

Impact of outreach on physics student development: Quantitative results from a national survey

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(Received 3 March 2025; accepted 5 November 2025; published 10 December 2025)

This work reports results from the first national study of the impact of student facilitation of informal physics outreach programs on their physics identity, sense of belonging, and essential career skill development. Drawing on results from studies at a single institution with a well-established physics outreach program, a national survey was developed and distributed through the Society of Physics Students' network to more than 5000 individuals. A total of 704 responses were received. Responses to closed-form questions on the survey were analyzed descriptively and using multiple regression analysis to evaluate the relationship between student participation in informal physics outreach programs and the constructs of interest. Results show that students' engagement in outreach was linked to increased confidence in communicating their physics knowledge, as well as to the development of key career skills. Additionally, facilitating informal physics outreach programs was a modest but significant predictor of a stronger growth mindset and a greater sense of belonging within the field, which are known to contribute to student persistence in their major.

DOI: [10.1103/mj85-87vk](https://doi.org/10.1103/mj85-87vk)

I. INTRODUCTION

Students entering an undergraduate physics program face many challenges to their success, including both academic and social hurdles. In recent years, studies have expanded our awareness of how addressing social challenges, such as belonging and growth mindsets, can support students in persisting and anchoring their academics [1–5]. Improving students' sense of belonging, defined as the feeling of being valued, accepted, and feeling like a legitimate member of their chosen scientific discipline [6], can reduce attrition rates [7,8]. While classroom interventions in recent years have sought to support the social side of learning more directly [9–11], programs beyond the classroom can also play a pivotal role in student development. Such activities include undergraduate research, teaching, extracurricular groups, and informal physics outreach programs. This work focuses on the latter of these opportunities.

We define informal physics outreach programs broadly as a set of activities beyond the classroom which bring students, faculty, and staff at colleges, universities, and national labs into direct or indirect contact with members of the public to engage with physics. These programs can vary widely in size and frequency, ranging from small star parties, to short videos shared on social media, teaching in prisons, and large festivals attended by thousands. Often, these programs rely on the facilitation of undergraduate students who help create and deliver content to groups of all ages.

Engaging in these programs can support the development of students' physics identity: interest and motivation, performance and competence beliefs, recognition, and sense of belonging [12]. The development of students' disciplinary identity and motivational beliefs can potentially increase student resilience within a chosen science, technology, engineering, and mathematics (STEM) major [13]. Additionally, participation in cocurricular experiences that develop abilities beyond the scope of classroom and laboratory studies—such as informal communication, teamwork, and creativity—has been identified as a high priority for physics programs. Through surveys of employers of recent physics bachelor's graduates, the American Physical Society and the American Association of Physics Teachers have emphasized the importance of these

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experiences in preparing students for 21st-century careers [14,15]. These studies clearly indicate that impactful, engaging courses must be combined with experiences outside the classroom to better provide undergraduate physics students with the opportunity to see themselves as contributing members of the physics community.

While informal physics outreach programs are common components of physics departments across a wide range of institutions, a broad investigation of their impact on the undergraduate student experiences that could inform specific recommendations for best practices has not been reported. This paper presents the results of the first nationwide study on the impact of informal physics outreach programs on undergraduate students who plan or facilitate them. We sought to determine how students' participation in outreach programs affects their physics identity, persistence, sense of belonging, and the development of 21st-century career skills. Additionally, we examined how students' demographics influenced their likelihood of engaging in informal physics outreach programs.

A. Background and prior work

Our prior results from a pilot study conducted at Texas A&M University showed that students who participate in the conception and execution of informal physics outreach programs experience the growth in their sense of purpose, and that such experiences provide the critical context needed to motivate persistence in physics [16–19]. This is not surprising since, through informal physics outreach programs, undergraduate students are offered the opportunity to practice leadership, planning, design, work in teams, explain physics concepts to others, all within a creative environment [16,20]. It also provides a rich and highly contextual opportunity for students to develop a physics identity, experience a sense of belonging, and practice important career skills [21,22]. Initiated with research by Hinko and Finkelstein [20], there is a growing interest in the Physics Education Research community in understanding how student participation in these programs supports the development of physics and STEM identities, enhances retention and persistence, and creates a feeling of community [23–30]. Growing research supports the idea that these outreach programs have a vital impact on the undergraduate students who help to conceive and facilitate them [16–18,20,22–24,31–33].

Prior research suggests that developing a physics identity can help students choose physics as a career and persist in the field [34]. Efforts to develop this identity have the potential to increase retention rates among students who might otherwise leave the field. Among the key factors influencing students' persistence in physics and other STEM fields are a strong discipline-based identity combined with a sense of belonging to the STEM community, integration into an academic department, receiving external recognition as a STEM professional, motivational beliefs

about doing physics, physics self-efficacy, and real-world experience [23,34–46].

Equally important is student exposure to teaching physics to populations outside the academic world—opportunities that are amply provided by informal physics outreach programs [19,32,47–49]. The flexibility of the program formats provides students with extensive opportunities to explain physics concepts to the general public. This communication format could potentially foster greater ownership and create opportunities for transformational experiences [16,17,19]. Recent research indicates that by facilitating informal physics programs, students can develop their communication and presentation skills, enhance their design and fabrication abilities, and gain teamwork experience, all of which prepare them for 21st-century careers [14,16,17,23,32]. Self-reported data show a positive impact on students' physics identity, the development of their physics voice, networking within the department and the broader STEM community, and their sense of being valued and accepted as a result of facilitating physics outreach programs [16–19,33].

