estimate	SE	*df*	χ^2	*p*
Intercept	**3.63**	**0.06**	**1**	**3640.39**	**<0.001**
Time	**0.15**	**0.02**	**1**	**52.14**	**<0.001**
PEER	**−0.18**	**0.08**	**1**	**5.58**	**0.02**
Female/male	**0.15**	**0.07**	**1**	**5.42**	**0.02**
FGCS	0.01	0.08	1	0.02	0.90

Scientific community values Cluster 1 ($N = 100$)

	Estimate	SE	*df*	χ^2	*p*
Intercept	**4.74**	**0.13**	**1**	**1320.68**	**<0.001**
Time	**−0.13**	**0.06**	**1**	**5.31**	**0.02**
PEER	0.04	0.12	1	0.13	0.72
Female/male	0.10	0.09	1	1.10	0.29
FGCS	0.15	0.12	1	1.66	0.20

Cluster 2 ($N = 218$)

	Estimate	SE	*df*	χ^2	*p*
Intercept	**5.54**	**0.05**	**1**	**14,688.07**	**<0.001**
Time	0.02	0.02	1	1.38	0.24
PEER	−0.09	0.05	1	2.68	0.10
Female/male	0.06	0.05	1	1.57	0.21
FGCS	−0.02	0.06	1	0.08	0.78

[a]Parameter estimates were calculated as PEER = yes, female/male = male, and FGCS = yes. Significant parameters are indicated in bold.

student self-perception. Demographic factors did not have significant effects on the rate of change in measures of student self-perception over the two-semester introductory biology course, as the interactions between demographic factors and time were not significant (Supplemental Table S11). However, demographic factors did relate to overall levels for some measures of student self-perception at each time point (Supplemental Tables S3–S5). For the larger self-efficacy cluster (cluster 2), values were signficantly lower for female students as compared with male students and significantly lower for PEER as compared with non-PEER (Table 4, Figure 1). In contrast, FGCS status was not significantly related to self-efficacy (Table 4, Figure 1). For the larger science identity cluster (cluster 2) that showed an increase in science identity over time, we found similar relationships with demographic factors as we did for self-efficacy (Table 4, Figure 2). In contrast, demographic

