Research Article

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Undergraduate STEM Students' Science Communication Skills, Science Identity, and Science Self-Efficacy Influence Their Motivations and Behaviors in STEM Community Engagement

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While numerous studies have examined how scientists perceive doing public communication and engagement, there is limited research on undergraduate science, technology, engineering, and math (STEM) student attitudes toward these meaningful activities. Undergraduate students are more diverse than STEM faculty and may serve as boundary spanners in communities, so exploring their motivations and behaviors in STEM engagement is valuable. For scientists, confidence in communication skills is one driver of public engagement behavior. In this study, we utilized a survey to examine how undergraduate STEM students' science communication skills as well as their science identity and science self-efficacy may drive motivation and behaviors in STEM community engagement. Our findings revealed that STEM students are motivated to do community engagement but lack opportunities to actually do these behaviors. Regression analyses revealed that year in academic progression did not increase STEM students' attitudes and behaviors in community engagement. However, science communication skills, science identity, and science self-efficacy were all predictors of student motivation and behaviors in STEM community engagement. These findings suggest that universities should intentionally provide training in science communication, continue providing support for students developing science identity and self-efficacy, and develop opportunities for undergraduate STEM students to do science outreach and engagement activities.

KEYWORDS undergraduate, community engagement, science communication, science identity, science self-efficacy

INTRODUCTION

Scientists engaging in the community

Science outreach or engagement programs can have multiple benefits, from encouraging K–12 students to pursue science, technology, engineering, and math (STEM) fields (1–3) to increasing community science literacy (4). More universities and informal science centers like museums, industry, or individual scientists have begun to value community engagement as an essential element to the role of their institution (5). However, for scientists to be involved in such community engagement activities, they must be both motivated to do so and have the support and skills necessary to do so. Surveys of scientists' intentions to do public science communication and community engagement show that they feel a lack of institutional support as well as a lack of personal communication skills in this area (6).

STEM students engaging in the community

Several studies have examined how scientists view public engagement and its importance in their professional identity (6–9). Different surveys have identified whether late-career or early-career scientists or STEM graduate students are most likely to engage in face-to-face or online communication about science, with varied results, depending on the study (10). STEM graduate students are often encouraged to do community engagement (5). However, there is limited analysis of how undergraduate STEM students may view community engagement. When analyzing STEM students as the purveyors of community engagement, studies show that civic engagement as an experiential learning experience is a high-impact practice in undergraduate STEM education, increasing student learning and benefitting universities (11). However, there is a lack of studies exploring what might motivate undergraduate STEM students to do science community engagement or what barriers may exist. It is important to explore these relationships, as undergraduate STEM students are more diverse than scientists and faculty members (12), growing in their professional identity as scientists

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(13), and may serve as boundary spanners between diverse communities and science (14, 15).

Measuring community engagement

There is a plethora of ideas of what might constitute engagement with the public about science (16). To operationalize our study, we utilized scales (see Table 1) that have previously been used to survey scientists (6, 17) to explore students' motivations toward community engagement as well as behaviors in community engagement. Scales 1 and 2 aimed to assess both the external factors and internal factors that drive undergraduates to participate in community engagement. Scientists face both the institutional pressures to participate in community engagement, but there has also been a shift toward more societal and internal desires to share science with the community (6). Scales 3 and 4 measured aspects of student behaviors in STEM community engagement. Scale 3 aimed to measure how and where STEM students engage in the community. Scale 3 was developed by looking at the literature to find examples of different venues where undergraduate STEM students can engage in community engagement. Many universities have implemented aspects of community engagement in their curriculum or as departmental extracurriculars (18). Student organizations and clubs are also an important aspect of undergraduate student experiences. Several universities have student-led organizations aimed toward STEM engagement (19). Another way scientists and STEM students can get involved with community engagement is through nonprofits and community agencies (20). Finally, religious organizations can have a presence on university campuses and play roles in community engagement related to science and health (21). One limitation of this scale is that it is not exhaustive of all possible engagement venues or descriptive of what activities students might be doing in these venues. Scale 4 assessed how often students participated in community engagement. Together, all four scales were used to measure the community engagement motivations and behaviors of students. We used these scales to answer the following research question:

> RQ1. What are undergraduate STEM students' community engagement motivations and behaviors?