However, these perceptions have relied on data from a relatively small number of participants drawn from a limited range of outreach programs. There is a clear gap in the literature examining a broader population of undergraduate physics students from various institutions across the country. This work generates a national dataset enabling a leap forward in our understanding of the connection between student facilitation of informal physics programs with their development as physicists, their sense of belonging, and their acquisition of skills needed for 21st-century careers—which can help to transform undergraduate student experience. Our team developed a survey that was distributed to the national network of the Society of Physics Students (SPS). The goal of this survey was to measure students' perceptions of their physics identity, sense of belonging, mindset, career skill readiness, as well as sample information about students' level of engagement with informal physics programs, along with student demographics. The new survey instrument was created with open and close-ended questions. In this paper, we present the construction, distribution, and analysis of the survey with a focus on the closed questions. The open-ended questions analysis will be presented in the subsequent paper, with the preliminary results published in the PERC proceedings [50].

B. Pilot study results and framework

An initial phase of this work has been completed at Texas A&M University [16–19]. A mixed-methods study was performed on the impact of five informal physics programs run by the Department of Physics and Astronomy on a relatively large number of undergraduate and graduate students. The students were mostly from physics and engineering departments. These five outreach programs

differed in scale and frequency, spanning from a large annual physics festival with thousands in attendance to smaller-scale events held year-round. Self-reported data on the dimensions of physics identity, sense of belonging, and development of 21st-century skills were collected using a survey instrument (117 responses) and interviews (35) with current and former undergraduate and graduate students.

The results of the pilot study survey data showed that over 80% of survey participants reported that participating in outreach had a positive impact on their ability to recognize connections between physics topics and on their overall depth of conceptual understanding in physics. More than 85% of survey participants reported that participating in outreach had a positive impact on their teamwork skills and ability to network within the physics department. These skills foster preparedness for 21st-century careers [14,15], preparing students to effectively engage in communication, teamwork, and design. When asked about their confidence in choosing a physics major, almost half of the responding students reported increased confidence in their choice after participating in outreach [16]. Women reported a statistically significant increase in confidence in their choice of a physics major after facilitating informal physics programs [17].

The results from the pilot study survey informed the design of the new survey used in this study to collect a nationwide data sample. The survey questions were grounded in theoretical frameworks similar to those used in the creation of the pilot survey. These frameworks included situated learning theory to define learning [51], transformative learning theory to explain how powerful learning occurs [52,53], as well as the Hazari *et al.* [13] model and the Dynamic Systems Model of Role Identity to define identity [54]. In the next sections, we will describe the survey development and distribution.

II. METHODS

A. Survey development

To explore the relationships between student participation in informal physics outreach programs and constructs including physics identity, mindset, and self-efficacy, we created a new survey. The survey questions, available in Supplemental Material [55], were developed based on themes from our previous studies at a single institution [16–19], as well as the collaborative expertise of researchers from Texas Lutheran University, Texas A&M University, the University of Texas at Austin, and the Statistical Research group of the American Institute of Physics. Likert scale items specifically sought to collect students' perceptions of their motivation and interest, sense of recognition from self and others, performance and competence beliefs, sense of belonging, confidence, desire to persist, growth versus fixed mindset, and self-efficacy. Further Likert scale items captured students' sense of

ability to use essential nondisciplinary, or career, skills (e.g., communication, teamwork, and networking). Additional non-Likert scale questions sampled students' level of participation in informal physics events and demographic factors (age, gender identity, identification as a member of the LGBTQIA + community, domestic or international student, ethnicity, neurodivergence, parents education, classification, and home institution). As responses to the neurodivergence item were inconsistent with prior findings, such as those reported in a survey of the American Astronomical Society [56], it was omitted from further analysis. Students who responded as participating in outreach also received prompts for three open-ended questions. As this work focuses on quantitative results, discussion of open-ended questions will be omitted from this paper.

B. Pilot survey and distribution

To gather a national sample, we partnered with SPS for distribution. Initially, the survey was distributed to members of SPS groups at three institutions, corresponding to the home institutions of authors T. E., T. S., and J. D. P. Students were emailed directly by the American Institute of Physics with weekly reminders sent over a three-week period. A total of 101 responses were collected for this pilot survey distribution. After reviewing responses, the survey was determined to be robust. That is, the sample surveyed was of sufficient size and representative of the population, questions measured their intended construct, and the survey was reliable. Analysis of responses showed consistency with prior results and high Cronbach α values for items targeting single constructs. A minor edit was made to one item, out of 61, at the suggestion of a member of the research team, but this did not change the meaning of the item.