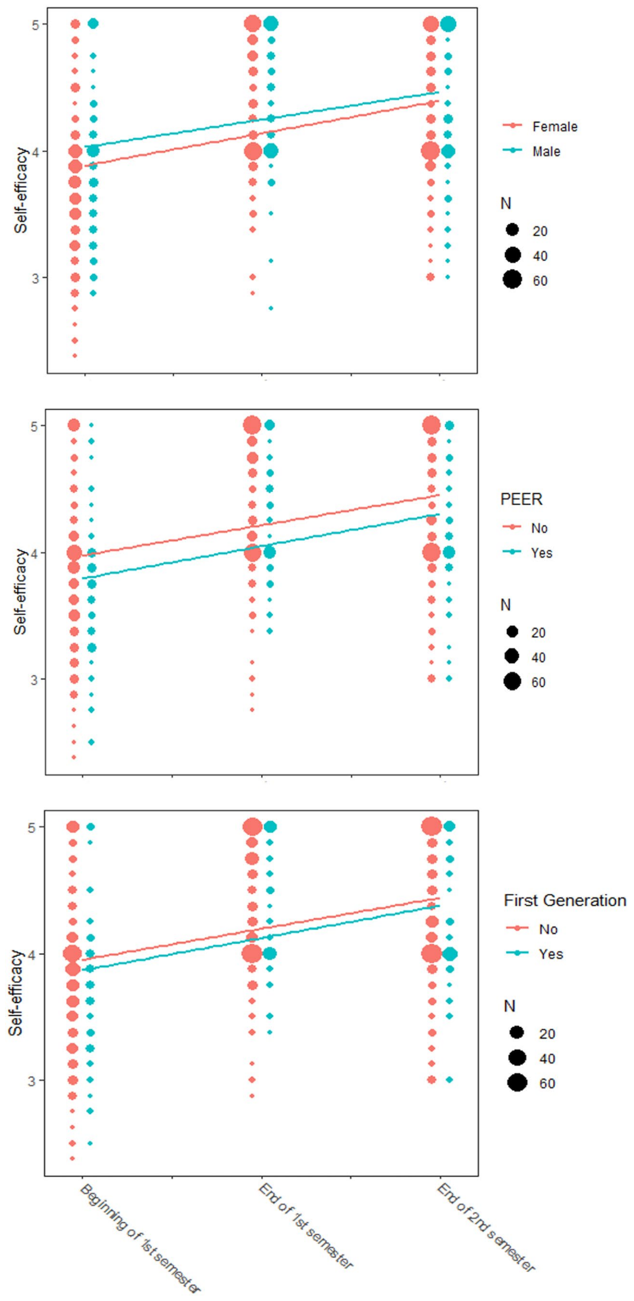

FIGURE 1. Developmental trajectories in student self-efficacy across a two-semester introductory biology course sequence for different demographic groups. Rate of change did not different significantly between groups, but PEER students and students who identify as female had lower overall self-efficacy. Two different clusters were determined by growth mixture modeling. However, one cluster was small, resulting in plots split by different demographic groups that were not meaningful. As a result, only the data for the larger cluster are plotted.

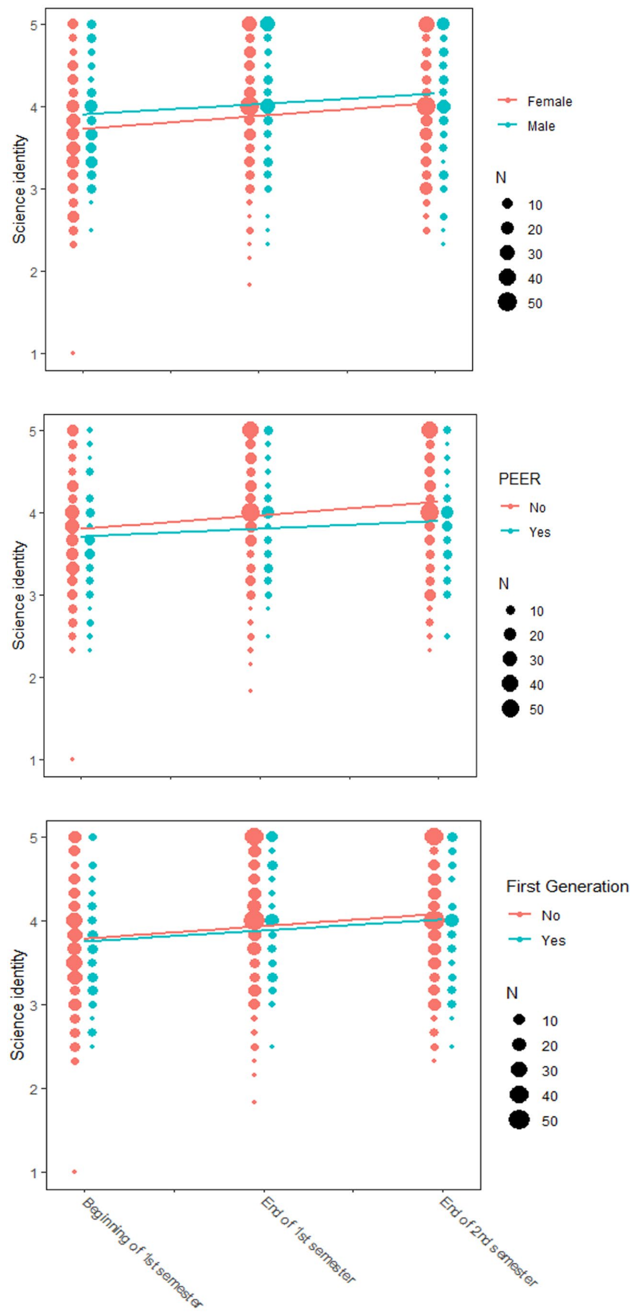

FIGURE 2. Developmental trajectories in science identity across a two-semester introductory biology course sequence for different demographic groups. Rate of change did not different significantly between groups, but PEER students and students who identify as female had lower overall science identity. Two different clusters were determined by growth mixture modeling. However, one cluster was small, resulting in plots split by different demographic groups that were not meaningful. As a result, only the data for the larger cluster are plotted.

