Towards mapping the landscape of informal physics educational activities

Dena Izadi,[1,*] Julia Willison,[2] Noah Finkelstein,[3] Claudia Fracchiolla,[4] and Kathleen Hinko[1,5]

[1]*Department of Physics and Astronomy, Michigan State University, 567 Wilson Road, East Lansing, Michigan 48824, USA*
[2]*Department of Physics, University of Central Florida, Orlando, Florida, 32816, USA*
[3]*Department of Physics, University of Colorado Boulder, Boulder, Colorado 80309, USA*
[4]*American Physical Society, 1 Physics Ellipse, College Park, MD 20740, USA*
[5]*Lyman Briggs College, Michigan State University, 517 E Holmes Road, East Lansing, Michigan 48824, USA*

(Received 3 January 2021; revised 19 August 2022; accepted 22 September 2022; published 13 December 2022)

Informal physics programs bring physicists together with youth and adults from local communities to engage with physics content outside of classroom settings. These public engagement or "physics outreach" programs are a significant endeavor of the physics community; however, we lack a systemic documentation of these efforts, which makes it difficult to situate physics education research on individual informal physics programs into a broader narrative. Additionally, informal physics programs have many formats and vary in terms of their audience, content, activities, and resources. It is important to understand these aspects of programs if we want them to be more equitable and inclusive. This work shows our early steps of a large project aiming to map the landscape of informal physics programs in the United States. Drawing from organizational theory, and using data collected from a national sample of programs, we have created and validated a survey for lead facilitators to capture the who, what, where, when, and why for their informal programs. After validation, we completed targeted data collection within one state as a test case for broader implementation. Our analysis of the sample ($n = 18$ programs at 6 institutions) shows that there are many different factors other than common presentation-style labels that are relevant, such as geographic reach, audience demographics, funding, and involvement of physics students. One notable finding is that university physics students play a big role in the operation of these programs, making them rich environments for the attention of physics education researchers and administrators at academic institutions.

DOI: 10.1103/PhysRevPhysEducRes.18.020145

I. INTRODUCTION

A. Motivation

Our understanding of how people learn physics comes largely from research conducted in the context of classrooms and "formal" physics courses. Much of this research considers physics learning to happen at the high school, college, or graduate level [1]. However, most of our time as humans is spent outside the classroom [2]. Learning that occurs outside of the confines of classroom structures is referred to as "informal," "nonformal," or "free-choice" learning [3–5]. For example, people may personally engage in informal learning by reading a popularized book about physics, attending a talk about physics for the public, or visiting a museum with exhibits about physics. Informal learning is different from formal learning because it is encouraged by our culture rather than required by law. It is also low or no stakes in terms of evaluation (i.e., there are no grades), with activities that are often learner determined with high levels of agency for learners [2]. Formal and informal learning environments overlap and lead into each other—for example, watching a television show about physics might make you interested in becoming a physics major, and taking a physics class might spur you to look more deeply into certain topics on your own time. Often physicists refer to informal physics activities that they themselves facilitate as "physics outreach," although more recently members of the community have been adopting less deficit-oriented language by using the term "public engagement" [6].

Researchers in the fields of science education, informal science education, museum studies, and science communication have developed large bodies of literature on understanding informal learning contexts [2,7]. We argue that there is a need to consider informal environments from a discipline-based perspective, in the same way that we recognize the value in studying discipline-based formal

*izadiden@msu.edu

education [8,9]. For the field of physics, this approach seems especially constructive, since physicists and physics students have a long history of creating environments and activities that support individuals in learning physics outside of the classroom [6]. In fact, public engagement physics efforts are the primary way that individuals in society, who are not actively taking a physics course, encounter physicists outside of their acquaintances and family members.

Some ways that university and laboratory-based physicists approach engagement are to give lectures to the public, engage with youth in afterschool programs and summer camps, develop open houses and physics festivals, write books connecting physics to aspects of popular culture, consult on TV shows and museum exhibits, create websites and hands-on activities, and perform demonstrations shows. This incomplete list of common formats of public physics engagement activities demonstrates the huge variety and breadth of parameters that matter for informal physics learning contexts—including variables such as program goals, audiences, facilitators, geographic location, physics content, and interactivity. The complexity and wide-ranging approaches of informal physics environments stand in contrast to the comparative homogeneity of formal classrooms. For example, in an introductory high school or college-level physics classroom, students are more likely to fall into a relatively similar age range and have similar backgrounds from previous formal learning (such as prerequisite classes or material learned at earlier points in the semester). In these learning environments, students are likely to be engaging in the same activity, are compelled to be in the classroom for specific periods of time, and are constrained by certain formal learning parameters, like due dates and grades.

In this way, the nature of informal physics makes it fascinating from a research perspective for gaining new insight into how physics can be taught and learned. Informal learning environments are free from many of the structures of formal learning, such as adhering to specific content or standards, or evaluating learners with grades or high stakes testing. These contexts often provide the ability for learners to make choices on their own or engage with friends. In terms of learning design, informal physics activities have the capacity to draw from other disciplines, and the opportunity to make design choices centered around creating moments of joy. For all these reasons, informal physics contexts provide fertile ground for research into learners' conceptual understanding of physics, the role of developing positive affect, the nature of physics identity, creativity in physics, as well as opportunities for innovative design-based research.

However, one key issue facing anyone engaging in either research or design of informal physics environments is that there is not a clear way to situate one's work within a broader understanding of informal physics efforts. Based on our experiences with physics departments in universities in the United States, it is likely that a statement of the following is true: many, if not most, physics departments do some sort of outreach to the public, and national physics labs and centers have robust public engagement efforts. However, this level of description is vague and not sufficient to give a picture of the total national effort by physicists to engage with the public. Currently, there is no national database for tracking information on physics outreach programs. Available information about individual programs and events varies in accuracy and can be difficult to find [10,11]. This lack of information also prevents informal physics practitioners and researchers from being able to leverage support from their institutions, situate themselves within the scope of others' work, or to connect with people doing similar work in their geographic location or with respect to the type of public engagement work they do. It also means that we do not know which audiences are being supported, if there are gaps with key demographics, or if physicists are connecting with some groups more often than others.

This lack of understanding is an issue of equity—currently, both researchers and practitioners are not informed by knowledge of others' efforts, and thus their decisions about program content, format, and goals may inherently support the unknown *status quo* [12]. Certain groups might be oversupported or undersupported with access to informal physics learning opportunities, while certain physicists and physics students might be overburdened or under-burdened with public engagement duties [13–15]. If there was more clear information of what exists and how it is working, then practitioners, administrators, and funding agencies could make better informed decisions of where and how to apply resources to make programs more inclusive and accessible [16]. We cannot uproot issues of systemic oppression that may exist in informal physics spaces if we do not have a clearer understanding of how these programs operate and the systems that create, support, and implement them.

An important note is that the data in this paper were collected prior to the COVID-19 pandemic in the United States; however, we argue that this work presents a picture of informal physics that is crucial to understand at this turbulent point in history. The COVID-19 pandemic is having a profound effect on all aspects of society, and has clearly disrupted public engagement efforts, including in physics. Engaging the public in informal physics activities while gatherings are threats to public health has made both running and studying informal education very difficult [17]. As a society, we recognize the need for formal education and have worked to adapt during these unprecedented times, for example, to online teaching, to address the needs of the students. Informal activities that have been running prior to COVID-19 pandemic may have a harder time adapting as budget cuts, personnel loss, and venue closure threaten their existence. The lack of a research-based understanding of the size and scope of informal physics efforts negatively affects our ability to support these programs and the people who benefit from them [18].

B. Goals of this paper

This paper is a first step in a broader research agenda that searches for answers to the following question: Can we determine a map of the landscape of public engagement and outreach efforts that physicists and physics students facilitate? In this initial study, we take two critical steps towards achieving an understanding of the role and breadth of informal physics: (i) We develop a framework and a methodology that will allow us to understand the landscape of informal physics across the United States. Data collection tools have been designed using a broad national dataset of informal physics programs. (ii) We also then apply the framework and methods to a specific sample of informal physics programs and report on the size and scope of these data. From this work, we are able to determine the effectiveness of the methodology and framework, as well as the challenges to scale the analysis to a national level.

To develop an appropriate framework, we need to consider not only how to collect information about informal physics programs, but also how to determine which aspects of programming are important for the programs to operate. We also need to consider how to organize the details of these efforts in a way that is useful for researchers and practitioners. A useful map of the landscape of informal physics should include a wide number of variables that define these efforts beyond their content delivery format (such as "demo show" and "summer camp"). Thus, to build a framework for informal physics contexts, we draw from existing business literature about how organizations, especially nonprofits, function. Organizational theories have helped us identify variables important to the functionality of informal programs, such as audience and personnel, as well as the connections between variables, to build a more robust picture of these learning contexts.