For the second phase, the survey was sent to more than 5500 student members of SPS chapters across North America. Periodic reminders were sent over the next 4–6 weeks, encouraging students to complete the survey. At the end of the collection period, a total of 704 responses were received. Representing a roughly 13% response rate, this is the largest dataset collected focusing on student engagement with physics outreach to date. To the best of our knowledge, this is the largest dataset on student engagement with STEM outreach conducted by any research team. Other studies focusing on student experiences have tended to draw on qualitative analysis of a small number of surveys [57–59] or, when employing a survey, have had fewer than 100 responses [60]. A breakdown of the demographics of survey respondents is shown in Table I. Women are slightly overrepresented in the sample compared to the percentage who earn bachelor's degrees in physics annually, while reported race and ethnicity closely reflect national trends for physics degree recipients [61].

TABLE I. Demographics of student responses ($N = 704$) to the national survey. In some cases, percentages do not add to 100% as respondents could select “I prefer not to respond.” For ethnicity, respondents were allowed to choose multiple answers.

Demographic	Percent (%)
<i>Gender</i>	
Men	41
Women	52
Another identity	5
<i>Classification</i>	
Freshman	15
Sophomore	17
Junior	29
Senior	39
<i>Race or ethnicity</i>	
American Indian or Alaska native	1
Asian or Asian American	9
Black or African American	6
Hispanic or Latino	12
Pacific Islander	1
White	77
<i>LGBTQIA+</i>	
Yes	27
No	64
<i>International student</i>	
Yes	11
No	89
<i>Parents' education level</i>	
Did not complete high school	3
High school diploma	9
Associates or technical degree	5
Some college/university	8
Bachelor's degree	31
Graduate degree STEM	13
Graduate degree non-STEM	13
Professional degree	18
<i>Outreach participation</i>	
Yes	71
No	29

C. Exploratory factor analysis

In developing the survey instrument, we hypothesized that we were measuring several constructs: physics identity (comprising subconstructs of interest and motivation, competence beliefs, recognition, and sense of belonging), persistence, confidence, self-efficacy, and mindset. To validate our constructs, we performed an exploratory factor analysis [62]. Items framed in a negative tone were inverted so scales matched positively framed items. As constructs were sampled by different numbers of items, and different items had different scales (3–5 Likert responses), each construct was normalized to a 0–1 scale. Doing so allowed for each construct to be weighted evenly whether they were sampled by two questions or by five

questions. Normalization did not alter any results reported in the next section. We conducted exploratory factor analysis with three and eight constructs. Factors were identified using principal component analysis using a Varimax rotation and a Kaiser normalization to produce orthogonal constructs [63,64].

Our *a priori* expectation was that the physics identity components would load together, with the same being true for the self-efficacy and growth mindset components. The survey included four items designed to target student self-efficacy. All four items loaded together, as expected, in a single factor which was termed self-efficacy. The mindset construct comprised three survey items. Two of these items loaded together with the third not loading with any other survey items. After discussion, these three items were condensed into a single factor termed mindset. The construct of physics identity did not resolve into a single factor but was split between five factors. The two items targeting recognition loaded together into the recognition factor. Items targeting belonging and confidence were seen to group together in their own factors which carry the same names, belonging and confidence. The motivation factor was composed of three survey items targeting interest and motivation as well as items targeting belonging and persistence. The competence factor was composed of three survey items targeting competence and one item targeting confidence. The factor loadings are presented in Supplemental Material [55].

The final seven factors that were identified and their constituent items are shown in Table II. This set of factors omits a single construct from the original list: persistence. The persistence item is observed to load primarily with items related to interest and motivation. This is understandable as the desire to persist in undergraduate studies toward a degree may be closely related to a student's interest and motivation to learn more physics [65,66].

D. Models

To examine the relationship between participation in informal physics outreach programs and individual characteristics, we employed logistic regression analysis. Dimensions included in the models comprised three categories: respondent characteristics (RC), institutional characteristics (IC), and the factors defined in the previous section. RC included a binary on student age determined by being younger or older than 24 (corresponding to traditional versus nontraditional aged students), gender identity, classification, race or ethnicity (respondents selecting more than one response were grouped as “two or more races”), orientation, and parents highest level of education. IC included whether their college or university was public or private, as well as the higher physics or astronomy degree awarded (bachelor's, master's, or Ph.D). Our regression models examining constructs relation to participation in outreach (PO) took the form:

TABLE II. The final factors produced from a exploratory factor analysis using a Varimax rotation and Kaiser normalization.

Factor	Items
Motivation	It is important for me to study physics/astronomy. I feel motivated to complete my physics/astronomy tasks. I am more interested in the field of physics/astronomy than I was when I graduated high school. I think about transferring to another major. I believe earning a bachelor's degree in physics/astronomy is a realistic goal for me.
Belonging	I feel I am part of my academic department/college community. I feel a sense of community with peers in my major. I have felt socially isolated in my major.
Competence	I could do an excellent job on assignments in physics/astronomy. I could do an excellent job on exams in physics/astronomy. I can operate physics/astronomy lab materials and equipment.
Confidence	I am able to explain physics/astronomy ideas to people outside my discipline. I can get full-time employment in my chosen field.
Recognition	I am able to explain physics/astronomy ideas to people in my discipline. I see myself as a physicist/astronomer.
Self-Efficacy	I believe others see me as a physicist/astronomer. I usually do well in mathematics. Mathematics is harder for me than many of my classmates. I am just not good at mathematics. I learn things quickly in mathematics.
Mindset	The harder you work at physics/astronomy, the better you can be. You can only learn so much physics/astronomy, and there is not much that can be done to really change that. I appreciate when people give me feedback on my physics/astronomy work, even if it's not all positive.

$$PO = f(RC, IC). \quad (1)$$

In addition to regressions where participation in outreach was the outcome variable, we ran additional models to examine relationships between physics identity, self-efficacy, and mindset. For each mode, we ran two regressions of the form:

$$\text{Factor} = f(RC, IC, FA, [PO]), \quad (2)$$

where the square brackets around participation in outreach [PO] indicate that regressions were run both with and without this independent variable.