factors were unrelated to self-efficacy and science identity for smaller respective clusters (Table 4, Figures 1 and 2), likely due to the small number of students in these clusters. Unlike self-efficacy and science identity, scientific community values were not related to demographic factors in either cluster (Table 4, Figure 3). Students either had moderate or high levels on the scientific community values scale that decreased (cluster 1) or did not change (cluster 2) over time (Table 4, Figure 3).

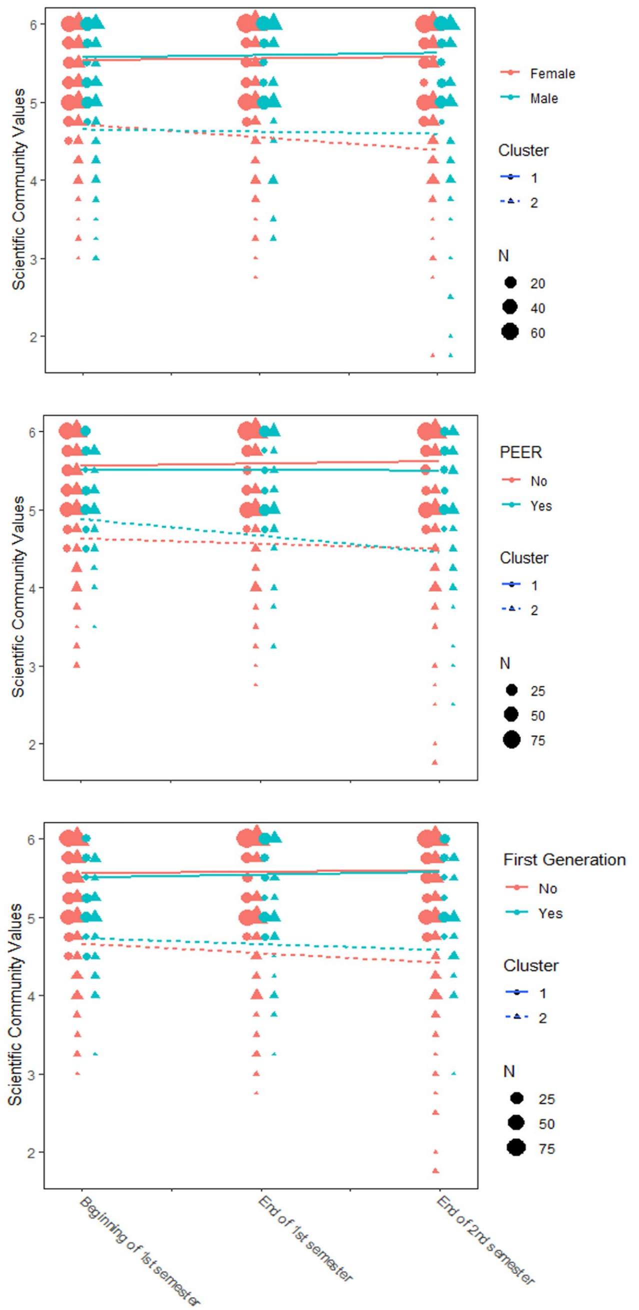

FIGURE 3. Developmental trajectories in scientific community values across a two-semester introductory biology course sequence for different demographic groups. Two different clusters were determined by growth mixture modeling. Demographic factors did not significantly affect rate of change or overall scientific community values.

RQ3: Do Demographic Factors Intersect in Their Relation to Student Self-Perception?