Here, we describe the operationalization of this framework to understand the nature of informal physics activities [19,20]. We collected data from programs and activities that are led by the physics departments, physics faculty members, physics graduate and undergraduate students, department staff members and programs with content centered around physics or astronomy topics. Using this framework, we developed survey and interview tools to collect information about informal physics programs from the leaders of such efforts. Next, we describe the process we developed to gather information about these activities through surveys and interviews with leaders in informal physics education. The development of our data collection methodology was done with a national cross section of programs and study subjects.

To determine the effectiveness of our framework and methodology, we tested them on a sample of informal physics programs. For this testing phase of our study, it was important to not solely focus on more established, more resourced, or well-known programs, such as programs that present at national conferences. This type of study design might exclude many student-run programs, programs with limited resources, or newer programs, and so would not necessarily be an accurate representation of the existing landscape. Our methods needed to comprehensively and systematically probe the landscape of informal physics programs—and thus we report on our investigation of a defined geographic region: a single state. This step is critical prior to attempting a larger scale map of the entire U.S. landscape, as such an effort will be heavily resource intensive. Michigan has a large number and variety of colleges and universities as well as national physics facilities, and it has large rural and urban populations with varying demographic diversity. Additionally, the majority of the research team is situated in this state, which allowed us to leverage our connections to practitioners. In this paper, we discuss the results from applying our framework and methodology to Michigan as part of the broader informal physics landscape and consider the implications for going forward on this project.

II. BACKGROUND

The varied nature of informal education activities makes it difficult to conduct a thorough and precise documentation of these efforts. However, there have already been some efforts to do so, both in physics and in the science education and informal education spheres. Here, we describe several previously implemented surveys and research studies that provide relevant context to our goal of mapping the landscape of informal physics activities on a broad scale.

In 2015, a short survey was conducted by the American Physical Society's (APS) Forum on Outreach and Engaging the Public (FOEP) [10]. This survey was composed of ten multiple choice questions asking about the nature of one's involvement in informal physics programs, one box for the member's email address, and another box for additional comments. One of the survey questions asked respondents to select options from 20 predetermined categories of types of outreach. Some examples of the categories were guided tours, open houses, science festivals, classroom presentations, and podcasts. The survey was sent to the listserv of the 1525 FOEP members database as well as advertised in the FOEP newsletter, and 343 responses were collected. Of these 64% of participants or respondents held senior positions (faculty, staff, etc.) with the remaining being students and postdocs. The most prevalent categories were public talks and/or public demos, followed by classroom presentations, lectures, science festivals, open houses, guided tours, websites, social media (including blogs, Twitter, Facebook), summer institutes, ask-a-scientist programs, cafés, scientifique, physics slams, videos or movies, and posters [21]. This survey report provided a snapshot of some of the efforts of APS physicists; however, it did not provide details on key programmatic features for individual programs, such as audience demographics or size, funding, or university personnel involvement. It was also unclear how some respondents interpreted the predetermined categories—for example, some categories such as "public lectures" may be more self-explanatory to respondents, but for other category options such as "classroom" and "posters," both which garnered a substantial number of responses, it is unclear how respondents interpreted them. The FOEP survey shows by sheer response rate that the physics community is invested in leading informal physics efforts, it does not provide the necessary deeper understanding of what characteristics are important for programs to function. For example, the report does not specify why public talks are the predominant category compared to the other outreach activities reported, what types of encouragement or support the institutions and departments were providing to their informal activities. Similarly, it is reported that some of the activities were narrowly defined as being specifically designed for women or minorities. However, it does not provide any understanding of why this is the case and what factors can help the programs overcome this issue. In other words, the FOEP report was not built on a robust research methodology meant to gather systematic or validated information, so its findings are limited as to the systemic nature of informal physics efforts.

Turning to studies done outside of the physics community, we find more research on the scope of different types of informal science learning settings. These studies have come largely from the fields of science education and informal science education, with some from discipline-specific science, technology, engineering, and mathematics (STEM) fields. Here we describe several studies that are useful to draw on for a research methodology relevant to informal physics efforts:

The mapping out-of-school-time science (MOST) report to the Noyce Foundation [22] is a study detailing characteristics of out-of-school STEM programs for middle- and high school-aged youth. This 2011 study uses a mixed-method technique with interviews of program facilitators, program documents, website information, and a questionnaire with basic information on programs. The MOST report ($n = 350$) includes after school offerings, multiweek camps, science-related work programs, and weekend workshop series that have been established for more than one calendar year. The study did not include independent activities such as essay competitions, science fairs, one-on-one mentorship programs, or tutoring. Respondents self-defined their programs as science focused, science rich, or being centered around science or STEM. They employed snowball sampling as a technique to increase their number of subjects, asking each participant to recommend additional participants, resulting in several hundred usable survey responses. Important themes emerging from the collected information included program structure, youth audience, program content, program desired outcomes, and cultural relevance.

A more recent study in the European context is SySTEM 2020 [23], a project funded by the Horizon 2020 European Research Council to map out science public engagement initiatives. The focus of this study is gaining a better understanding of the types and kinds of programs in operation in Europe. SySTEM 2020 is coordinated by the Science Gallery Dublin and maps the efforts that encourage learning beyond the classroom across 19 countries [23]. This study looked at learning ecologies, educational approaches that focus on science, technology, engineering, the arts and mathematics (STEAM), using large-scale quantitative data collection through questionnaires [24,25] and created an interactive data visualization (a map) through which the reader can explore organizations and STEAM activities across Europe. This map so far has grouped the existing programs across a number of different dimensions including geographical location and country of origin, sources of income, if they collaborate with formal education, and topics combined with STEAM.

There have also been a number of large national studies that focus more on the evaluation of informal STEM programs; while we are not focused in this paper on outcomes for audiences, we briefly mention these studies as they have large numbers of informal science program participants, and thus demonstrate a methodology relevant to our project. In 2005, a study was done by The Center for Informal Learning and Schools (CILS) [26] to better understand how informal science institutions can effectively inspire and reinforce science learning for school children. This study identified systemic and institutional structures that strengthen science in school and after-school programs; it surveyed 500 informal science institutions from across the country, including zoos, arboreta, and natural history museums. In 2016, National Academies published a report on chemistry informal science education efforts [27,28], which summarizes at the time practices for communicating chemistry to the public. This report described various categories of content reflected by practicing chemists. In another 2017 study of chemistry outreach activities, the authors collected survey data from college students and faculty or staff members involved with collegiate chapters of the American Chemical Society (127 students) and Alpha Chi Sigma (65 students) [28]. The focus of this study was characterizing expected outcomes of outreach events, the types of activities and chemistry content widely practiced, and how outreach practitioners evaluate the success of events.

The aforementioned studies paint a picture for us about what we know and what we need to know to better understand how informal physics programs and activities function. While these studies provide an initial overview of the rich landscape of informal programming, the reporting has often been about programs with larger reach and visibility and/or connections. This leaves aside a large number of initiatives that are less visible (i.e., they are less funded, managed by students or small local communities), therefore hindering our understanding of the ways in which the public can engage with physics in their local area. This research project seeks to draw from the methods of the informal STEM education studies described above and apply them in understanding the informal learning landscape of physics particularly. Additionally, a common motivation of the studies described above is the need for knowledge of the informal learning landscape so as to provide guidance for policy makers and administrators about investments of resources. In the same way, we seek to connect our research outcomes with both informal physics practitioners and those in positions of power and authority within our physics institutions.

A. Constraints on this study

The findings from the studies mentioned above span an array of informal education activities. What they do not show is a common language and scope around different activities that the scientists can agree on. For example in the FOEP survey, which was directed at professional physicists who are APS members, participants were asked what "outreach activities" they did, and one category was "classroom presentations." This language and meaning are different from that used in the SysTEM 2020 report where potentially deficit language like outreach has been replaced with "public engagement," or the MOST report which considers only "out of school" activities.

In consideration of the different ways that practitioners approach these educational experiences, we need a way to determine what to "count" as an informal physics activity, as well as how to communicate it consistently with practitioners. To address this issue, we have found the Michigan public engagement framework developed by Aurbach at the University of Michigan to be very useful [27,28]. Aurbach led a series of meetings at the University of Michigan with stakeholders in public engagement to discuss current activities and how they connect to the mission of a land-grant university. The result of this work was a comprehensive framework that identifies 12 categories spanning all of university public engagement; three of these categories (which also overlap with each other) are centered on developing educational environments that are relevant for our study goals: *alternative/ lifelong/ informal learning*, *community-engaged/ service learning*, and *P-14 education and educational outreach*. other categories (such as *applied practice* and *consulting* and *business* and *entrepreneurship*) are more centered on or around professional development opportunities for those already connected to one's disciplinary field and are not as relevant to this study.

Considering the variety of public engagement activities identified by Aurbach, the FOEP survey, and others, it was necessary to implement some constraints on the first stage of this project in order to collect robust and valid data about informal physics. Thus, in this paper, we limit our focus to informal physics efforts associated with academic (non-industry) physics communities. These include programs or events run by individuals or groups in physics departments, national laboratories, or centers associated with a university or college. While there are many physicists working in industry or nonprofit settings outside of academia, some of whom might do public engagement, this scope was too large for this initial study. Additionally, we focused on "programs," "activities," or "events" that were beyond the individual volunteer efforts of a single faculty member or student—for instance, a faculty member might judge a science fair or speak to high school students on their own, but it is not an effort associated broadly with the physics unit at their academic institution. Because of the many connections between physics and astronomy, including shared resources at several institutions, informal astronomy programs were included in this study.