In total, 15 regression analyses were performed where each had about 27 variables, totaling over 400 hypothesis tests. Unless otherwise stated, statistically significant results in the next section are presented only for instances where $p < 0.01$. We set the rigorous alpha level to reduce the likelihood of type 1 errors.

III. RESULTS

In this section, we highlight results from the closed questions from the national survey on student impacts of facilitating outreach programs. As noted in Table I, 71% of respondents participated in either some (45%) or most (26%) physics or astronomy outreach events offered by their department. Broadly, students who participated or did not participate in outreach programs were equally comfortable approaching faculty in their departments for help

when they did not understand something. When comparing their awareness of these events, students who had participated in outreach were slightly more likely to report how often such events were offered through their department, Table III. This difference is statistically significant (Mann-Whitney U , $p < 0.01$) with an effect size of 0.580. Students who participated in outreach reported favorably about their perceptions of support, with 35% strongly agreeing and 41% agreeing that these activities were supported by their departments.

When asked about their comfort explaining topics from physics or astronomy to others both in and outside of the discipline of physics or astronomy, students who participated in outreach reported higher average scores, Table IV. Students who had engaged in outreach programs were more likely to report being able to explain physics or astronomy ideas to others both in ($p < 0.01$) and outside ($p < 0.001$) of their home departments, with effect sizes of 0.567 and 0.594, respectively.

TABLE III. Student responses to the prompt “How often are outreach activities available through the physics/astronomy department?” Responses are separated by those who reported participating or not participating in outreach activities.

	Never (%)	Rarely (%)	Sometimes (%)	Most of the time (%)
Participated	1	16	47	35
Not participated	9	20	46	26

TABLE IV. Student responses to prompts “I am able to explain physics/astronomy ideas to people in/outside of my discipline.” Responses are separated by those who reported participating or not participating in outreach. Response choices were strongly disagree (SD), disagree (D), neither agree nor disagree (N), agree (A), and strongly agree (SA).

	SD (%)	D (%)	N (%)	A (%)	SA (%)
<i>In discipline</i>					
Participated	0	2	9	57	32
Not participated	0	5	14	58	23
<i>Outside discipline</i>					
Participated	0	3	8	55	33
Not participated	0	7	18	53	22

Student motivations for engaging in departmental outreach programs are shown in Table V. Respondents could select multiple options, and the provided list, developed from pilot studies, appeared to capture the majority of students’ motivations. The most common motivations were finding the discipline fascinating (76%), giving back to the community (70%), and (unsurprisingly) fun (79%). The next most common motivations were to get to know new people (50%), learn new things (57%), and enhance their disciplinary knowledge (55%). This is consistent with responses in a separate question asking to what extent their physics or astronomy knowledge had improved due to their outreach activities, where 30% reported “a great deal,” while 66% reported “somewhat.” The least common motivations were seen to be students figuring out if the discipline is right for them (13%) and obtaining extra credit for a class (10%).

Table VI shows responses to prompts, posed to students who indicated they had participated in informal physics outreach programs, about their perceptions related to career skills. Specifically, how frequently they used them as well as how prepared they feel to employ these skills in their future endeavors. These career skills represent a significant portion of skills identified as important to 21st-century

TABLE V. Student responses to “Why do you participate in physics/astronomy outreach activities? Please select all that apply.”

Choice	Selected (%)
Because I want to learn new things	57
I think that physics/astronomy is fascinating	76
To help me determine whether physics/astronomy is the right major for me	13
To get to know people	50
Extra credit for a class	10
Outreach helps me understand physics/astronomy better	55
Because it is fun	79
I want to give back to my community	70
Other	6

careers [14] and reported as being commonly used by recent bachelor’s degree holders in both engineering and computer science positions [67]. Students reported relatively high levels of use for most skills, particularly communication, including verbal explanations and non-verbal communication (e.g., posters and videos), and being able to be creative. A high percentage of students (> 90%) reported developing their conceptual understanding, creativity, and networking with other students some or most of the time while engaging in outreach. Respondents also reported high levels of networking and connecting with others in the department, mainly other undergraduate students and faculty, with others such as staff or researchers being less common. Leadership opportunities were slightly less commonly reported, though students still rated being well prepared to employ these skills during outreach activities. The data indicate that students overwhelmingly feel (> 90%) somewhat or well prepared to employ all of the skills from Table VI in their future careers after earning their degrees.