According to the Theory of Planned Behavior, a combination of motivation and perceived behavioral control impact an individual's behaviors (22). Thus, for RQ1, we generated the following hypothesis:

> H1. Student motivations in community engagement will increase their behaviors in community engagement.

Because much research in the area of STEM community engagement assesses how graduate students and scientists are involved in the community, we wanted to additionally assess the following research question and hypothesis:

> RQ2. How does undergraduate STEM students' year of academic progress impact their community engagement motivation and behaviors?
> H2. Students farther in academic progress will have higher community engagement motivations and behaviors.

What factors may influence STEM students engaging in the community?

While many factors may influence whether and how STEM students engage in the community, we identified three factors in the literature—science communication skills, science identity, and science self-efficacy—that could be key influences. Like internal and external motivations, these can be mapped to the Theory of Planned Behavior (Fig. 1). Scientists are driven by both societal and institutional (external) outcomes of their engagement and communication efforts as well as by assessment of their own skills or self-efficacy (internal) ability to engage (10). Thus, we wanted to measure these three factors in undergraduate STEM students.

Scientists have cited communication skills, or lack thereof, as impacting their work in public engagement and communication of science (6). Similarly, this relationship may exist for STEM students. Akin and colleagues examined confidence in science communication skills and behavioral intentions to participate in public communication of science as underpinned by the Theory of Planned Behavior. They showed that science communication skills developed during a training for STEM graduate students led to increased intention to engage in science communication activities (23). Hanauer and colleagues have developed a science networking and communication scale that measures undergraduate students' capabilities and confidence in communicating scientific knowledge to different audiences (24). In the current study, we used this scale (24) to quantify students' confidence in their science communication skills and its potential relationship with community engagement motivations and behaviors.

Science identity has also been shown to have a connection to community engagement. Science identity refers to both an individual's sense of identity as a scientist and their sense of belonging in the community of scientists (25). One area of community engagement is civic engagement; science identity has been shown to moderate how students participate in the political and civic nature of science (26). Additionally, participation in community engagement programming, such as K–12 science outreach activities or citizen science projects, increases the science identity of both the STEM students and the community members involved in the programming (27, 28). It is possible that growing in science identity increases STEM students' community engagement behaviors, and conversely, participating in community engagement activities increases their science identity, linking the two in a synergistic relationship. Lastly, science identity drives K–12 student career choices toward STEM (29).

TABLE 1
Survey scales and items

Construct	Scale items	Reference(s)	Cronbach's alpha in our study population
Motivations for STEM community engagement (more external)	Scale 1: How important is engaging with your local community in STEM engagement or outreach activities. . . . . .in furthering your individual growth as a scientist? . . .in your individual connection to your community? . . .to your university as a whole? . . .to your university department? . . .to your future employers?	5, 17	0.789
Motivations for STEM community engagement (more internal)	Scale 2: How important is each objective when engaging with local community in STEM engagement activities? • Connecting with members of your community in a shared experience. • Increasing individuals' confidence and excitement in engaging with science topics and spaces. • Practicing presenting your scientific findings to increase your individual confidence in science. • Collaborating and communicating with community members. • Increasing trust in the scientific community. • Engaging in a discussion about a position or viewpoint to learn what individuals think about certain issues. • Informing the public about scientific issues. • Improving science communication skills.	5, 17	0.818
Venues for STEM community engagement	Scale 3: In which ways and how often do you engage with your local community in STEM engagement activities? • As a curricular, class assignment. • As an extracurricular through a student organization. • Through a college department as an extracurricular. • Through volunteering with a local nonprofit or governmental agency. • Through a religious organization.	18–21	0.818
Frequency of STEM community engagement	Scale 4: Overall, how often do you engage with your local community in STEM engagement or outreach activities?		NA[a]
Science self-efficacy	Rate your agreement with these statements: • I feel confident in my ability to be successfμL in my science courses. • I feel capable I can apply the skills learned in my classes to real-life situations. • I feel confident that I can develop technical science skills.	28	0.82
Science networking and communication	Rate your agreement with these statements: • I feel confident I can communicate scientific knowledge to my peers. • I feel capable of communicating scientific knowledge to nonscientist community members. • Discussing science with others increases my confidence as a scientist.	Based on 23	0.755