Another important constraint we implemented in this study was to limit our search to "in-person" activities, such as after-school programs, summer camps, public talks and lectures, demonstration presentations, open houses, science festivals, and planetarium shows.[1] Media-related works, websites, books published to popularize physics, television-related activity, movies, or games are not included in the current study. The choice to exclude these forms of media was made to simplify the methodology for the initial phase of the study, as explained in the following section. One reason for this decision is that our initial efforts to develop instruments to collect data showed us that there were significant differences in the language needed to obtain information about media-related works—for instance, asking about the number of volunteers might not make sense when someone is the author of a popularized physics book. Investigating media-related efforts is a goal for our future work.

III. THEORETICAL FRAMEWORK

To get a sense of the landscape of informal physics, we look to the variety of existing frameworks to understand the main components of individual programs that influence their functionality. Programs can be interpreted as

[1]This manuscript and part of the study was prepared prior to COVID-19 in the U.S. In our recent work [17,18], we discuss the impacts of the pandemic on "in-person" activities, including adapted virtual activities and events.

organizations, for the key reason that programs, similar to organizations, consist of individuals and groups who interact with each other and perform some activities to deliver some tangible products or intangible outputs. Turning to the business literature, we find that organizational theory is a good fit for characterizing the nature of some informal physics programs [11,19,20]. In this study we have chosen to focus on the public engagement types from Aurbach's framework that are relevant to educational settings, mainly alternative/lifelong/ informal learning, community engaged/service learning, and P-14 education and educational outreach [29]. However, this framework does not describe in detail the components that are important in each of these categories; also, it is meant for public engagement in general and is not specific to science or physics.

A. Organizational theory

Organizations are defined as systems of coordinated action among individuals that have different interests, knowledge, and preferences who come together for a number of common and uncommon goals and purposes [30]. In early management studies, organizations were defined as single purpose and static units; however, in practice, an organization's goals may frequently change [31]. Researchers and managers considered organizations to be performing well if they were able to achieve their intended goals (effectiveness) and used relatively few resources in doing so (efficiency) [32–34]. Later studies of organizational assessment and diagnosis moved beyond the measurement of output and work methods to consider the impact of work environments [35].

The area of *organizational theory* (OT) refers to a set of interrelated concepts that studies the effect of social relationships between the individuals within the organization along with their actions on the organization as a whole. When theories of organizations emerged, their main purpose was to study ways that could improve the efficiency of organizations. Over the years, different frameworks and studies have been developed to model the complexity of organizations from different viewpoints [36–40]. Recent studies mostly focus on the relationship between the different aspects of organizations and their environment. This set of theories looks at organizations from multiple perspectives and considers individual and group dynamics. Given this complexity, understanding how organizations move in the right direction, how they measure their performance, and the factors associated with good performance are something that organizational theory seeks to characterize. There is not a single rigid framework for OT; rather, different manifestations of the theory of organizations have produced a set of constructs and definitions that can be applied to different contexts.

B. Contextualizing organizational theory for informal physics

We propose that organizational theory is appropriate for characterizing the nature of some (although not all) informal physics activities and programs. As with organizations, some models of informal physics programs are functional structures with groups of people who come together with common and uncommon goals, interests, and knowledge. Organizational theory is a useful lens to look at the varied landscape of informal physics activities as it is flexible enough to be applied to different types of organizations. There are many research papers and books on how organizational theory has been conceptualized for and applied to academic environments and research institutes [32,34,41–43].

Organizational theory of nonprofit organizations (NPOs) is a variation on broader OT theories, and is especially applicable in the context of informal physics programs as the goal of these organizations is not to make money [44]. NPO dimensions are connected to the longevity, sustainability and the efficacy of organizations and include board members or stakeholders (people involved in decision making and accountability), finances (fiscal health and performance), environment (technical, capital and social context), management (how the organization is run and seeks to achieve its goals), resources (tangible and intangible, including human resources), and program (what the organization does and its outcomes) [44].

In past work, we applied these constructs related to NPOs [19] to informal physics programs, and found them to be a viable tool to illuminate some structurally important aspects of the informal physics programs. However, a number of aspects did not map usefully to the context of informal education programs. In subsequent work, we did emergent coding within the broad NPO categories on data sets from four different cases of informal physics programs, labeling the structural elements and cultural practices salient for each program [20]. From this study, the emergent codes were reorganized and major themes were identified resulting in the codification of six main categories of organizational theory contextualized for informal physics programs [11,20].

Figure 1 shows these adapted categories and definitions of these categories are shown in Table I. *Personnel* are the people involved in the functionality of the program, *program* is the content, format and logistics of the events and activities, *audience* is the group of participants that are engaging with the program content, *resources* are the physical and financial aspects of the program, *institution* is the larger organization that the program is affiliated with, and *assessment* is the means by which a program evaluates its outcomes. For the landscape project, we developed specific research questions associated with each of these adapted categories—these are also shown in Table I. These questions get at the detailed understanding of the informal physics landscape that we are looking to document.

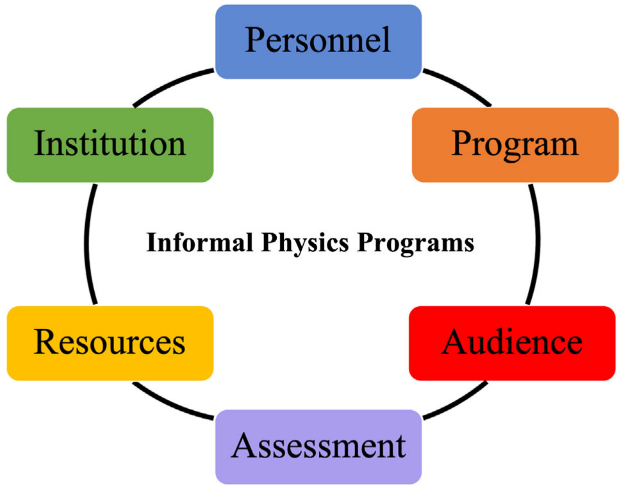

FIG. 1. Adaptation of main components of organizational performance for informal physics programs.

IV. METHODOLOGY

Unlike college courses that have up-to-date information published on university registrar websites and in many cases available syllabi, informal physics programs can be difficult to find current (or any) online information. In preliminary internet research we extracted as much information as possible in our key categories—program, audiences, personnel, resources, and institution. However, it was not a surprise to us that online information available did not provide details on all the different categories for programs and often current program information or contacts were missing or out-of-date. (We did find that public engagement programs for bigger centers or seemingly longer running initiatives had more current and robust online information.)

Therefore, to obtain detailed and current program information, we developed a survey, coupled with a follow-up interview protocol, to be taken by lead facilitators of the programs. In prior work [19], we found that although

TABLE I. The six main adapted categories, their definitions, and associated research questions for the context of informal physics programs.

Category	Definition	Research questions
Personnel	The people involved with the functionality of the program. Examples: directors, presidents, volunteers, graduate students	• Who facilitates the programs? • What is their background and training? • What are the different kinds of facilitator positions? • How many personnel from each institution (e.g., program leads, students, etc.) are involved with the programs?
Program	Logistical and programmatic details of the organization. Example: content, structure, history, objectives	• What physics and astronomy content is being presented? • What is the format and frequency of the activities? • What kind of activities are offered? • What are the programs' goals, missions, or objectives? • How long have the programs been running? • Do programs charge fees for attendance?
Audience	The people that the organization is "reaching." Example: local communities, K-12 students, college students	• What is the geographical reach of the programs? • How many people are participating? • What are the demographics of the audience?
Resources	The physical and financial assets that the organization utilizes. Example: donations, physical spaces, grants	• How are informal physics programs funded? • Are community partners involved? What is their role?
Institution	The umbrella establishment that the program is housed under. Example: Universities, National labs, Physics centers	• What is the role of the administration of the institution in the informal programs? • What types and demographics of institutions are engaging in informal physics?
Assessment	Evaluations regarding the organization, (sometimes conducted to evaluate itself). Example: Survey taken by the audience, and research done on the efficiency and/or effectiveness of the program	• How do informal physics programs assess or evaluate themselves? • What instruments and tools do practitioners use for the evaluation and/or assessment of their program? • How are evaluation and assessment used to improve informal programs?

interviews were a useful tool in understanding the cultural and structural aspects of individual programs, they did not provide sufficient data about basic program features that could be aggregated with data from other programs. With six categories to explore, the interview time was most useful for gathering information about experiences in the program rather than factual and logistical information. For instance, asking program leaders to recall the number of volunteers who were undergraduates, graduate students, postdocs, and faculty, takes up time that is better spent on asking about the experiences of those groups of volunteers in the program.