To explore the possibility of intersectionality of demographic groups resulting in differences in overall levels of measures of student self-perception, we used mixed effects models with two-way interaction terms between demographic variables. For all three measures of student self-perception, none of the interaction terms were significant (Table 5), suggesting no significant effects of intersectionality.

RQ4: Are Effects of Demographic Factors on Science Identity Mediated by Their Effects on Self-Efficacy?

Both self-efficacy and science identity were significantly related to PEER status and gender (Table 4). However, self-efficacy was significantly correlated with science identity at each time point, with the strongest correlations within a time point (Supplemental Table S12). After controlling for the effect of self-efficacy on science identity (cluster 2 only), PEER status and gender were unrelated to science identity (Table 6).

DISCUSSION

Unique Developmental Trajectories Observed in All Three Measures of Self-Perception

Our models indicated two clusters within our population for all three self-perception measures. For both self-efficacy and science identity, a large cluster (with more than 94% of students) showed increase in measures from the start of the year to the end of the year. For self-efficacy, the smaller cluster began at intermediate values and increased nonsignificantly over time. In contrast, for science identity, the small cluster showed a decrease over that time. Cluster sizes were more even for scientific community values, where the larger cluster (with more than 65% of students) showed high and stable scores, while the other cluster showed low and decreasing scores. The high and stable cluster had initial average scores of more than 5.5 on a six-point scale and thus may have had limited opportunity for observed growth. The observed decrease in cluster 2 for scientific community values occurred at both the end of the first and second semesters, while the observed increases seen in the larger clusters of self-efficacy and science identity largely occurred by the end of the first semester and then maintained through the end of the year.

Why most growth occurred in self-efficacy and science identity in the first semester and why community values did not show an increase are unclear. One possibility is that the first-semester course content, which focuses on student-led experimental design, better supported growth in these self-perceptions than second-semester content, when students worked on faculty-based projects with prescribed methods. Course content may have also impacted scores due to the more challenging nature of the second-semester content, when students work on course-wide data sets, which can be large and difficult to analyze. It is also possible that ceiling effects became more prevalent with the higher second-semester scores.

FGCS Status Relates to Community Values Cluster

First-generation college students were overrepresented in cluster 2 of community values, which exhibited lower initial and decreasing scores. Contrastingly, no demographic group was found to be overrepresented in the self-efficacy or science identity clusters. Others have found that role models are important in developing students' scientific community values and that students who identified more strongly with research mentors showed higher commitment to scientific community values (Hernandez *et al.*, 2018). It is thus possible that overrepresentation of first-generation college students in the lower

TABLE 5. Effects of interactions between demographic factors on measures of student affect based on mixed effects models[a]

Self-efficacy Cluster 2 (*N* = 297)

Parameter	Estimate	SE	*df*	χ^2	*p*
Intercept	**3.67**	**0.05**	**5054.72**	**1**	**<0.001**
Time	**0.25**	**0.02**	**190.33**	**1**	**<0.001**
PEER	**−0.16**	**0.09**	**3.48**	**1**	**0.06**
Female/male	**0.18**	**0.06**	**8.38**	**1**	**0.004**
FGCS	0.05	0.09	0.27	1	0.60
PEER × female/male	−0.07	0.13	0.28	1	0.60
PEERS × FGCS	−0.02	0.13	0.02	1	0.90
Female/male × FGCS	−0.16	0.13	1.41	1	0.23

Science identity Cluster 2 (*N* = 301)

Parameter	Estimate	SE	*df*	χ^2	*p*
Intercept	**3.62**	**0.06**	**1**	**3363.35**	**<0.0001**
Time	**0.15**	**0.02**	**1**	**52.14**	**<0.0001**
PEER	−0.11	0.11	1	0.96	0.33
Female/male	**0.16**	**0.08**	**1**	**4.03**	**0.04**
FGCS	−0.03	0.12	1	0.06	0.81
PEER × female/male	−0.16	0.16	1	1.05	0.31
PEERS × FGCS	−0.04	0.16	1	0.07	0.80
Female/male × FGCS	0.15	0.17	1	0.77	0.38