(Continued on next page)

TABLE 1 (Continued)

Construct	Scale items	Reference(s)	Cronbach's alpha in our study population
Science identity	Rate your agreement with these statements: • I have a place in the scientific community. • I consider myself a "scientist." • The scientific community accepts me. • The scientific community values my role and knowledge as a community member outside of science. • Taking part in community engagement strengthens my identity as a scientist.	28	0.892
Demographics			NA

[a]NA, not available.

But once students have chosen STEM as a major, does their science identity, which once was a driving force in that choice, continue to drive their choices in the STEM activities they take part in, such as community engagement? In this study, we used a scale to assess undergraduate students' science identity (30) to analyze how it impacts community engagement due to the several connections science identity has to both community engagement programs and the trajectory of STEM students.

Another factor that can drive students' desires to participate in community engagement is science self-efficacy. Science self-efficacy refers to an individual's confidence and belief in their ability to complete science tasks and skills. Self-efficacy has been shown as a driver of civic engagement (31–33). Science self-efficacy has been shown to influence STEM students' science engagement in both the classroom and on social media (34). Potentially, increasing the science self-efficacy of STEM students may give them the tools and confidence to engage in science with the community. We utilized a scale to assess undergraduate students' science self-efficacy (30) to analyze how it impacts students' community engagement activities.

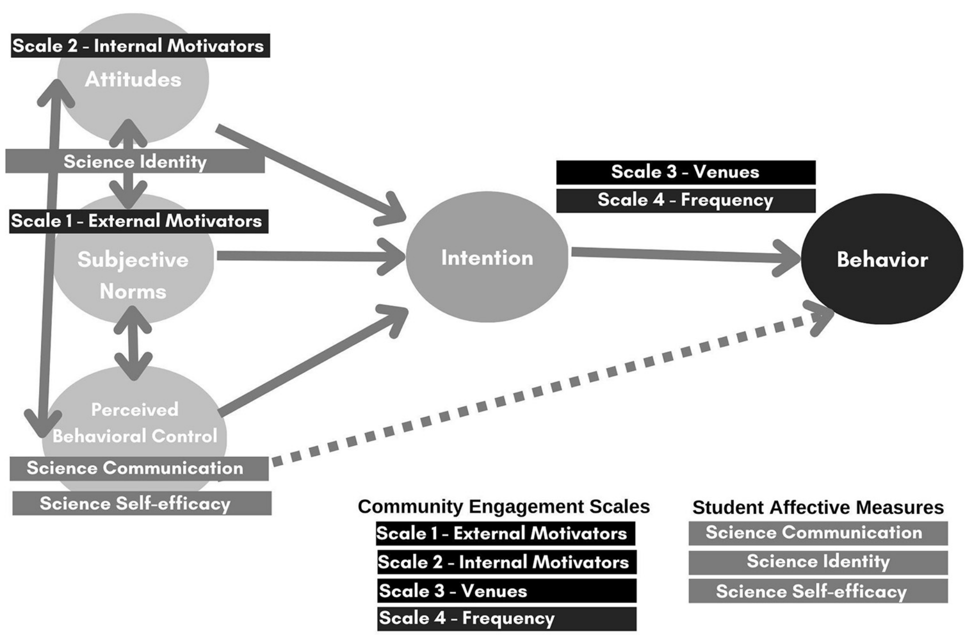

FIG 1. Mapping of survey measures according to the Theory of Planned Behavior. The Theory of Planned Behavior shows how attitudes, subjective norms, and perceived behavioral control impact both behavioral intentions and behaviors (arrows) (22). In our study, scale 1 (external motivators) relates to subjective norms, and scale 2 (internal motivators) relates to attitudes. Science identity, which contains elements of internal attitudes about oneself as well as perception of acceptance by the community of scientists, relates to both attitudes and subjective norms. Confidence in science communication skills and sense of science self-efficacy relate to the perceived behavioral control an individual feels to engage in the community. Scales 3 and 4 measure a combination of behavioral intentions and behaviors.