In order to answer the questions in Table I, we undertook a two stage process: (i) We developed and validated two instruments (a survey and a follow-up interview protocol) that are able to obtain information about the features of informal physics programs. This step was done with a nationally distributed sample. (ii) Then using a systematic and comprehensive approach, we identified programs within our test case state of Michigan and administered these instruments. In this study, we will focus mainly on the survey design, validation, and results; future manuscripts will focus on interview design and analysis.

A. Survey design and validation

From our experiences as informal physics practitioners and from prior research, we know that practitioners of informal physics do not have a common language to describe informal physics programs; thus an iterative process of survey design and validation would be a crucial step in our methodology. For example, "physics outreach," "public engagement," and "informal physics" are all used on AAPT and APS websites [6,45,46]. By survey validation, we mean making sure that the wordings, the language used, and the overall questions designed for our survey protocol have been interpreted appropriately and consistently among all those completing the survey.

In the first phase of development, a survey was distributed to 15 lead facilitators representing 11 different informal physics programs ($n = 5$ for Michigan-based programs; $n = 6$ for programs based in other states.) We recruited programs that were recommended or introduced to us at conferences (such as APS, AAPT, and PERC), by colleagues (at FOEP) and through personal connections. To assist with validation, the initial survey had more open-ended questions allowing participants to describe their program in their own words, from which we were able to identify themes and key language issues. Our survey also included an open-ended feedback question at the end, which asks respondents to comment their feedback and share their thoughts on every aspect of the survey protocol. For two of the informal physics programs in this sample, we collected surveys from three individuals who were leaders in the same program, which allowed us to triangulate between responses for a single program. All participants gave follow-up email or phone interviews to understand the nature of their responses. In addition, we collected survey responses and held an hour-long focus group with nine physics education researchers from the lead author's home institution, which allowed us to get feedback from experts in physics education research to complement the feedback from the informal physics practitioners. All feedback was used to restructure and revisit the language and format of the survey.

For the second phase of development and validation we modified language and converted several open-ended questions to multiple choice, which reduced the length of time needed to take the survey, an issue mentioned in earlier feedback, and crucial for successful wider distribution. Eleven additional participants took this survey, for a total of 26 surveys representing 22 programs, along with 17 follow up interviews.

From the development process, we learned that survey language needed to be carefully chosen, precise, and with clear definitions of the words. The diversity of different types of programming makes it difficult to refer to variables universally—for example, some respondents preferred referring to their programs as "events" or "activities." In one case, responses from three different facilitators of the same program were different because their understanding of the definitions for some words were different from each other and us. Some of the examples of words with multiple interpretations were audience, personnel, staff, partners, and volunteers. To resolve this issue and reduce the confusion, the survey has examples of such words to distinguish between them.

B. Survey content

The final survey consists of 34 survey questions aligned with the six categories of our informal physics framework and the research questions from Fig. 1. Some example survey questions (with the associated category in italics) are "How many *personnel* from your institution (e.g., program leads, facilitators, volunteers, etc.) are involved with this program/event/activity?", "Please describe the format and frequency of the activities of your *program*/event.", "Please select any *audience* demographic groups that your program/event focuses on recruiting.", and "Is there any evaluation or *assessment* associated with your program/event/activities?". To take into account that a lead facilitator may be involved in multiple informal physics efforts, the survey was designed to collect the information for up to three different programs that the facilitator is involved in. Also, to understand our sampling and the representation of different groups in informal physics leadership, we included a set of optional demographic questions at the end of the survey about the survey taker's gender identification, racial or ethnic background, country of origin, ability status, and identification as LGBTQ+. The survey

FIG. 2. Organizational theory codes for the survey questions. The six framework themes are color coded for better visualization. The second row on the table shows the total code counts for the six framework themes. The survey question numbers starting from the fourth row, correspond to the question numbers in the same order they appear in the Qualtrics platform. The 9 optional demographic questions of the survey are excluded from this figure.

was designed using Qualtrics software platform [47]. The full survey is provided in the Supplemental Material [48].

Figure 2 shows how each survey question could be coded with the framework categories; this coding allows us to check the distribution of categories across questions and the overlap of categories in the questions. We asked the most questions related to programming (21 questions), while personnel (10 questions), audience and resources (each 9 questions) were the next most prevalent categories. Questions about programming often were cross cutting, meaning that other categories naturally overlapped with program information.

Our overall aim is to characterize the size and scope of informal physics education in the United States—e.g., to "map" its diverse landscape. To this end, the methodology that we found to be necessary to obtain reliable and accurate data serves as evidence toward the complex and varied nature of this landscape. The lack of common language found in our development and validation process demonstrates this point, as well as shows that practitioners can have different philosophical perspectives on informal physics. Thus, a meaningful contribution of this study is the validated survey instrument itself.

V. TESTING OUR METHODS ON A STATEWIDE SAMPLE

After finalizing our survey, we implemented a data collection strategy across the state of Michigan, as a case study for the broader national landscape project. We do not claim that Michigan is representative of the entire nation, but rather that the variety of informal physics programs in the state provide a good starting ground for understanding the details of programming more broadly.

A. Systematic data collection

Before administering the survey, we employed several strategies to first identify informal physics programs. The state of Michigan has over 90 public and private colleges and universities [47,49]. We looked specifically at institutions that granted physics degrees (associates, bachelors, doctorates)—in Michigan, resulting in 35 sites [50]. For these institutions, we looked at their department websites for basic information about their outreach activities as well as the Society of Physics Students (SPS) web pages, for these groups are often involved in some form of public engagement. Sometimes the information from the university-associated websites was not sufficient or nonexistent; thus, we also conducted Google searches with specific keywords such as "outreach," "informal,", "nonformal," "public engagement," "physics" and the name of the different institutions. As several research team members live in Michigan, we have personal knowledge about the institutions of higher education in the state, which served a face validity check as to whether we were missing programs from institutions. Persons who could be identified as the lead facilitator were emailed with a request to take the survey, and if necessary, reminder emails were also sent to improve our response rate. We also recruited participants in the study from attendees at the MIAAPT regional meeting. In addition, we included a question in the survey asking participants to name any additional informal physics programs they might be aware of in their institutions or elsewhere.

Of the 40 facilitators contacted in the state of Michigan, a total of 21 survey responses were received representing a 53% response rate. Our criteria for including programs in the study were that either (i) programs and activities that are either facilitated, led and/or run by the physics departments, individual physics faculty members, physics graduate and undergraduate students, department staff members; or (ii) contentwise, the programs centered around the specific topics physics and/or astronomy. In the interest of inclusivity, programs that had vague online information about their physics or astronomy content were included initially (for example, describing themselves as STEM); however, if no specific connections to physics or astronomy departments, students, or content modules were found after the survey, they were removed from the study. If a program had broader science content, but was sponsored or supported directly by a physics or astronomy department, it was included. Programs that have a broad science focus and also not be directly affiliated with a physics-specific academic unit, for example, a campus-wide science festival, were not included. However, some of the physics and astronomy specific programs included in the dataset may participate in such an event as part of their regular program activities.

The final Michigan sample includes 18 different informal physics programs and spans over six different institutions, including 5 public universities, 1 private university, and 1 national lab which is physically located at one of the public universities. The universities in our study are generally predominantly white institutions and are located in rural, suburban, and urban areas of the two Michigan peninsulas. We do not include more details of the specific universities here to protect the anonymity of the programs.

In the following sections, we present the details of the landscape of Michigan achieved from our collected data. We organize the results based on the six adapted categories of organizational structures. Breaking down the analysis into these categories helps us to see how the programs can be grouped in different dimensions rather than just by format, such as "demo show" or "public physics lectures." This analysis provides a richer understanding of both the components that are necessary for these programs to function as well as the scope of the programs collectively.

VI. STATEWIDE LANDSCAPE

A. Personnel

In this study, personnel refers to two distinct groups, the lead facilitators who took our survey and the other people that volunteer to help with events and activities. Personnel are critical to the function of the programs as they are responsible for the main tasks; understanding who these physics students and physicists are and what they do in the programs is necessary to understand how these programs function and perform in connection to their home institutions.

Our research questions about personnel (repeated from Table I) are

- Who facilitates the programs?
- What is their background and training?
- What are the different kinds of facilitator positions?
- How many personnel from each institution (e.g., program leads, students, etc.) are involved with the programs?

1. Lead facilitators

Figure 3(a) shows the distributions of the main position held by the lead facilitator of the informal physics programs in our sample. Lead facilitator refers to the person who took the survey and is in charge or responsible for most of their program activities. In our sample, the majority (43%) of lead facilitators are undergraduate and graduate students. Staff is the second largest category—here "staff" refers to paid employees of the institution who are not considered faculty or instructors, and who are also not students. All the staff in our study were hired to do public engagement or outreach for either all or part of their job responsibilities. For about a quarter of programs, faculty are in the main leadership role; tenure-system faculty led programs in 14% of the total cases. None of the students or faculty were paid directly for leading the informal physics efforts, but were involved either as volunteer or service work.