A. Results from regression models

The broad relationships between participation in outreach and the identity factors produced by factor analysis are shown in Figs. 1 and 2. Constructs were used both as independent and dependent variables within the series of models. Arrows within the figures are oriented toward the outcome variable of each of the regression models. Only statistically significant relationships are described in this subsection. All other tests not mentioned upheld the null hypothesis of no difference.

Below, we detail results for regression models first focusing on models with participation in outreach, followed by all other models. The baseline comparison for hypothesis testing was a domestic, traditional aged, white, male senior, at a Ph.D. granting institution, with at least one parent with a bachelor’s degree. This baseline was selected as it represented the most common demographics of respondents to the survey.

1. Outreach

Regression models, following Eq. (2), show statistically significant connections between student participation in outreach and constructs, as shown in Fig. 1. It is observed that participation in informal physics outreach programs is a significant predictor of both students’ growth mindset ($\beta = 0.044$) and sense of belonging ($\beta = 0.074$). These relationships were observed to be positive, with respondents showing greater sense of belonging or a more growth mindset toward their physics intelligence and abilities when having participated in outreach.

The model, based on Eq. (1), also indicated that student classification was the only factor that impacted students likelihood of participating in outreach ($\beta = -1.341$). Freshmen were approximately 4 times less likely to have

TABLE VI. Student responses to prompts about how often they use, or how well prepared they feel to use, various career skills in physics or astronomy outreach activities. Blank entries are due to a corresponding question not being posed in the survey.

Skill	While participating				Prepared		
	Never (%)	Rarely (%)	Sometimes (%)	Most of the time (%)	Not at all (%)	Somewhat (%)	Well (%)
Verbal communication	3	14	36	46	2	36	61
Nonverbal communication	7	19	36	38	5	40	55
Storytelling	7	17	41	35	7	44	49
Team leadership	9	22	35	34	5	36	59
Event leadership	11	22	32	34	6	42	52
Design and building	9	24	34	32	...	...	...
Creativity	2	8	38	52	2	35	63
Conceptual understanding	1	10	41	49	...	...	...
Networking (other students)	1	5	37	59	1	26	73
Networking (faculty)	3	14	34	49	3	33	64
Networking (other)	6	17	30	26	9	37	54

participated in outreach compared to seniors. It is important to note which factors did not show a statistically significant difference in participation in outreach. Students who did not identify as men were no more or less likely than men to

have participated in outreach. There were also no differences observed based on race or ethnic identity, status as an international student, being a first-generation college student, or identifying as a member of the LGBTQIA+ community.

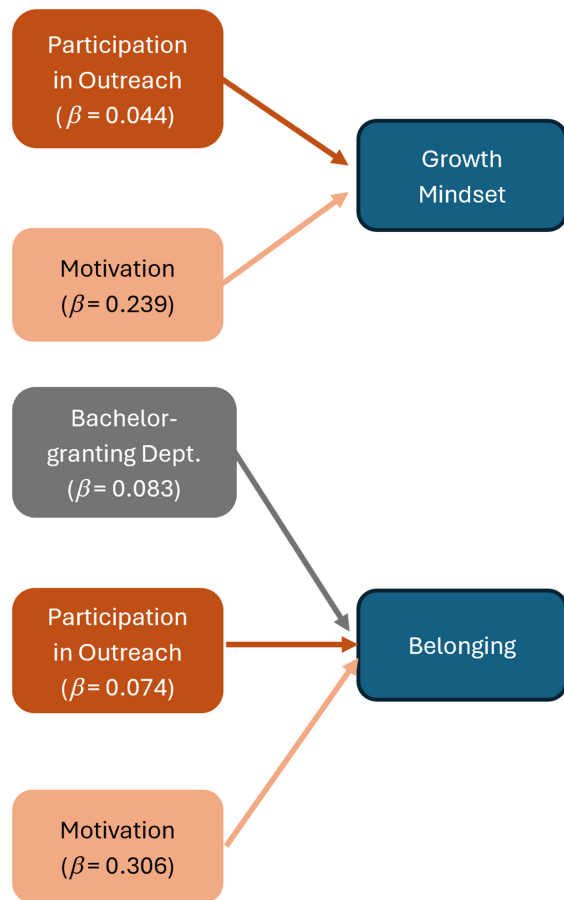


FIG. 1. Visual representation of the logistic regression models where participation in outreach was a statistically significant predictor of the outcome variable, growth mindset, and belonging. All relationships shown are significant at the $p < 0.01$ level.

2. Factors

The factors listed in Table II are known to play a vital role in students' tendencies to persist within the discipline. To robustly compare results from the national survey to prior studies, we present models exploring the factors of motivation, self-efficacy, belonging, competence, confidence, and recognition. These models drew on Eq. (2). Figure 2 presents a schematic of each regression model. Only statistically significant relationships are described in this subsection. All other tests not mentioned upheld the null hypothesis of no difference.

Growth mindset was seen to be positively predicted by motivation ($\beta = 0.239$), in addition to participation in outreach as noted above. That is, students who reported higher levels of motivation were more likely to also exhibit a greater growth mindset. Additionally, first year students were more likely to exhibit a greater growth mindset compared to students with other classifications.

