Exploring Impacts of Outreach on a National Sample of Undergraduate Physics Students

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Physics departments frequently run informal physics outreach programs, often to the delight of their local populations. The programs are typically run as part of the mission of these departments, or as part of establishing broader impacts from their research efforts. While the impact to audiences has long been an important area of focus, more recent research into informal physics outreach programs has shown that the students who help to run these programs tend to experience improved physics identity and develop career skills vital for the 21st century. Prior work, however, has been limited to a small number of institutions with modest numbers of facilitators in their studies. This has left a clear gap in the literature examining a broader population of undergraduate physics students from varied institutions across the country. Therefore, we developed a survey and distributed it through the national network of the Society of Physics Students. The goal of this survey was to measure students' perceptions of their physics identity, sense of belonging, students' mindset, and related constructs, as well as collect information about how often they helped to run informal physics outreach programs. Here, we describe the construction, distribution, and analysis of the survey with attention to both closed questions and open ended questions. Preliminary results from regression models show significant positive relationships between participating in outreach programs with measures of students' physics identity and growth mindset. Findings from open ended questions show significant, interrelated themes highlighting the multifaceted impacts of outreach on areas including students' resilience, internal perceptions, transformative experiences, and disciplinary development.

2024 PERC Proceedings edited by Ryan, Pawl, and Zwolak; Peer-reviewed, doi.org/10.1119/perc.2024.pr.Perry

I. INTRODUCTION

It is well known that students' disciplinary identity and sense of belonging can be important factors in students' resilience within their major and potentially help with the retention efforts [1–3]. The development of students' motivational beliefs, self-efficacy, recognition, and "real-world" experience are considered important factors in students' persistence in, or attrition from, physics and other STEM fields. Thus, developing these factors has the potential to increase retention rates for students, especially among underrepresented minority populations [4–17]. Understandably, most research to improve STEM students' college experience is concerned with the formal classroom or lab environment. However, there are a growing number of studies that report on the potential positive impact of extracurricular programs such as outreach, also called public engagement or informal programs, that university students facilitate. Physics outreach programs are less structured, provide more flexibility with implementation and students ownership, do not require changes in the curriculum, and can potentially enhance students' experiences.

Recent research shows that through the facilitation of physics outreach programs, students improve their communication skills, design, and presentation skills, and they get an opportunity to work in teams; all of which help prepare students for their 21st-century careers [4, 18–21]. Students reported the development of a physics identity, improved networking within the department and a broader STEM community, and their feeling of being valued and accepted as a result of their facilitation of physics outreach programs [4, 18, 19, 22, 23].

Prior studies on student experiences through facilitation of physics outreach programs were limited to very few types of programs and institutions. This research presents the results of the first nationwide survey of the undergraduate students' experience in informal physics outreach programs. Based on our pilot study survey [18], we have created a new survey instrument with closed and open-ended questions distributed through a national network to maximize responses from undergraduate physics students. The goal was to create a large dataset allowing for an broad examination of how outreach programs support undergraduate student populations. This paper presents an initial step in the data analysis. We address the following research questions: (1) Does the facilitation of physics outreach programs relate to students' physics identity, mindset, and self-efficacy for a national sample of undergraduate students? (2) Do physics outreach programs provide students with opportunities for transformative and memorable experiences, such as changing perceptions about themselves and utilizing their physics expertise in real-world settings?

II. METHODS

A new survey was developed, based on themes evident from our pilot studies at a single institution [18, 19, 22, 23], to collect students' perceptions on their physics identity, self-efficacy, growth/fixed mindset, confidence, and sense of ability to use essential non-disciplinary career skills. The survey also sampled students on their frequency and reasons for engaging in outreach, as well as their perceptions of departmental support for such programs. Students who identified as participating in outreach received three open ended questions. To gather a national sample of undergraduate physics students, the survey was distributed through the Society of Physics Students (SPS). Initially, the survey was sent to students from three institutions, with reminders encouraging participation sent over three weeks. A total of 101 responses were gathered during this pilot survey. The survey was robust. A minor wording change was made to a single item, out of 61 items. The survey was then sent to the remaining of 5,500 email contacts from SPS, with periodic encouragement to complete the survey sent over a six week period. A total of 704 responses were received.