Figure 3(b) shows how the lead facilitator classifies the individual or group responsible for the organization or sponsorship of the program. In alignment with Fig. 3(a), 45% of the informal physics programs in our sample are hosted by student groups or organizations. Separate from

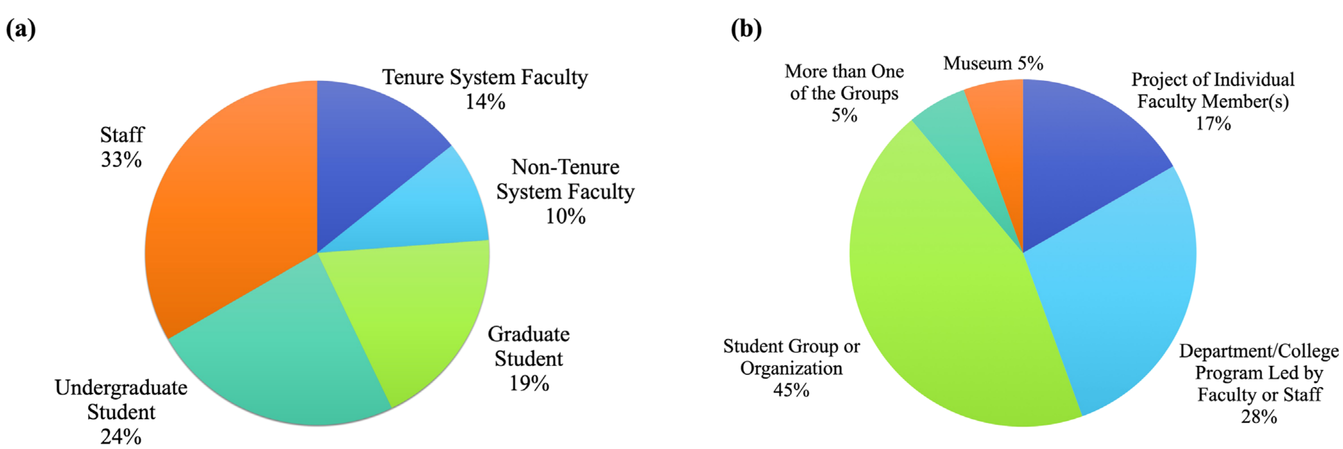

FIG. 3. (a) Distribution of the lead facilitator's main job at their home institution. (b) The category breakdown of the person or group that is responsible for the program.

student groups, a portion of programs are categorized as belonging more generally to a department or college and were run by faculty or staff (28%). One example from this category is a university-based planetarium that is supported financially from college funds and run by department staff members. Programs initiated by individual faculty (17%) are a smaller fraction, and include efforts that are part of a broader impact requirements for a faculty member's grant. Other categories are programs run by a museum or one that is run by more than one of the units.

As these data show, over three quarters of the programs in our sample are not led, sponsored, or organized by faculty, the group of physicists arguably positioned to benefit the most and be given more credit for improved public perception of physics. In contrast to faculty, students and staff have less power within the hierarchy of academic institutions as well as the physics community; we suggest that this finding may be one reason that some informal physics programs exist on the margins of departmental awareness and support. Tension can result from the these power differentials, as described in a follow-up interview with the lead facilitator of a science cafe, Tom, who also teaches as instructional staff in his department, explained his frustration about his program's connection to the institution:

> *"I never really got much in the way of actual support from the department, either advertisement or financial support, or anything like that. So I got a pat on the back in some sense at one point, but other than that, yeah. I don't even know how many people in the physics department knew I was doing it."*

This distribution of labor may not come as a surprise to those involved in informal physics work; however, it may run counter to narratives in the physics community about who takes on the burden for leading and organizing physics public engagement opportunities, especially local community events.

Another interesting finding related to the lead facilitator role was the name of the position associated with the informal physics program. We found nine different kinds of titles that the facilitators held in their positions in their programs. "Director," "organizer or co-organizer," "coordinator," and "manager" were most popular, followed by "leader," "advisor," "chair," and "president or vice-president." In contrast to formal classrooms, where faculty have the common titles of professor or instructor, the variety of titles assigned to lead facilitator demonstrates the diversity and variability of informal physics programs and their leadership. One explanation may be that there is a less hierarchical structure in informal programs, which allows more agency to the participants in determining roles and titles.

2. Lead facilitator demographics

Looking at the demographic question responses, eleven of the lead facilitators (52%) self-identified as men, 9 as women (43%), and one person identified as other or nonbinary. This percentage of women is substantially higher than the average population of women physicists and physics students in the U.S. [51]. Three of the facilitators self-identified as members of LGBTQ+ community. The majority of participants in our study identified as white/Caucasian ($n = 16$), with other participants identifying with multiple racial backgrounds ($n = 4$), and one participant choosing not to respond. This is also a higher number of people of color in the lead facilitator role compared to the broader physics population [51]. None of the facilitators identified themselves as being a person with a disability. Two-thirds of participants are under the age of 34, mostly students and early career faculty. These data indicate that in our sample, some demographic groups that are underrepresented in physics may be overrepresented in leadership roles in informal physics programs.

3. Program personnel

Program personnel are the physics students, staff and physics faculty who help with the creation and implementation of the events and activities. Most of the program personnel are volunteers, while some programs have several staff people, faculty, or students who are paid. The total personnel involved across all 18 programs in our sample is reported at 500 to 600 people per year. Different programs in our study have very different numbers of personnel (Fig. 4). Eight programs in our study fall into a midrange of 6 to 30 people per year, with two smaller programs run by 5 or fewer people. Significantly, close to half of the programs have more than 30 people. Among those programs, there is one program that leads a national effort, and has approximately 150 people involved per year, mostly local undergraduate students, who travel across the country to deliver STEM demonstrations to K–12 students.

Figure 4 provides a closer look at the distribution of academic status of the program personnel. On the x axis, program numbers are organized based on the ascending

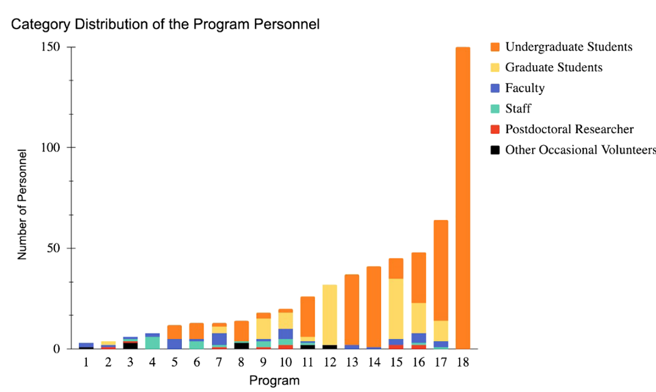

FIG. 4. Distribution of the programs' personnel based on their physics status. Program numbers are organized based on the ascending order of their number of personnel.

order of their number of personnel. Programs 11–18 are the largest and also contain the largest percentages of student personnel. Undergraduate and graduate students combined form the biggest group of the personnel, with a total of ~470 per year in the programs sampled. Ten programs in our sample have more than 70% students of their total personnel each year, with another four programs having 50%–70% students. On the other hand, the group with the least involvement are postdoctoral researchers, with 11 programs in our sample having no postdoctoral researchers involved and the rest of the programs either one or two postdoctoral researchers involved.

The size of these midrange and larger programs show the collaborative nature of facilitating informal physics education. Clearly, physics student involvement is essential for the functioning of informal physics programs. The personnel numbers shown here point to the relevance of informal physics programs as entities that can support physics students and physicists.For example, in other work we have shown that informal physics groups can function as communities of practice, which can support identity development [52]. Furthermore, for many programs, students, staff, and faculty work together to put on program actvities; this overlap suggests that informal physics programs might be able to flatten traditional hierarchies within academia by allowing faculty and students to collude in engaging public audiences.

VII. PROGRAM

The program framework category characterizes the main events and activities that take place when the personnel are interacting with the audience around some type of physics content. Pertinent information to the program category includes the physics and astronomy content, the types of activities and events that are being organized, and the format and frequency of the activities. Our research questions about programs (from Table I), are

- What physics and astronomy content are being presented?
- What is the format and frequency of the activities?
- What kind of activities are offered?
- What are the programs' goals, missions, or objectives?
- How long have the programs been running?
- Do programs charge fees for attendance?

A. Physics and astronomy content

One way of mapping out the programs is based on the content they cover during their events and activities. An open-ended question in the survey asked the participants to describe the physics and astronomy content of the activities of their program. Eleven different physics subtopics and seven astronomy subtopics were identified among the responses. *Classical Mechanics* and *Electricity and Magnetism* were each reported nine times being the most

FIG. 5. Word cloud of the most covered physics and astronomy subtopics. The size of the word shows how frequently it was reported on an open-ended survey question to describe informal program content.

reported physics subtopics, followed by *Nuclear physics* reported seven times. In Fig. 5 we used the words of the respondents to create a word cloud, so *Introductory physics* is differentiated from *Classical Mechanics* and *Electricity and Magnetism.* The subtopic *Stars* was reported thirteen times, followed by *General Astronomy* reported eleven times. Current physics research topics were mentioned six times and the current astronomy research topics were mentioned once in the free responses. While half of the programs covered either astronomy or physics topics, the other half of the programs ($n = 9$) covered topics on both.