Belonging was observed to be positively predicted by several factors including motivation ($\beta = 0.306$), being enrolled in a bachelor's granting department ($\beta = 0.083$), as well as participation in outreach as noted above. Students reporting higher levels of motivation were more likely to feel a greater sense of belonging in their department. Additionally, students enrolled in departments that award bachelor's degrees, but no graduate degrees, exhibited higher measures of their sense of belonging.

Self-efficacy was positively predicted by students' confidence ($\beta = 0.193$) and negatively predicted by being a junior ($\beta = -0.058$). That is, students who reported being more confident about their physics abilities also

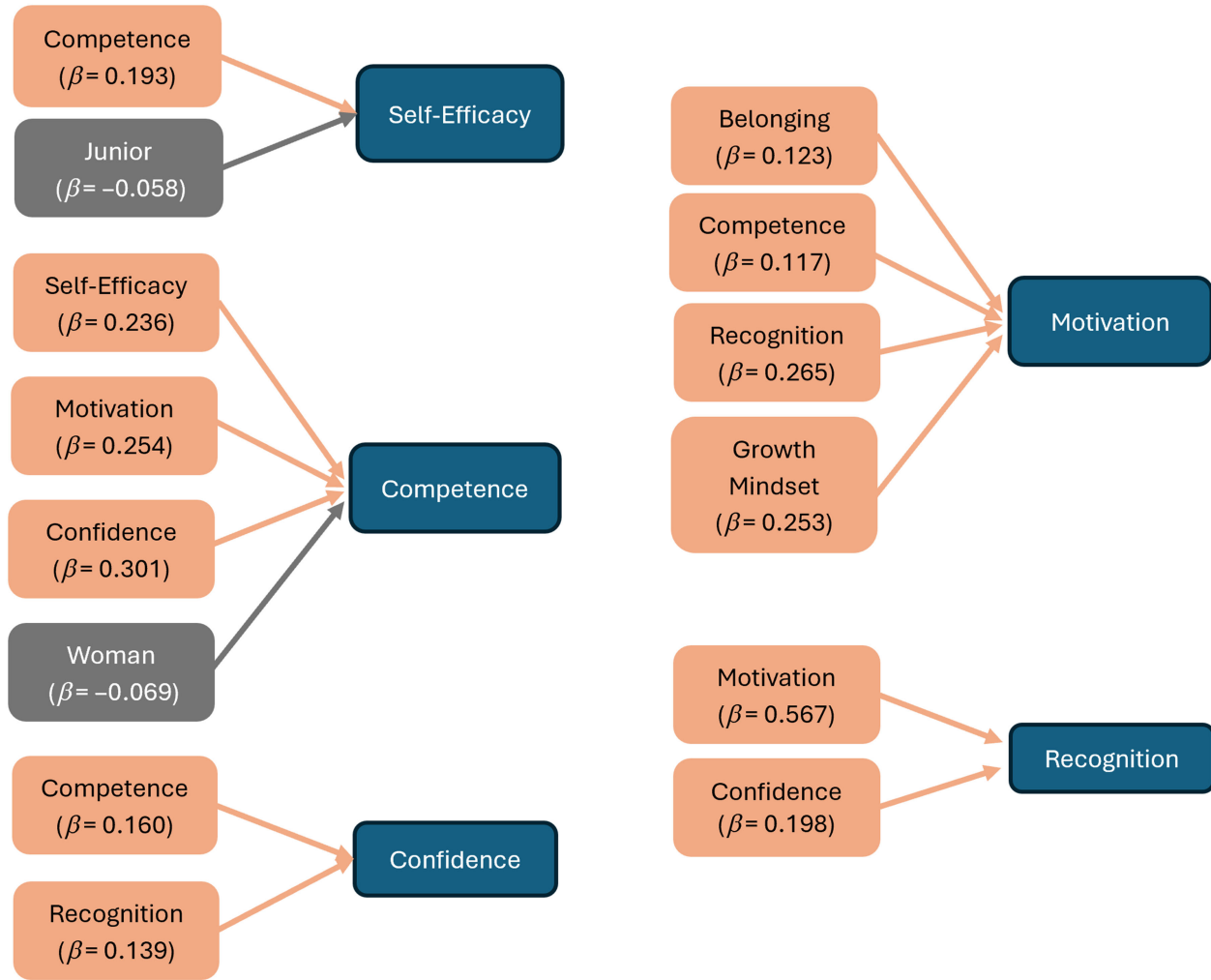


FIG. 2. Visual representation of the logistic regression models for the remaining factors at the $p < 0.01$ level. In these models, participation in outreach was not a statistically significant predictor of the outcome variables.

reported greater self-efficacy. Students classified as juniors, who comprised 29% of the dataset, reported statistically significantly lower self-efficacy compared to students in other classifications. No statistical difference was noted for other classifications. These results were independent of whether participation in outreach was included or not in the model.

Motivation was seen to be positively predicted by four other factors: recognition ($\beta = 0.265$), growth mindset ($\beta = 0.253$), belonging ($\beta = 0.123$), and competence ($\beta = 0.117$). Students who felt more recognized by themselves or others as a physicist or astronomer were more likely to report higher levels of motivation. Students exhibiting stronger signals of growth mindset were also more likely to report higher levels of motivation. Although students' perceptions of their own belonging and competence in the discipline were slightly lower predictors, as shown by their β values, they are still positively correlated with motivation. These results were identical whether participation in outreach was included or not.