Scientific community values Cluster 1 (*N* = 100)

Parameter	Estimate	SE	*df*	χ^2	*p*
Intercept	**4.73**	**0.13**	**1**	**1253.83**	**<0.0001**
Time	**−0.13**	**0.06**	**1**	**5.34**	**0.02**
PEER	−0.01	0.18	1	0.00	0.97
Female/male	0.15	0.11	1	1.74	0.19
FGCS	0.09	0.18	1	0.25	0.62
PEER × female/male	−0.14	0.25	1	0.30	0.58
PEERS × FGCS	0.20	0.24	1	0.70	0.40
Female/male × FGCS	−0.06	0.24	1	0.06	0.81

Cluster 2 (*N* = 218)

Parameter	Estimate	SE	*df*	χ^2	*p*
Intercept	**5.55**	**0.05**	**1**	**13,920.48**	**<0.0001**
Time	0.02	0.02	1	1.38	0.24
PEER	−0.11	0.08	1	2.29	0.13
Female/male	0.03	0.06	1	0.21	0.65
FGCS	−0.03	0.09	1	0.14	0.71
PEER × female/male	0.09	0.12	1	0.62	0.43
PEERS × FGCS	0.0004	0.12	1	0.00	1.00
Female/male × FGCS	0.07	0.13	1	0.30	0.59

[a]Parameter estimates were calculated as PEER = yes, female/male = male, and FGCS = yes. Significant parameters are indicated in bold. Interaction effects could not be calculated for science identity cluster 1 because of low sample size (*N* = 19).

TABLE 6. Effects of demographic factors on science identity (cluster 2) when controlling for self-efficacy based on a mixed effects model[a]

Parameter	Estimate	SE	*df*	χ^2	*p*
Intercept	**2.14**	**0.12**	**1**	**319.76**	**<0.001**
Time	**0.04**	**0.02**	**1**	**4.41**	**0.04**
Self-efficacy	**0.41**	**0.03**	**1**	**194.94**	**<0.001**
PEER	−0.09	0.07	1	1.70	0.19
Female/male	0.09	0.06	1	2.46	0.12
FGCS	0.004	0.07	1	0.004	0.95

[a]Parameter estimates were calculated as PEER = yes, female/male = male, and FGCS = yes. Significant parameters are indicated in bold. *N* = 300.

and decreasing cluster of community values may indicate less personal identification with scientific role models. What proportion of lab instructors and undergraduate LAs for our study population were first-generation college students is unknown. Exploring this further may be an interesting area of future research.

Female and PEER Students Had Lower Self-Efficacy and Science Identity Scores Than Male and Non-PEER Students

Within the self-efficacy and science identity student clusters that showed increasing scores, we found that female and PEER students' average scores were lower than scores for male or non-PEER students. These lower self-efficacy and science identity scores observed at the beginning of the year persisted to the end of the course sequence. This observation is consistent with previous studies that have shown lower self-efficacy or science identity for female or historically underrepresented students (Adedokun *et al.*, 2013; Hazari *et al.*, 2013; MacPhee *et al.*, 2013). Although gender and PEER status were related to self-efficacy and science identity within the main clusters, FGCS status was unrelated to these measures of self-perception, which is interesting; it is possible that our university setting, which is highly selective and offers several supports for first-generation or low-income college students (e.g., 1915 Scholars Program, STEM Pathways, Emory FLIP, and Questbridge), may influence why we did not detect differences in self-efficacy or science identity for our FGCS population.

In contrast to self-efficacy and science identity, demographic factors were unrelated to scientific community values within each cluster. As noted earlier, FGCS status and gender were related to cluster membership, which might make it less likely to find a relationship with these factors within a cluster. Interestingly, PEER status was unrelated to scientific community values either between clusters or within clusters. The presence of a PEER role model (as either a lab instructor or undergraduate LA) in one-third of the lab sections for our study population may have influenced this result, as role models have been found to be particularly important for developing scientific community values (Hernandez *et al.*, 2018).