It is interesting to note the prevalence and specificity of reported topics. The largest categories of topics are all introductory levels, which may be related to the facilitators' perception of what is accessible to certain audiences, the equipment that is available, or the pedagogical approach to activities. Astronomy topics represented over half the content, which speaks to the resources that astronomers and astrophysicists apply to public engagement and is likely a product of the history of planetariums and observatories as informal learning spaces [47,49]. Content is also geographically influenced—for example, Michigan is home to national nuclear physics facilities, which is why this topic is featured in Fig. 5. We hypothesize that on a national scale we would see trends in content that are regionally dependent, such as more content on accelerator or particle physics located near those kinds of facilities.

B. Program format and frequency

Format and frequency are often closely tied characteristics of a program, and formats can vary widely between individual programs. Thus, asking questions about program format and frequency of contact proved to be one of the most challenging questions to write in the survey. For example, if we had a narrower survey asking only about presentations like public lectures, we could craft specific questions about how many weeks per year it was offered and how long on average each individual event would take. However, for a summer program that invites youth to campus, these questions do not make very much sense to the survey taker, and the response of one week per year would make it seem like a small program in comparison to the lectures. Likewise, aggregating a public lectures series that runs five times per year and a summer program running five days per year is also misleading. Asking about contact hours between audiences and the programs has issues as well—as informal learning is by definition free choice, audience participation is optional, and someone might attend one event in a series without attending more or be unable to attend more than one event due to the nature of the program.

Therefore, we kept questions about format and frequency open ended, and used the respondents' own words to delineate groups. In practice, these groups are similar to how we might refer to these programs colloquially. From our dataset we could form the following groups:

- *Presentation format*: Programs providing oral presentations that are intended to communicate information about one or multiple particular physics topics. These presentations last between 30–60 minutes and are often accompanied by some interactive parts. They are often part of a series and reoccur on a biweekly or monthly basis. These types of presentations include
  - *Public lectures* are talks that may be part of a lecture series and can be pitched at different levels, for example weekend talks for high school students or nighttime talks for adults at local bars.
  - *Demo shows* are presentations that provide information and illustrate how some physics concepts work through a series of demonstrations, which may involve crowd participation.
  - *Observatory or planetarium shows* are presentations held at astronomical observatories or planetariums for general audiences and may be coupled with observing opportunities at the telescope or dome shows.
- *After school or club format*: Programs that provide activities and illustrate physics concepts for K-12 students outside of school time. They can be held at community, school, or sometimes university campus locations. Afterschool programs and clubs are designed to provide safe, secure places that children can go to on a regular basis. Sessions often meet weekly or monthly, and last between 30–120 min.
- *Camp format*: Programs that provide educational and recreational activities for specific age groups during a limited period. They can last multiple consecutive days, with most of the day dedicated to activities, and in some cases informal interactions occurring outside of workday hours. They are usually offered in summers, and may be offered for one week, with multiple weeks for different age groups.

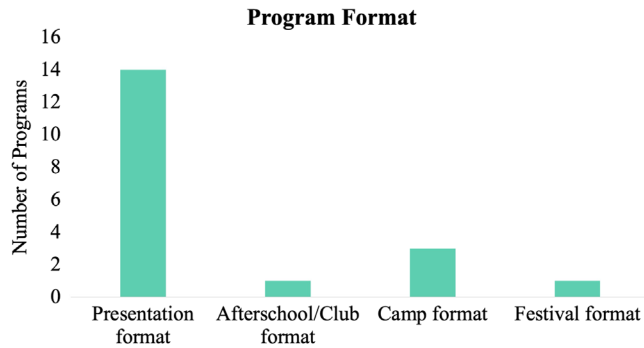

FIG. 6. Counts of the types of program format in our sample.

- *Festival format*: Science or physics festivals, open houses, or "physics days" that showcase physics concepts over a wide range of activities such as lectures, workshops, live experiments, and panel discussions. They typically last a full day (or multiple days); however, interactions between facilitators and specific audience members can be for only a few minutes (for tabletop activities) or an hour or more (for presentations). Festivals and open houses often occur as annual events.

Figure 6 shows the distribution of program formats in our sample. The large majority of programs fall into presentation format ($n = 14$). Three programs can be described as a camp format, and one program is a festival format. One of the programs that mainly includes different presentation formats also includes club format. These categories are emergent from our sample and are not exhaustive of all types of informal physics programs.

One thing to note from these data is the dominance of a presentation format—this finding is in line with our personal experiences of informal programs supported by physics institutions. One-time, short-term interactions with self-selecting audiences may be convenient for physicists strapped for time between teaching and research and other service obligations. Presentation formats are also likely to be less resource intensive and require less personnel (and less personnel training) than afterschool or camp formats. However, as a physics community looking to improve our public engagement, it is important to think about how impact may be coupled to format—i.e., how short interactions vs lengthier interactions in informal physics programs may affect their audience. On the other hand, another factor is exposure—i.e., size of audience, which can be restricted by different formats based on available resources (see next section).

C. Program activities

Another way to understand programs is to consider how the audience participates in the activities. Figure 7 shows how often lead facilitators report audiences engaging in common types of program activities. This information is

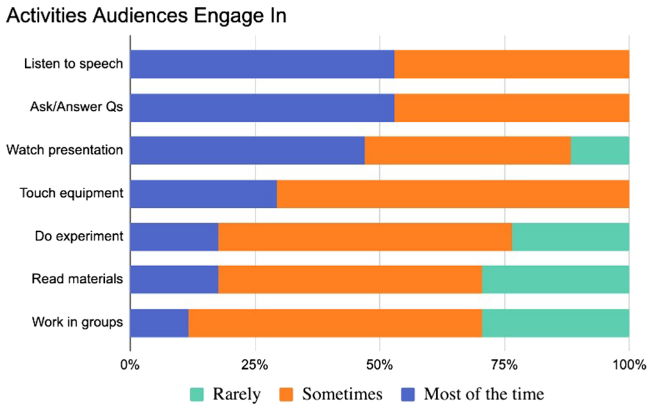

FIG. 7. Different activities that the audience participates in during informal physics events.

complementary to Fig. 6; here we break down the types of interactions that are most prevalent in the program. Since we have a large number of presentation-style formats in our sample, it makes sense that there are high counts for watch presentation, listen to speech, and ask and answer questions. Doing experiments, working in groups, and touching equipment were the top three "sometimes" ranked activities. A program might sometimes engage its audience in "work in groups" or "touch experiments" although the majority of its activities fall into "presentation format." For example, a program based around demonstrations may most often do presentations but sometimes incorporate an element of inquiry with hands-on tabletop activities. These results highlight the range of interactions that can happen within a certain program format, and show that even for presentation-style formats, interactions with the audience are an important component of informal education program design.

D. Program goals and objectives

Goals and objectives for informal physics programs and activities can be very dynamic, and dependent on various aspects. The activities are designed by the people who start a program, and some shared goals are set at the beginning or along the way for the personnel to work together. In addition, programs are not only composed of individuals, but also interdependent groups with different immediate goals. For example, a college level program can have some immediate goals set by the institution or the department, but the faculty members and the students who work together in the program can have different goals, derived from their specialization, research, or field of study. Furthermore, the audiences who attend the programs will have different goals and these are not necessarily aligned with those of the personnel.

We asked the facilitators who participated in our study to share their perception of the goals and objectives of the informal physics programs that they were reporting on. Overall, we find that lead facilitators focused on having an impact on the audience. The language around the responses mostly fell into two types: (i) to "empower," "inspire," "engage," and "create inclusive" physics education spaces, and (ii) to "reach," "provide," and "give" something to the participants. The majority of responses were in the latter group.

For example, Natalie is an undergraduate student who serves as the outreach co-chair of the student astronomy group. In her survey, she explains the mission of their program *"to provide the university students, faculty, staff and the local community with resources and educational material on astrophysics as well as to cultivate interest in STEM and astronomy among the student body."* In her interview, she explains the objectives that led to their outreach activities:

> *"When the club was founded, outreach was not a part of the picture. That came up about 10 years ago. We realized that if we are going to get funding from the department, we need to be doing something with that funding. It couldn't just be essentially a social group anymore, it had to have some sort of value. So that's when we started doing public outreach."*

It is interesting to note that from the facilitator's point of view, the main objective for running informal physics activities is more oriented towards "giving" something to the audience, which is also in line with the historical (and often still current) use of the word "outreach" rather than "informal education" or "public engagement." Lead facilitators also wrote about considering the needs of the audience as individuals, considering the needs of the broader local community, and emphasizing the importance of diversity in the audience demographics.