Competence was observed to be positively predicted by three factors: confidence ($\beta = 0.301$), motivation ($\beta = 0.254$), and self-efficacy ($\beta = 0.236$). These relationships indicate students who felt more confident in their physics, who are more motivated in learning the subject, or who exhibited greater self-efficacy were more likely to report higher levels of their individual competence. Women's responses indicated that they felt less competent compared to men ($\beta = -0.069$). These results held whether participation in outreach was included or not.

Recognition was positively predicted by motivation ($\beta = 0.567$) and confidence ($\beta = 0.198$). Here student motivation is seen to be highly predictive of student recognition, which combines internal and external perceptions. Confidence is positively correlated with recognition, although the correlation is weaker than that with motivation. These results were independent of whether participation in outreach was included in the model.

Confidence was seen to be positively predicted by competence ($\beta = 0.160$) and recognition ($\beta = 0.139$).

Students who felt more competent in their physics knowledge and abilities or who had higher measures of internal and external recognition were more likely to perceive themselves as confident. These results were independent of whether participation in outreach was included in the model.

IV. DISCUSSION

In expanding beyond single institution studies, we have created, distributed, and analyzed a survey with a national sample of undergraduate physics students to explore the impact of informal physics outreach programs on their development. As seen in Table IV, students who engaged in outreach were more comfortable discussing disciplinary ideas with those both in and out of their field. This signifies an enhanced confidence in their knowledge and their communication of that knowledge to both physics and nonphysics audiences. This may be due, in part, to the fact that informal physics outreach programs are intrinsically active learning environments for undergraduate students beyond the formal structure of a course allowing them to refine their ideas and take ownership of their knowledge.

Results from Table VI show that informal physics outreach programs allow for the development of a broad set of essential career skills, which are not typically incorporated into traditional physics courses. Outreach programs vary in size, frequency, and focus but often rely on undergraduate student efforts to plan, setup, populate with demonstrations or activities, and of course deliver to highly varied audiences. This provides a social and unstructured landscape allowing students to take on a variety of roles and duties which lend themselves to the development of these skills beyond the formal classroom. These skills were identified as essential for 21st-century physics careers, in part through surveys of employers who hire physics bachelor's graduates [14,15]. Results are in agreement with our prior, single institution studies where students reported repeatedly about the impact of outreach on their communication, design, teamwork, leadership, and networking [16,17]. Given that physics courses are typically centered around development of understanding of physical principles, associated problem-solving skills, and lab procedures, it is no surprise to recall how rare opportunities are for students to use communication, design, and leadership skills. The data collected show that students engaging in informal physics programs perceive themselves as receiving significant opportunities to use these skills and feel very well prepared to employ them.

As this is a new survey, in discussing our results, we will split our focus into two categories. First, we will contextualize results compared to prior literature of social constructs to note similarities and differences with existing knowledge. Second, we will interpret the unique knowledge from the regression models focused on the role

of student participation in informal physics outreach programs.

When we evaluated the results of this survey, we found that there is broad similarity with the results with prior research from physics and STEM education. Physics identity can play an important role in student development and persistence within the field. Results from our regression models showed that the constructs related to physics identity, including motivation, recognition, competence, and sense of belonging, were all interrelated. For example, students reporting a higher competence score were also more likely to report a higher motivation. This means that reporting a higher measure in one construct in the model could predict a higher outcome in other constructs. The interrelatedness of these factors is similar to what has been observed in other studies of physics identity, supporting the validity of the measures from our sample [12,16,17,68].

Unsurprisingly, growth mindset and belonging were also both connected to student motivation. Studies from math and computer science have noted the strong link between a sense of belonging and student interest in continuing their major [69,70]. This link has also been noted for mindset in prior studies where interventions boosted measures of student interest and motivation in secondary science students in the United Kingdom and undergraduate computer science students in the United States [71,72]. It may be that course work alone is not enough to impart such a growth mindset, which has been observed to stagnate or decrease across introductory courses [73]. Students with a growth mindset about their discipline are more likely to persist and overcome challenges, inevitable in their physics or science careers [74,75].

Curiously, the measure of self-efficacy did not depend on gender or ethnicity. While competence was observed to be lower for women, it did not depend on ethnicity. It has often been observed in prior research that women and students from underrepresented groups in physics exhibit lower measures of these constructs across multiple studies [39,76–78]. One potential explanation for the difference noted in self-efficacy could be due to the focus of the survey itself, which was about students' general feelings toward physics without reference to a classroom context. Indeed, this phenomena has been observed broadly for STEM students in a study by Wilson *et al.* [79]. They noted that STEM self-efficacy was higher when measured generally about a discipline than for specific courses within a STEM discipline. This was especially true for women and students from underrepresented groups [79].