Consistent Rate of Development in Self-Perception across Demographic Groups

While we found a relationship between FGCS status and gender on cluster membership for scientific community values and significant relationships between PEER status and gender within the main clusters for self-efficacy and science identity, demographic factors were unrelated to the rate of growth for any of our self-perception measures across two semesters of introductory biology. This indicates that course content impacts students across demographic groups similarly. However, any initial gaps observed between groups' self-perception scores persist through a year of introductory biology. As a consequence, females and PEER students who had lower initial scores for self-efficacy and science identity failed to "catch up" to male and non-PEER students. In addition, scientific community values for first-generation college students remained lower than those of non–first-generation college students at the end of two semesters of introductory biology.

Lack of Evidence for Intersectionality of Demographic Factors in Relation to Self-Perception Measures

Given that we found some relationships between demographic groups and measures of student self-perception, we considered the possibility of intersectionality between demographic factors, as has been found in previous studies (MacPhee *et al.*, 2013; Byars-Winston *et al.*, 2016). In contrast to these previous studies, we found no significant interactions between PEER × gender, PEER × FGCS status, or gender × FGCS status for any of the three measures of student self-perception that we used.

Self-Efficacy Mediates Demographic Relationships with Science Identity

Independent of the conceptual model (e.g., SCCT, TMSI) by which measures of student self-perception are related to intermediate and long-term outcomes, such as persistence in STEM and ultimate career choice, understanding the relationships between different self-perception measures and potential mediating effects of these relationships is important. The three measures that we examined were significantly positively correlated with one another, especially within a particular time point. As a result, mediating effects of these relationships were possible. In particular, we found that the effects of PEER status and gender on science identity were mediated by their effects on self-efficacy. These demographic factors were no longer related to science identity at each time point when we controlled for self-efficacy at that time point.

Implications

Although we had a high response rate for our survey, we still observe a small number of student clusters, similar to previous work with lower response rates. While it is possible that even higher response rates would result in larger numbers of clusters, the small number of clusters we found does suggest that a large majority of students fall into just a few growth trajectories over a year of introductory biology course work for the three measures we examined. Follow-up studies to identify interventions that can target students with specific growth trajectories may be useful and applicable to large groups of students.

The similar rate of change observed across all demographic groups and the large majority of students in clusters exhibiting growth in self-efficacy and science identity are reassuring, especially given the high response rate for our survey, and suggest that first-year biology supports growth of most students. However, as females and PEER students begin with lower overall self-efficacy and science identity scores, this suggests a need to accelerate their growth in order to close the gap between groups. Several studies have found research experience and quality mentorship to be key factors relating to PEER student self-perception and persistence (Hurtado *et al.*, 2009; Hernandez *et al.*, 2013; MacPhee *et al.*, 2013; Estrada *et al.*, 2018). In addition, a study by Aikens *et al.* (2017) found that the structure of a student's research mentoring correlated with student self-perception. Specifically, men and PEER students were more likely than females, Caucasians, and Asians to have a closed-triad mentoring structure wherein the undergraduate has a direct relationship with both the faculty member and graduate or postdoctoral student and that this closed-triad structure was correlated with higher science identity. Another study found that sources of self-efficacy growth for females differ from those for males, with vicarious learning experiences being more important for female students and mastery experiences being more important for male students (Sawtelle *et al.*, 2012). More detailed understanding of how research experiences, mentoring, and vicarious learning affect self-efficacy levels for females and PEER students may suggest implementation strategies that lead to better outcomes for these groups.

Importantly, our finding that the relation of gender and PEER status to science identity was mediated by self-efficacy suggests that instructional strategies that can increase self-efficacy for these students in particular (e.g., research experiences, direct relationships with faculty research mentors, increased vicarious learning opportunities) have the potential to increase science identity in tandem.