Almost all the respondents in our sample said the focus of their program goals were the audience; this goal of course makes sense, but the omission of other stakeholders is relevant, for example, having an impact on the personnel, such as volunteer physics students, was only mentioned once, in reference to "getting the department engaged in local community partnerships."

E. Program history

The lifetimes of the majority of the informal physics programs in our sample have been quite long, see Fig. 8. There are three programs who have been running for more than 40 years; perhaps not surprisingly, they are all planetariums. There are three programs who have been in existence for less than 10 years: two of them are run by individual faculty members, and another one is a student organization or group. Nine other programs have lifetimes between 10 and 40 yr; finally, three student facilitators reported that they were not sure about how long their programs have been running.

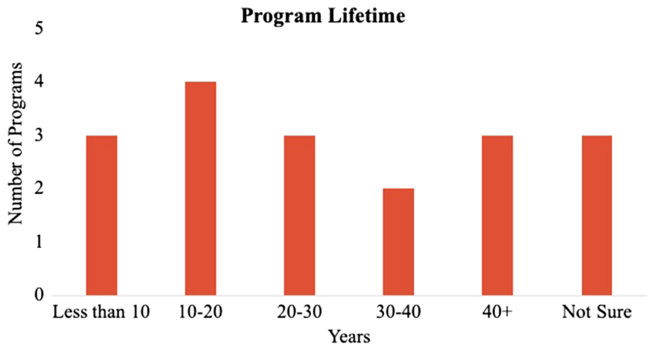

FIG. 8. The length of time in years that programs in our sample have been running.

We also asked facilitators about any hiatus in the history of the programs. Among the 18 programs, four programs had suspensions during their run time, and eight programs did not. The reasons for the suspensions included building repair or maintenance, overspending, and for faculty to devote more time to research. For the rest of the programs the facilitators (mostly students) did not know this information. This information does not include suspensions that happened in 2020 during the COVID-19 pandemic (for more analysis on COVID related program concerns, see Ref. [17]).

The long-running times for these programs are striking to see in aggregate. One might ask how these long-running times are possible? In some cases, the same person, usually a faculty member, remains in charge of program activities for many years, in at least one case in our data, until retirement. In other programs, for instance those run by students, the leadership roles must pass from person-to-person, which can also result in changes to program content. For example, Natalie, the outreach co-chair of the student astronomy group, explains how activities were maintained even with natural student turnover:

> *"…I had a really awesome mentor [John]. And John was the outreach co-chair at the time… And so, when he graduated, my best friend and I—he's the other outreach co-chair at the moment and he will be continuing in that position next year… we saw places where we could improve upon it, and then, John had set goals of the time that he luckily hadn't got the chance to see through… [The previous student leaders] had the ideas and we knew we had the skills to implement them… As for what's made outreach sustainable in the last 10 years, it depends on who is handling it."*

Informal physics programs may be perceived as peripheral activities; however, for programs in operation for multiple decades, programs can have a long-term presence not just in the department but also the surrounding community. In order to maintain their longevity, programs also need to be flexible in terms of their goals, values, and capacities over time, as community needs change. Looking at these histories, we see that informal physics can offer real opportunities to connect people with physics content and physics institutions, with the potential for these experiences to manifest in future career choices.

F. Program fees

We asked the facilitators if they charge any fees for attendance and if not, if they encourage donations. In thirteen programs the events are free for the audience, three programs charge their participants for all or some of their events, and there are two programs that are free, but they encourage donations. All of the programs that charge participant fees are part of larger dedicated outreach facilities that have permanent staff and buildings to maintain (i.e., planetarium-museum), or they require intensive staff involvement from the institutions due to the amount of time that is required to run the program (i.e., summer camp).

VIII. AUDIENCE

In this section, we present on the informal physics programs attendees in our sample, as described by the lead facilitators through the survey. Here we note that the term "audience" is not ideal as it can imply a deficit approach to public engagement. However, for many of the programs in our study, it is necessary to distinguish between the groups of physicists and physics students involved in the design and implementation of informal physics activities and the members of varied publics who engage in physics learning during the events. It is also true from our research that the majority of programs do in fact have this delineation, where the audience is not involved in the design or implementation of the activities. Thus, we use the word audience to be able to speak generally about different formats of programs and distinguish from "personnel"—although alternatives like "physicist participants" and "community participants," while still not ideal (as physicists are part of communities too), may be better descriptors for a subset of programs.

Although we are interested in information about the audiences, in the scope of this study, we are only getting at that data from the perception of the survey taker. Additionally, many programs do not have consistent measures of audience participation or attendance. Because of these considerations, our understanding of the audience will not be complete and thus we necessarily limit our research questions about the audience here (from Table I):

- What is the geographical reach of the programs?
- How many people are participating?
- What are the demographics of the audience?

A. Geographic reach

Figure 9 shows the distribution of "geographical reach" of the programs in our sample as described by their lead facilitators. Five programs reach the city or town where

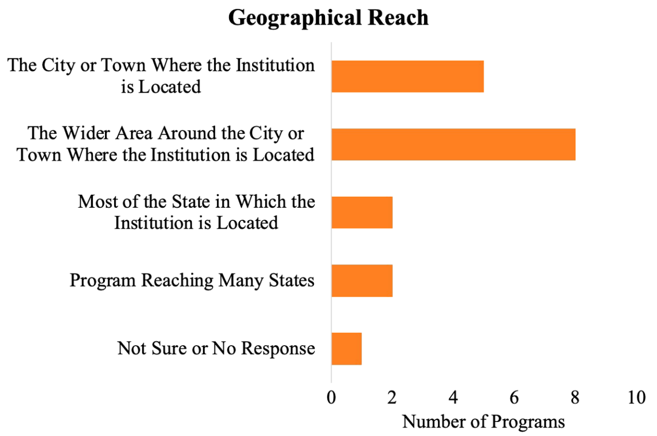

FIG. 9. The geographical reach of the programs in our sample.

their home institution is located, and eight additional programs reach the wider area around the city or town where their home institution is located, including adjacent rural areas or suburbs. For example, a program might state it reaches the "mid-Michigan" area. There are a few programs that reach a statewide or national audience as well.

These data indicate that institution location may be a limiting factor to the distribution of informal physics programs in the state. Michigan has large rural areas that are not adjacent to an institution in an urban or suburban location, and only one of the institutions in our sample is actually located in a rural area. Thus, informal physics programs may still not extend to significant areas of the state.

From our interviews we find that programs are often aware of the limitations of their reach and are looking to address this. For example, one program director explains

> *"… So what [we] really wanted to do last year is expand upon the programs. So we've started doing a lot more outreach to local elementary schools. We've done things as far as Detroit, which is about 30 miles away… And then, also making sure that when we have public outreach requests that someone is doing it. We don't always meet that goal, especially in the summertime but that is the goal that we're not turning people away."*

As the physics community is concerned with impacting more people across a larger area, the geographic view can help us get a sense of what opportunities are available for audiences to engage in. We could use this information to assess how to distribute resources and promote the development of new informal physics programs or extend the reach of the existing ones. For example, we could think about supporting programs that may be stretched thin for the population density in the city in which they are located.

B. Audience attendance

Audience attendance for various programs is associated with the format of the events and activities and the frequency that those programs operate. Figure 10(a) shows the typical attendance per session for the programs in our sample. Not only the "audience size per session" data in our sample varies drastically due to the different format and frequency of the programs, but also inside each program audience sizes vary for different groups of activities. Figure 10(b) shows the program attendance per year for every program in our sample. This distribution includes the repeat counts for the audience of the programs that are held with higher frequencies than once a year. As a result, audience size comparison between different programs is not particularly meaningful. However, there are 7 total programs that each serve more than 1000 people per year; they all are presentation format (public talks, demo shows, and observatory shows). The largest audience in our sample is a national program run out of a Michigan institution with more than 100 000 people per year.