Importantly, student participation in outreach was positively associated with students reporting more of a growth mindset and/or a greater sense of belonging within the discipline. Although the strength of this association is modest, student engagement in informal physics outreach programs contributes to their sense of belonging within the physics community, as well as their growth mindset

providing resilience in the face of failure and belief that their physics intelligence can improve over time. This result with mindset is similar to our work in Randolph *et al.* [17] which showed that growth mindset was an important factor for the experience of women in physics at a single institution with a well-developed outreach program. Similar to mindset, students' sense of belonging can also have a significant impact on persistence within the field of physics [6]. Tests of interventions aimed to promote belonging have shown significant improvements, particularly for students from traditionally underrepresented groups in physics [2]. Those who feel like outsiders have been seen to leave physics at higher rates [80]. This again agrees with a result from our prior work in Rethman *et al.* [16] connecting student facilitation of outreach with a higher sense of belonging to the STEM community.

As the statistically significant link between participation in outreach and mindset is a novel observation not previously reported in the literature, we plan to explore this relationship in greater depth in future work. Our results indicate that students who participate in outreach exhibit strong indicators of a growth mindset. This raises the question of whether students with a higher growth mindset are more likely to engage in outreach programs. When we tested this model, growth mindset was found to be predictive of outreach participation, but only at the $p < 0.05$ level—above the threshold of significance used in this study. Future investigations will include analysis of open-ended survey responses to further examine this relationship.

Informal physics outreach programs may support the development of a growth mindset and belonging simply through their nature of being designed to provide opportunities for students to demonstrate their knowledge in low stress and fun environments. Far from the stress of homework and grades, students are able to show off their passion and knowledge of physics, often in ways that may reinforce their learning [19]. Also, outreach programs provide authentic opportunities for students to connect with fellow students, faculty, and researchers, as also noted in Rethman *et al.* [16]. These programs also provide a rich playground for students to take ownership of projects, serving as the lead on demonstrating or even creating experimental apparatus that can be shown to dozens or even thousands of members of the public. Such programs often bring together teams of students as well, fostering camaraderie and teamwork among physics students [16].

It is interesting to note that for all the demographics analyzed in the regression models, only being a first year student was seen to have a significant, negative impact on students' likelihood of participating in outreach. While discussion of null results is uncommon, Conlin *et al.* make the case that discussion of such results can be beneficial to broadening our understanding of physics education [81]. Despite the persisting gender imbalance

and underrepresentation of multiple ethnicities in physics [67], students who do not identify as men are no more or less likely to engage in outreach than men, and there are no statistically significant disparities in participation due to race or ethnicity. Though these data are insufficient to proclaim outreach as a great equalizer in engagement across demographic factors in physics, it is a positive signal that such programs appear to invite and benefit from the participation of all physics students.

V. LIMITATIONS

While results from the national survey demonstrate interesting relationships, we must note some limitations in our results. All data collected were self-reported from SPS members responding to the survey. There is also a possibility of selection bias, as the recruitment messaging stated that the survey focused on outreach, although it was carefully worded to invite all participants. Further, due to the nature of hypothesis testing, there is potential that a small portion of the statistically significant (or not) results may be due to Type 1 (rejecting a true null hypothesis) or Type 2 (failing to reject a null hypothesis) errors. This may also be influenced by sparsely populated demographic categories in the sample. The purely quantitative nature of the results presented here lacks nuance as to the experiences of students engaging in informal physics outreach programs. This will be the focus of a subsequent paper analyzing responses to the open-ended questions included in the survey.

VI. CONCLUSION

This work reports on the development, distribution, and analysis of the first national survey of the impacts of student participation in informal physics outreach programs. Drawing on our expertise, we developed a survey to measure constructs of physics identity, sense of belonging, and mindset, which was distributed to the national SPS network of more than 5500 students and received 704 responses. Students who engaged in outreach programs reported being more comfortable explaining ideas from physics or astronomy to others both in and out of the discipline. A majority of participating students reported using essential career skills such as communication, networking, design, and leadership during informal physics outreach programs and feeling prepared to use them. Students who participated were also slightly more likely to see outreach events being offered regularly from their departments, potentially due to their engagement generating more awareness.

Results from the survey broadly mirror prior studies on physics identity and offer new knowledge about the potential benefits of outreach programs on university student development. These results provide important insights into how constructs that can be highly impactful to the student experience are related to student participation

in informal physics outreach programs, which are run by many departments throughout the United States. In particular, participation in outreach was observed to be positively linked with students reporting a higher growth mindset and a greater sense of belonging. These results can potentially serve as a helpful justification for departments looking to develop, expand, or implement informal physics outreach programs, which do not necessarily have high capital costs to improve their student outcomes without changing their curricula. Such changes may be highly equitable across all student demographics, as only being a first year student was negatively associated with the likelihood to participate in outreach programs. No differences were observed based on gender or ethnicity. These departmental efforts could be particularly impactful when combined with guidance from the Effective Practices for Physics Programs project, which provides specific recommendations for programmatic changes supporting community engagement [82].

Within this work, we have presented quantitative results from the national survey, without reference to responses to open-ended questions. Analysis of the open-ended questions will be the focus of a subsequent study, which will provide essential nuance to contextualize the reported impacts of informal physics outreach programs on the students who facilitate them.

ACKNOWLEDGMENTS

This work was supported by NSF Grant No. IUSE 2214493. We would like to thank Brad Conrad for his assistance in distributing the survey.

DATA AVAILABILITY

The data are not publicly available. The data are available from the authors upon reasonable request.

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