TABLE 2
STEM majors represented in the survey participant pool

Major	No. of students
Animal and Equine Sciences	1
Soil and Crop Sciences	1
Biomedical Engineering	5
Chemical and Biological Engineering	1
Civil and Environmental Engineering	1
Electrical and Computer Engineering	1
Mechanical Engineering	1
Ecosystem Science and Sustainability	3
Fish, Wildlife, and Conservation Biology	7
Biochemistry and Molecular Biology	16
Biology	22
Chemistry	3
Physics	2
Psychology	1
Zoology	21
Biomedical Sciences	19

TABLE 3
Demographics of survey participants

Category	Demographic	No. with response (*N* = 110)
Gender identity	Man	18
	Woman	86
	Nonbinary	5
	Prefer not to say	1
Race and/or ethnicity	Asian American or Pacific Islander	3
	Latino/Latinx or Hispanic	8
	White	88
	Multiracial or multiple selected	9
	Prefer not to say	2
Academic progress	1st year	24
	2nd year	20
	3rd year	37
	4th year	16
	5th year	9
	Other	4

There are synergistic relationships between many of these factors; for instance, cultivating science self-efficacy can facilitate cultivating science identity (35). Notably, all three affective measures—science communication skills, science self-efficacy, and science identity—have been shown to correlate with student STEM retention and success, especially for underrepresented students (24, 26, 30). Therefore, in this study we measured these three affective measures and how they correlated with student community engagement. We used these to answer the following research question and literature-driven hypothesis:

> RQ3. How do undergraduate STEM students' science communication and networking skills, science identity, and science self-efficacy correlate with their community engagement motivations and behaviors?
> H3. All three undergraduate student affective measures will positively correlate with their community engagement motivations and behaviors.

METHODS

Survey creation

A large landscape survey for undergraduate STEM students was created using validated scales from the literature (Table 1). All items were reliable in our study population (Cronbach's alpha > 0.7).

Survey distribution

The survey was distributed in Spring 2022 to students in STEM departments and STEM-focused registered student organizations at a large R1 land-grant university. This work was approved by the Institutional Review Board of Colorado State University. In total, $n = 110$ students completed the entire survey. Students were asked to indicate their major when they took the survey (Table 2). If students listed 2 majors, they were tallied under the first major they listed. Demographics of survey participants are listed in Table 3.

Statistical analysis

Analyzing results began with calculating the Cronbach's alpha to determine scale reliability. Descriptive statistics were compiled by calculating the mean and standard deviation for each affective measure (science communication skills, science self-efficacy, and science identity) and for each community engagement scale. One-way analysis of variance (ANOVA) followed by Tukey's *post hoc* analysis was used to compare descriptive statistics for the four community engagement scales.

In addition to descriptive statistics, simple linear regressions were used to examine the relationship between the independent variables of motivations and the dependent variables of behaviors. Additionally, simple linear regressions were used to examine the relationship between the independent variables of students' affective measures (science communication skills, science self-efficacy, and science identity) as well as year in school and the dependent variables of their community engagement motivations and behaviors.

TABLE 4
Descriptive statistics of the 110 survey responses[a]

Parameter	Scale 1	Scale 2	Scale 3	Scale 4	Science communication	Science self-efficacy	Science identity
Mean	3.536	3.883	2.889	2.63889	4.10	4.088	3.616
SD	0.723	0.583	0.601	1.32072	0.737	0.800	0.736

[a]Scales 1 to 4 refer to the constructs and items listed in Table 1.