To explore relationships between variables related to closed questions, we assumed a null hypothesis of no relationship between variables and employed multivariate regression models to test these hypotheses. Three different multivariate analysis tools were used based on the dependent variable for each model. Where the dependent variable was binary (yes/no), we employed logistic regression. Where the dependent variable was a Likert scale, we used ordinal logistic regression. Where the dependent variable was numeric, we used ordinary least squares regression. We incorporated a mixed-methods analysis of responses to open-ended questions to draw out the nuances which may elucidate reasons why certain variables are, or are not, significantly related. Prior to analysis a code book was developed combining elements from multiple prior studies.

Data collected from the 704 individual responses were anonymized by researchers and staff from the American Institute of Physics's Statistical Research. Demographic information was solicited from each respondent and then categorized when appropriate. For instance, respondents were asked their age (A) and then categorized as a binary for being traditional aged (<24) or non-traditional aged ($\geq$ 24). Institution types (IT) were binned by highest awarded physics degree (Ph.D., Master's, or Bachelor's). Respondents were also asked to self-identify their gender(G) (man, woman, another identity), classification(CL) (freshman, sophomore, junior, or senior), parents level of education (PE), race/ethnicity (R/E), identification as a member of the LGBTQIA+ community or not (LGBT), and involvement in outreach (O). Each respondent could be non-responsive to these questions. Several constructs, including physics self-efficacy (SE), physics identity (PI), competence (C), and mindset (M), related to multiple Likert scale items and composite scores were generated based on the total numerical score for all items assuming a positive orientation of the scale. For categorical variables with more than two categories, we compared to a reference group only as there is no pair-wise comparison possible for every combination. The reference group, based on the dominant responses across each category, was taken to be white, a man, a senior, having at least one parent with a bachelor's degree, and attending a doctoral granting institution.

Respondents who indicated that they had participated in informal physics outreach programs received prompts for three open response questions: (1) What has been your most memorable experience from participating in physics/astronomy outreach? (2) How has participating in outreach provided you with opportunities to utilize your physics/astronomy knowledge in a real-world setting? (3) How has your perception of yourself as a physicist changed through your participation in physics/astronomy outreach?

Respondents were allowed to answer or skip each item. To analyze and characterize students self-reported experiences, we employed a deductive coding process based on multiple theories and themes emergent from our prior studies [18, 19]. These included a framework for physics identity described by Hazari et al. [24], the Dynamic Systems Model of Role Identity (DSMRI) [25], situated learning theory, transformative learning theory, essential non-disciplinary skills relevant to 21st century physics careers [20], and outcomes related to career trajectories.

A total of 43 codes were employed in this work, organized into six categories. These included *Identity*, *Community*, *Affect and Experience*, *Disciplinary Skills*, *Non-disciplinary Skills*, and *Outcomes*. The category of *Identity* incorporated both Hazari et al. [24] physics identity framework (interest/motivation, internal and external recognition, performance and competence beliefs) and elements from DSMRI (curiosity, worldview, legitimate peripheral participation, and confidence). *Community* consisted of sense of belonging (also from Hazari et al. physics identity framework), connections with peers and audience, accountability at four different levels (role based, outreach leadership, discipline or scientific community, general public), and impacts from authentic interactions with audience members. *Affect and Experience* had codes of seeing new perspectives, transformational experiences and changing assumptions, excitement in facilitators or audience, being uplifted and empowered, desire to persist in the field or major, and feelings of authentic purpose or impact from the programs. *Disciplinary Skills* incorporated technical or mathematical skills, conceptual understanding, developing a sense of real world connections, and design. *Non-disciplinary Skills* consisted of creativity and innovation, teamwork and leadership, networking, communication with peers and audience, as well as teaching skills related to scaffolding and zone of proximal development. *Outcomes* included codes related to student trajectories towards an academic path, a non-academic path, or a teaching path. If students responding to open response questions, detailed above, about impacts of outreach mentioned unrelated activities (e.g. a summer research experience), it was not coded as an impact related to outreach.