Why students increased in self-efficacy and science identity but not scientific community values in our study is unclear. However, many of the students who enroll in our introductory course sequence are interested in pursuing postgraduate training without a significant research component, such as medical school, which might make them less engaged in the scientific research community. Future studies could examine student motivation in taking the course sequence to examine whether this is related to community values trajectories.

Another implication from our study is that strengthening development of scientific community values in the FGCS population may be particularly important, as this group was overrepresented in the low and decreasing scientific community values cluster. Role modeling and inclusion of helping others as a STEM career path may be two potential ways to do this (Hernandez *et al.*, 2018).

LIMITATIONS

Student Population

It is important to note a few limitations of our study. Our study was performed at a highly selective research university, so this may limit the generality of our findings. Our yearlong analyses excluded students who only completed one of the two semesters of the course sequence. A number of students choose to only complete the first-semester course for a variety of reasons (i.e., certain postgraduate programs only require a single semester of biology lab, some students change degree/career plans during the first semester, scheduling conflicts occur, and some students experience poor performance). Students who did not continue to the second-semester course did have lower self-perception scores on the whole at both the beginning and the end of the first-semester course. In addition, the percentage of first-generation students in our sample decreased from 24.2% to 20.4%, and the percentage of non-male students in our sample decreased from 65.6% to 64.1% from Fall semester to Spring semester. However, the percentage of PEER students in our sample increased slightly from 23.0% to 24.0%.

Our analysis did not allow us to control for the attrition and shifts in demographics in our sample. As a result, our conclusions only apply to those students who completed both semesters of introductory biology. It would be interesting for future studies to explore why non-continuing students only complete one semester and how this choice may intersect with demographics and self-perception.

Sample Size

Due to our sample size, our analyses pooled multiple demographic groups into either the PEER or non-PEER groups. Thus, we would not detect differences between individual racial/ethnic groups. Several past studies have, in fact, detected meaningful differences in self-perception measures between PEER and non-PEER subgroups. For example, D'Lima *et al.* (2014) found that Asian-American students had lower self-efficacy measures than Caucasian or African-American students. In a study of Black and Latinx students, Byars-Winston *et al.* (2016) found that Latinx female students had higher science identity levels than other groups. Another study on mentoring structures of undergraduate researchers found that, while mentoring structures impacted self-perception for PEER students and female students, mentoring structure had no significant impact on Asian students and that Asian students had lower science identity scores (Aikens *et al.*, 2017).

Sample size may have also limited our ability to detect intersectionality of demographic factors. The comparison with the largest sample (PEER × FGCS status for science identity) had only 33 PEER, first-generation college students out of 302 students in that sample. Future studies with a larger number of students have the potential to uncover important effects of intersections in students' identities on the development of student self-perception.

Duration of Study

Another limitation of our study is that we only measured self-perception over two semesters, so we cannot speculate as to how self-perception may change beyond this. While longitudinal studies are limited, in a 5-year longitudinal study, Robinson *et al.* (2018) found three distinct science identity trajectories with changes in years 2–4 seen in two of the three groups, suggesting the potential for self-perception to change later in students' academic careers. Furthermore, Estrada *et al.* (2018) found that science identity and scientific community values, but not self-efficacy, measured in students' junior year were predictive of persistence in STEM pathways for up to 4 years postgraduation.

CONCLUSIONS

Our study of three self-perception measures predictive of STEM persistence suggest that different growth trajectories can be detected over the course of a year of biology instruction. We found that measures that increase do so at similar rates for all demographic groups. However, student self-perception was lower for females and PEER at the start of college-level biology education, and these differences remained after 1 year of instruction. Studies into potential underlying causes for initial differences in self-perception measure or influences on self-perception trajectories in first-year students, particularly pertaining to self-efficacy in female and PEER students and scientific community values in first-generation college students, while beyond the scope of this study, are likely to be important areas of future research.

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