RESULTS

Descriptive statistics for the seven scales—four community engagement scales and three student affective measures—in our study are shown in Table 4. Of note, within scale 3, item 5 about religious organizations was significantly lower than the other scales, although collectively the entire scale had a Cronbach's alpha of >0.8. This suggests that students engage in STEM engagement via religious organizations the least compared to the other venues.

To answer RQ1, we performed an ANOVA between the four community engagement scales (Fig. 2). Overall, students had higher motivations toward community engagement (scales 1 and 2) than behaviors in community engagement (scales 3 and 4). Students were more motivated by personal and internal factors (scale 2) than institutional and external factors (scale 1). We also wanted to analyze how students' motivations (scales 1 and 2) impacted their behaviors (scales 3 and 4). As shown in Table 5, there was a significant influence of both motivation scales on both behavior scales. However, internal motivations had a stronger effect (larger R^2) than external motivations.

To answer RQ2 about the influence of students' academic progress on their affective measures or their community engagement motivations and behaviors, we performed another set of linear regressions. Interestingly, there was either a negative correlation or no significant correlation between year of academic progress and the community engagement scales (Table 6).

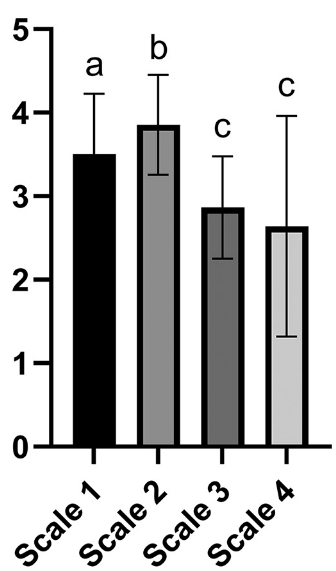

FIG 2. Descriptive statistics of STEM student attitudes and behaviors toward STEM community engagement. A one-way ANOVA followed by *post hoc* Tukey's test showed that for a versus b, P was 0.01, and for a or b versus c, P was <0.0001. Scales 1 to 4 refer to the constructs and items listed in Table 1.

Finally, to answer RQ3, we examined what factors might influence students' STEM community engagement attitudes and behaviors. The linear regression had significant P values for all predictors (student affective measures of science communication skills, science identity, and science self-efficacy) for all dependent variables (STEM community engagement scales 1 to 4). We interpreted our correlations using Gignac and Szodorai's meta-analysis of individual differences research and effect sizes (36), in which R^2 of 0.01 to 0.04 indicated a small effect size, R^2 of 0.04 to 0.09 indicated a moderate effect size, and R^2 of >0.09 indicated a large effect size. We found a medium to large effect size influence on all predictors on all four community engagement scales (Table 7). Overall, however, the effect sizes were larger for science communication and science self-efficacy compared to science identity. Interestingly, in the descriptive statistics, students rated their science identity as lower than both their science communication and their science efficacy (Table 4). Ultimately, however, there was a strong correlation between all three student affective measures (science communication, science identity, and science self-efficacy); linear regressions utilizing any of these of these measures as predictors of the other two led to R^2 values of >0.3 (regression tables not shown). Thus, there was a very strong correlation between all three student affective measures, which had smaller, albeit still significant with decent effect sizes, influences on STEM community engagement motivations and behaviors.

DISCUSSION

While several studies have examined scientists' motivations and behaviors for STEM community engagement (6, 9, 17) and some studies have examined undergraduate STEM students' work in specific skills like science civic engagement (11, 33), there is a dearth of research about undergraduate STEM students' motivations, behaviors, and attitudes toward STEM community engagement overall. This study contributes to this gap in the literature, specifically assessing undergraduate STEM student motivations, affective measures, perceived behavioral control, and behaviors related to STEM community engagement via the lens of the Theory of Planned Behavior.