Open ended responses were gathered from 239 surveys, with the majority of respondents giving non-trivial answers to all three questions. Three researchers coded all of the responses, working in two teams. To ensure consistent coding, subsets of 12 surveys were coded in three rounds, with researchers meeting to compare and resolve differences after each round. At the end of the coding process the interrater reliability was $\kappa = 0.90$. Codes were then combined into a single file for analysis.

To examine significant relationships between codes and elicit central themes to student experiences through outreach, we employed a network analysis with clustering, a valuable tool for investigating complex relationships between different fundamental units (e.g. people, ideas, codes) [26, 27]. After each survey was coded, a matrix of Pearson's correlation coefficients was calculated using MaxQDA Analytics Pro, where pairs of codes are examined for where they do, and do not, appear together in the text of each document across the dataset. For this work only correlations with a significance level of $p < 0.001$ were examined. The matrix of correlations is used as input to create a 1-mode network using the UCINET software [28] generating a visual representation of significant relationships (edges) between nodes (codes). Eigenvector centrality, accounting for the strength and number of significant correlations, was used to size the nodes, with larger nodes having higher centrality [29]. To reduce the map to core themes, a Girvan-Newman clustering algorithm [30], robust for Q values above 0.30 [31], was employed.

III. RESULTS

A. Regression on closed-response questions

To determine if participating in outreach contributed to students' self-efficacy, physics identity, growth mindset, or competence scores, four ordinary least squares regressions were run with the model:

$$\text{Score} = f(A + G + IT + CL + PE + RE + LGBT + O). \quad (1)$$

Results indicate that participating in outreach is positively related to a student's physics identity ($p < 0.001$), growth mindset ($p < 0.001$), and competence ($p < 0.05$). No significant relationship was detected between participation in outreach and self-efficacy. Some other factors were found to be significantly related to these scores, but a full treatment of these relationships is beyond the scope of this short paper.

B. Network analysis on open-response questions

Results of a network analysis at the $p < 0.001$ level are shown in Fig. 1. Using a Girvan-Newman clustering algorithm, codes were grouped into six distinct clusters of interrelated ideas with $Q = 0.476$. Each of the clusters was given a name which represented the core theme of the related ideas.

While a full treatment of the clusters is beyond the scope of this short paper, we briefly summarize and highlight major ideas from each cluster below.

The cluster represented by the green hourglass shapes was termed *resilience* as it related themes of confidence, belonging and desire to persist in the major with being empowered through engaging in outreach activities. Students reported that working in outreach helped to reinforce their sense of being a part of the physics community and validating their choice of major, or even their potential to succeed in the future. One student drew a particular contrast with classes sharing "even though my classes are difficult, which can be discouraging, I am reminded [through outreach of] how far I have come in my understanding of physics/astronomy...."

The cluster of pink triangles was termed *internal perceptions*, as codes within this cluster are primarily about shifts in students' internal beliefs, in particular their internal recognition of themselves as a physics person, their performance and competence beliefs, and legitimate peripheral participation, or shifts from being novice to more expert. Students mentioned they felt more confident, or being a more "legit" physicist after facilitating outreach programs. Outreach also provided students with opportunities for transformational experience. In the words of one student outreach both "made [them] love physics and astronomy that much more" while also making them "realize how more accessible the field needs to be to others who are interested in the fields."

The cluster comprised of dark red inverted triangles was termed *transformation*, comprising codes centered on changes of beliefs and perceptions mixed with interest, motivation, excitement and curiosity, as well as students' broader worldview. When reflecting on the opportunities gained through outreach, one student shared their view that "Socrates got it right when it came to asking a question with another question. Communication is a skill that we scientist[s] need in order to show others what we learn to better the future." This demonstrates a shift in student perspectives about the role or importance of communication in a scientist's skill set. For another student, outreach helped broaden their views of their own abilities, specifically sharing that they "see [themselves] as someone who is fitter for educating others, rather than solely doing research."

The cluster of blue squares was termed *audience dialog* due to the abundance of codes related directly to facets of engagement between student facilitators and members of the general public. Through authentic and unstructured dialog with audiences, students were frequently able to refine and improve their communication skills, and work to scaffold or negotiate meaning with audiences to effectively share their scientific understanding. Other central ideas within this cluster arise from the importance of the authenticity of these unstructured interactions and the valuable external recognition or uplifting feelings those interactions contributed for student facilitators. This is well represented by one student who shared their most memorable experience as "working with children and high-school aged students. I find it especially rewarding to mentor high-school aged girls, as that is what had the largest impact on me and it feels good to give that feeling to others. The most memorable is when I had a high-school girl who hadn't been interested in physics prior to the outreach activity we did, but then shared afterwards how interest[ed] it made her in physics."

The cluster comprised of black squares was termed *disciplinary development*. Codes within this cluster are related primarily to constructionist impacts through creation activities and enhanced physics knowledge. As one student put it "the demonstrations required us to see how feasible and practical the theoretical knowledge actually is." While not all facilitators engage in the design process of creating new demonstrations, some do, and many gain from this process in deepening their understanding of specific physics topics while being able to develop their skills of creativity in bringing demonstrations to life to share with audiences.

Our final cluster, made of the red circles was termed *disciplinary connectedness*. This small cluster focuses on student experiences connecting and communicating with others in their home departments. While some of the reported effects may be transient, such as one student's memorable experience being "rebuilding my department's community post-COVID", other students spoke more broadly about their new connections through outreach. One student encapsulated these connections sharing that they "feel better involved with [their] major" while another shared their most memorable experience being the "relationships [they've] built with other participants" from their department. Outreach provides significant opportunities for students to make authentic connections with their classmates, with students from other years in their majors, with faculty, and potentially with graduate students and post-docs depending on their institution types.

IV. DISCUSSION & CONCLUSIONS

This work, drawing on a national sample of undergraduate physics students, allowed us to examine the impact of facilitating informal physics outreach programs beyond single institutions with well-developed programs. Drawing on our expertise, we created a survey to measure a series of constructs identified as central to students' outreach experiences [18, 19] and applied appropriate regression models to assess relationships. Results show that students who engage in outreach are more likely to report higher measures of physics identity, growth mindset, and competence. No such relationship was observed for self-efficacy. As the regression models may not account for causation of the relationships we see two potential explanations: (1) that students with strong physics identity, etc. are more likely to choose to participate in outreach events, or (2) that students who participate in outreach events develop strong physics identity, mindset, and competence. Drawing on responses to open ended questions, we favor the second explanation as outreach fosters an environment for growth and change for students in ways that a formal