TABLE 5
Linear regression values for the relationship between student community engagement motivations and behavior

Predictor	Parameter	Scale 3, community engagement venues	Scale 4, community engagement frequency
Scale 1, external motivations for community engagement	Slope	0.4880	0.4889
	F	49.68	7.561
	df	1, 108	1, 108
	P value	<0.0001	0.0070
	R squared	0.3151	0.06543
Scale 2, internal motivations for community engagement	Slope	0.6844	0.5965
	F	84.77	8.018
	df	1, 108	1, 108
	P value	<0.0001	0.0055
	R squared	0.4397	0.06911

Key findings of the study

As hypothesized, students' motivations to do community engagement impacted their behaviors (RQ1 and H1). However, students overall had a higher desire to do STEM community engagement (scales 1 and 2) than behaviors in actually doing STEM community engagement (scales 3 and 4). Within desires, they were more motivated by personal connections (scale 2) than by institutional objectives (scale 1), and the influence of these personal motivations on their community engagement behaviors was stronger. This is a notable difference from scientists, whose STEM engagement behavior is often driven by pre- versus post-tenure status and whether or not their institution supports engagement work (6). This difference is unsurprising, given that STEM students are likely less cognizant of institutional demands. Additionally, since STEM students are more diverse than faculty (12), personal connections and motivations in students may differ compared to those in faculty. However, career scientists can also be driven by the intrinsic reward of public communication of their science (7), which matches what we found as a primary driver in undergraduate STEM students. The lower ratings for community engagement behaviors (scales 3 and 4) suggested that students have a lack of venues and opportunities in which to do community engagement, even though they are motivated to do it (scales 1 and 2). This highlights the need to create training and opportunities for students to enact their desires to do STEM community engagement.

Interestingly, year of academic progress had either no influence or a negative correlation with community engagement motivation and behavior (RQ2 and H2). This was in contrast to our hypothesis. This suggests that passivity toward undergraduate student STEM community engagement is not a useful strategy; students will not naturally develop these skills without interventions or explicit opportunities in which to participate in these activities. Explicit training in public engagement has been shown to increase scientists' willingness to participate in such engagement (10, 37).

In order to support student attitudes and behaviors in STEM community engagement, we examined what factors impacted these measures (RQ3 and H3). As hypothesized, increasing student science communication confidence, science identity, and science self-efficacy increased students' community engagement attitudes and behaviors. Science

TABLE 6
Linear regression values analyzing the relationship between student year of academic progress (1st, 2nd, 3rd, 4th, or 5th year) and community engagement scales 1 to 4[a]

Predictor	Parameter	Scale 1	Scale 2	Scale 3	Scale 4
Year of academic progress	Slope	−0.2189	−0.1616	−0.09744	−0.02832
	F	17.70	13.22	4.122	0.07151
	DFn, DFd	1, 104	1, 104	1, 104	1, 104
	P value	<0.0001	0.0004	0.0449	0.7897
	R squared	0.1454	0.1128	0.03813	0.0006872

[a]Scales refer to constructs and items listed in Table 1.

TABLE 7
Linear regression values analyzing the relationship between student affect measures and community engagement scales[a]

Predictor	Parameter	Scale 1	Scale 2	Scale 3	Scale 4
Science communication	Slope	0.2858	0.2765	0.3467	0.4976
	F	11.05	15.07	23.82	9.012
	df	1, 108	1, 108	1, 108	1, 108
	P value	0.0012	0.0002	<0.0001	0.0033
	R squared	0.0928	0.1225	0.1807	0.07701
Science identity	Slope	0.2270	0.1821	0.1898	0.6786
	F	6.688	6.029	6.157	17.97
	df	1, 108	1, 108	1, 108	1, 108
	P value	0.011	0.0157	0.0146	<0.0001
	R squared	0.05831	0.05287	0.05393	0.1426
Science self-efficacy	Slope	0.1853	0.2422	0.2942	0.4819
	F	5.195	13.42	19.54	10.04
	df	1, 108	1, 108	1, 108	1, 108
	P value	0.0246	0.0004	<0.0001	0.0020
	R squared	0.0459	0.1105	0.1532	0.08503

[a]Community engagement scales 1 to 4 and student affective measures in the first column refer to constructs and items listed in Table 1.