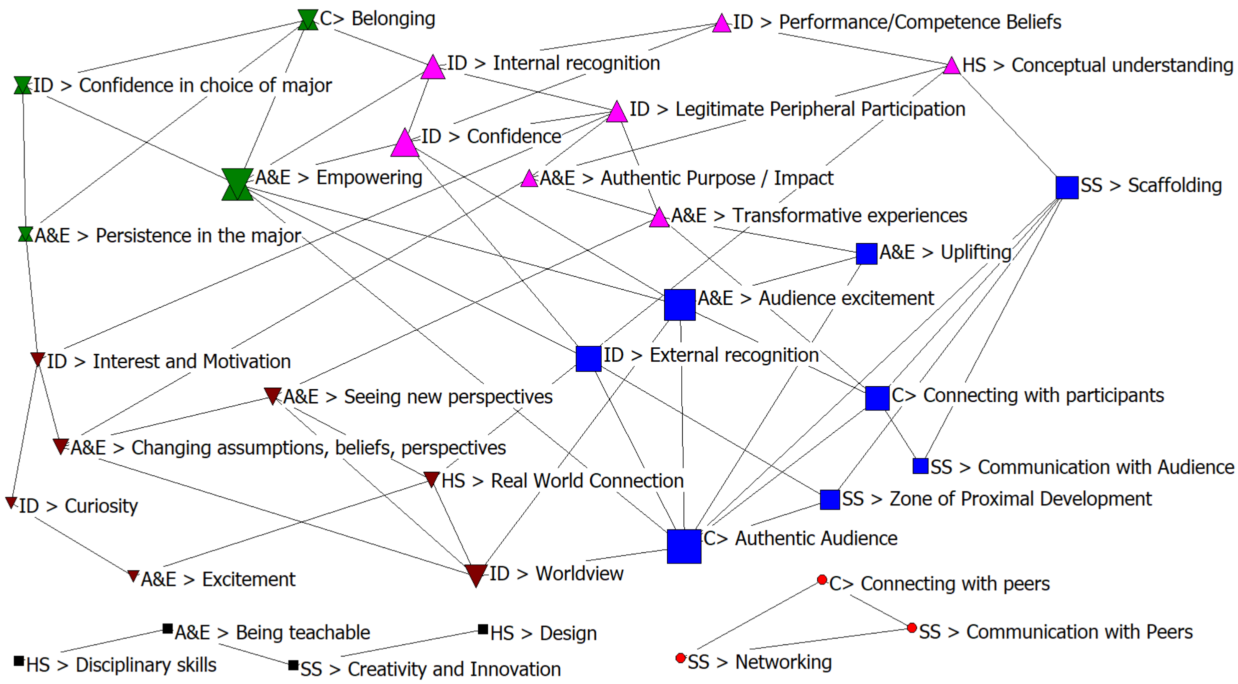

FIG. 1. Network map of relationships between codes employed in this study at the $p < 0.001$ level. The size of the nodes indicate their Eigenvector centrality. Colors and shapes of the nodes denote distinct clusters, $Q = 0.478$, of statistically interconnected ideas representing more closely related themes as determined by a Girvan-Newman clustering analysis. The labels represent soft skills (SS), hard skills (HS), affect and experience (A&E), community (C), and identity (ID).

classroom may not.

Results from a network analysis and clustering algorithm showed student experiences included a significant theme of resilience. That is, working through outreach made them more confident in their choice of major and developed a desire to complete their degrees, similar to a study of women's experiences through outreach [19]. This mirrors results from research in both high schools and college which link development of disciplinary identity with student choices of pursuing STEM majors [3, 9]. Further, due to authentic experiences resulting from the more unstructured nature of outreach, students gain opportunities for transformative experiences, evolving their beliefs and perspectives about themselves and their chosen discipline, often supported heavily through interactions with, and teaching, their audiences. Facilitators of outreach also were able to both grow their disciplinary knowledge and advance their internal perceptions of themselves as physicists. Through explaining physics to others, students may not only gain more motivation to learn physics deeply [32], they also can refine their understanding of the material [33], and enhance their physics identity [4, 18, 19, 21].

Results from this national sample mirror, and appear to confirm, results from our pilot studies [18, 19, 23] that participation in outreach has a strong relationship and impact of students' physics identity, mindset, resilience, and development of essential career skills. Statistical analysis of closed survey questions showed statistically significant and positive relationships between participating in outreach with having a growth mindset, a strong physics identity, and higher sense of competence in the discipline. Student experiences, captured through open ended questions, were found to be grouped in a small but varied set of clusters, most notably themes surrounding resilience, internal perceptions, disciplinary development, and transformation. While this is a promising result, we do note some limitations in interpreting the results, including that some demographic categories were sparsely populated, potentially leading to false negatives in the models. Further, the responses to the open ended questions were brief, not allowing for the full nuance of students' experiences to come to light. Future work will focus on developing a broader dataset and soliciting more in depth student experiences, including those underrepresented in physics, to help more fully describe the impacts of engaging in outreach.

V. ACKNOWLEDGEMENTS

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

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