communication skills and science self-efficacy were slightly stronger predictors than science identity. This is similar to what has been found for scientists, in which lack of confidence in communication skills constrained their public communication activities (6) and building their confidence in their communication skills increases public engagement intentions (10). While we found that science self-efficacy increases students' community engagement attitudes and behaviors, others have found that participating in STEM community engagement activities increases students' self-efficacy in their particular science field (38). Thus, there may be a positive feedback effect whereby interventions to increase either students' science self-efficacy or their community engagement behaviors have an impact on the other. Thus, promoting STEM students' opportunities to participate in STEM community engagement can have valuable impacts on not only the community but also the students.

Overall, these results show that undergraduate STEM students desire to engage with the public and value community engagement but lack venues and opportunities in which to engage in community engagement. Having more confidence in their science communication skills, more science identity, and/or more science self-efficacy increases students' motivations and behaviors in STEM community engagement.

Limitations

This study was completed at a large land-grant university. Different results might occur at community colleges, liberal arts colleges, or other institutions. Additionally, our sample was disproportionately white and female, which matches the demographics of many STEM (especially life science) students at our institution. Our sample also had a large proportion of life sciences majors. Students of different demographics or fields of study may have different motivations, barriers, and behaviors. Finally, there are certainly factors other than the predictors we examined that may influence STEM student community engagement motivations and behaviors. Analysis of interviews and focus groups with diverse groups of students about this topic may reveal themes about other constructs that should be quantitatively examined.

Finally, there are also different scales than those we used in this study to measure scientists' and engineers' perceived skills in community engagement, such as those described in references 39 and 40, that could be explored, compared, and validated in undergraduate STEM student populations. Additionally, further investigation to explore STEM students' attitudes, skills, and behaviors in different models of community engagement, such as those promoting public understanding of science and science literacy versus richer public engagement in science (41), would enable clarity on how to best train STEM students in this area.

Implications for undergraduate STEM education

Our results revealed a lack of venues or opportunities for STEM students to participate in STEM community outreach. Universities can create programming to support students' opportunities to meaningfully engage with communities about science (42–45). One example could be courses like course-based undergraduate research experience (CURE) labs being adjusted to integrate authentic research experiences with community and justice projects (46). Working with K–12 students may be a particularly impactful training ground that impacts both the K–12 students and the STEM students who do such STEM engagement activities (47–50). Interestingly, participating in science outreach programs as a K–12 student increases the chances that that student will pursue STEM (29, 51, 52); once these students become undergraduate STEM majors, they should be encouraged to engage in that pipeline and mentor the next generation of K–12 students. Some studies have found that prior STEM community engagement and outreach experience is a predictor of self-efficacy in such activities in STEM professionals (40). Providing opportunities to develop STEM students' experience in STEM community engagement during their undergraduate years can provide a lifetime of confidence in further community engagement. Finally, universities and educators should help undergraduate STEM students appreciate the wide range of STEM community engagement activities, from traditional one-way "outreach" activities to more collaborative two-way community-engaged research models (53).

Fortunately, confidence in science communication skills was a positive predictor for both community engagement motivations and community engagement behavior. Thus, training in science communication skills, especially inclusive science communication skills that would facilitate equitable community engagement (23, 54, 55), should be included in undergraduate STEM curricula and will facilitate increases in community engagement attitudes and behaviors. Such science communication trainings have been shown to support public science communication behavioral intents in STEM graduate students (23) and STEM professionals (40). Similarly, interventions that have been shown to support students' science self-efficacy and identity, such as active learning in the classroom (56), should also increase students attitudes and behaviors in STEM community engagement. Since student science communication skills, science identity, and science self-efficacy are also predictors of STEM retention (24, 30), investing in training students in these activities may serve the dual purpose of encouraging STEM retention as well as STEM community engagement. Our findings also suggest the need for more research to establish a potential synergistic effect among these factors and the potential for STEM community engagement to be another activity that supports undergraduate student STEM retention.

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