While public lectures may have audiences in the hundreds but only once a month for an hour, in contrast, programs like summer camps are resource consuming and thus may accommodate only tens of participants for 8+ hours per day for a week. One staff member, David,

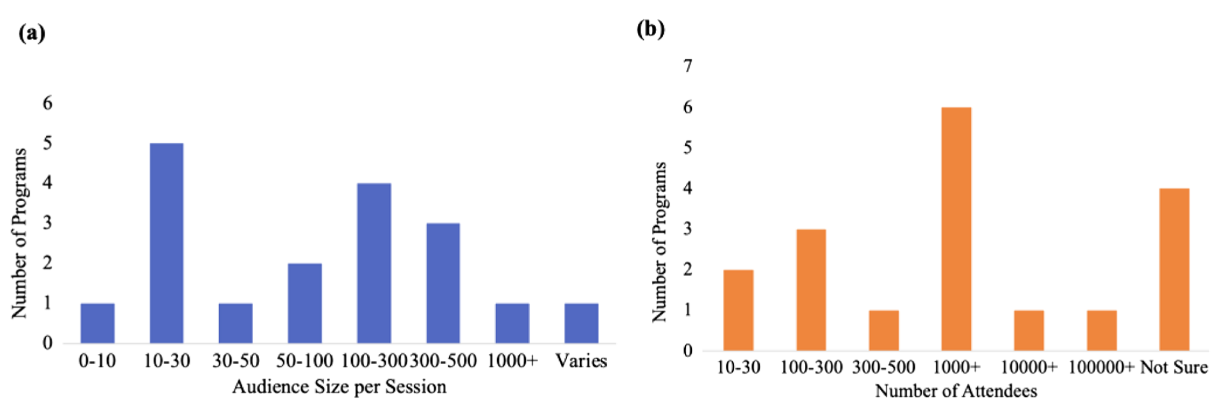

FIG. 10. (a) The distribution of the typical number of attendees per session in our sample. (b) The distribution of the audience size per year, including the repeat attendees for various activities and sessions.

who leads a one-week length summer camp for high school students every year, explains how he is unable to fit in all the great applicants their program receive due to limited resources they have

> *"… It's killer because almost all of them are fantastic. And then, when I turn them away and they're like they have never been turned away, because they're really good. And they're like, "What's wrong with me?" I'm like, Look, it's just we have so many. Keep applying."*

C. Audience demographics

According to the lead facilitators, the age range of the typical audience attending Michigan programs is broad. Among the collected data, there are nine programs that are intended to reach groups of all ages. There is one program with the audience of "adults only," one program with the audience of "K-12 only," and one program with "K-16 only" audience age range. The six remaining programs focus on specific groups, such as K-8, secondary, or postsecondary only, as shown in Fig. 11.

Figure 12 shows the distribution of the demographics that the programs in our sample focus on recruiting,

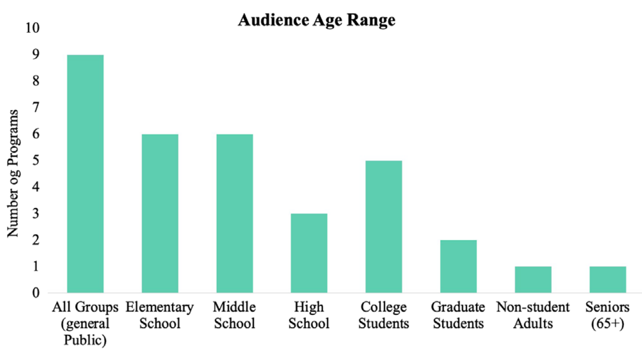

FIG. 11. Distribution of the audience age ranges in different programs in the sample.

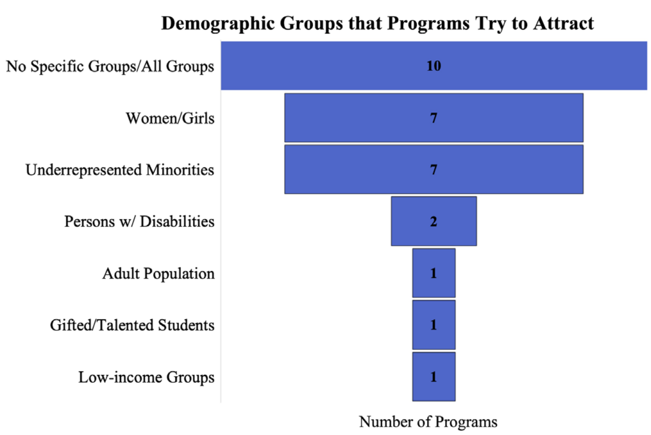

FIG. 12. The audience demographics that the programs try to attract.

according to the lead facilitators. The categories shown were choices in the survey question along with a comment box to add other categories not listed. Ten programs do not focus on attracting any specific groups or are interested in attracting all groups. The rest of the programs aimed to attract specific groups of audiences, with the top two categories being women or girls and underrepresented minorities.

From Fig. 12, we find no programs reported focusing specifically on people living in rural areas and only one program focused on people from low-income households, even though Michigan has large populations of those groups [53]. It could be that such programs were not reached through our sampling methods. We can also see from the data that a number of lead facilitators selected multiple or all options. It is not clear if this way of thinking about audience demographics is good or if it could result in too broad of an approach to program design, not drawing deeply from experiences of different local groups to create meaningful activities.

These data do not tell us if these demographic groups are collectively experiencing more or less access to structured, institution-based informal physics learning opportunities. It is also important to note that the actual audiences that individual programs attract are not necessarily representative of the demographic makeup of their geographical area and/or who the facilitators of the program had tried to attract to the program. In follow-up interviews, multiple lead facilitators spoke about their perceptions of actual audience demographics versus anticipated demographics. In one case, a presentation-style program running for over 30 years, the lead facilitator explained the participants of this program are "families, couples on dates, groups of students looking for something to do, and individuals that love science." However, while the participants are somewhat ethnically and racially diverse, they do not reflect the demographic makeup of their city. The facilitator adds that "while Detroit is [about 80%] Black, the attendance at our shows is probably closer to 25% Black, though that is observational anecdotal data." In another presentation-style program run by a student group, the lead facilitator reports that they try to attract women or girls and underrepresented minorities; however, s(he) also adds that the typical audience is "predominantly white, slightly more males than females." One more example is a presentation-style astronomy program that is led and run by an individual faculty member, Tom. Tom mentions how he would like to understand the audience demographics of his program and that it is not as diverse as he wants it to be:

> *"What is our demographic—I mean, I can look at the crowd and I know what our demographics are. They're not great. They're not particularly diverse. They're coming from a very predictable group of people. So it would be nice if there was some way of understanding that."*

IX. OTHER THEMES

Below we report out on the categories of resources and assessment.

Resources: Resources include the funding, external sponsors, community partners, as well as the items, spaces, and equipment needed to run the events. Our research questions about resources, as shown in Table I, are

- *How are informal physics programs funded?*
- *Are community partners involved? What is their role?*

In the survey, it was difficult to ask about budgets and sources of funding because it might touch on sensitive information that lead facilitators might not want to or be able to share. We do find that almost all the programs in our sample have some kind of funding from their home institution. However, we do not know the ratio of funding from the home institution to other external sources of funding—for example, the fraction of programs' budgets funded by physics departments. At least four programs identify the National Science Foundation as providing some funding, either through a specific grant, or indirectly through national lab funding. Lead facilitators also report other sources of funding, such as private company funds, community donations, money from alumni and emerita faculty, and university endowments. Restaurants were also mentioned as contributing food to some events.

The results show that funding is necessary to keep these programs operational, and that institutional connection is the main source of financial support. In challenging financial times for universities, such as during COVID shutdowns, informal physics can be in a precarious position [17]. We also find that many of these programs rely on nonpaid volunteers to deliver activities—these free "human resources" allow operating budgets to be kept significantly smaller than if students were paid hourly for their efforts.

Over one-half the programs identify that they work with community partners to help with running events. Some community partners named were local community colleges, elementary and middle schools, children's or science centers, and local teacher organizations. The roles that were mentioned for these partners included providing the venue for events, help with advertising, arranging activities, and recruiting audiences. Programs that did not work with community partners had activities located at the home institution.

Assessment: The assessment category encompasses both assessment and evaluation techniques. Here we combine these two ideas into one category, as from our validation work, we found that some practitioners did not necessarily distinguish between these two terms in the same way that researchers or professional evaluators might. Thus, this category includes ways that programs check to see if they are achieving their goals as well as whether audiences are reaching certain learning objectives. Our research questions about assessment, as shown in Table I, are

- *How do informal physics programs assess or evaluate themselves?*
- *What instruments and tools do practitioners use for the evaluation and/or assessment of their program?*
- *How are evaluation and assessment used to improve informal programs?*

Facilitators of only six programs indicated that their program does some sort of evaluation or assessment, while the rest of the programs selected that they do not do any evaluation or assessment, or are unsure. For the programs who answered yes, the majority of them used surveys after events (either emailed or paper) to get feedback from the audience on event logistics, interest in STEM topics, and interest in STEM careers. A few programs used a combination of pre- and post-survey. One program mentioned doing interviews with some participants but did not explain a more formal analysis strategy. The main purpose of these measures was for reflecting on program goals and looking for ways to improve the program. The exception was one program that is part of a national lab with large NSF funding; this program does more extensive evaluation and has even partnered with faculty in a College of Education to do a research project on the program.

Based on our past experience as lead facilitators ourselves and in discussion with other members of the informal physics education community, we are not surprised by the fact that most informal physics programs have almost no formal evaluation or assessment built into their programs. It takes significant resources to collect and analyze this information even if for internal evaluation only. Conducting broader assessment or research is even more resource intensive and also requires expertise that many of the lead facilitators do not have as part of their training. Another significant issue is that typical assessments for formal physics learning environments are simply inappropriate for informal activities due to voluntary, often short term, and varied backgrounds of the audience. Typical formal education assessment techniques, like grades, standardized tests, and even presurveys and postsurveys would not provide accurate information and would likely have audiences opt out of or may in fact turn audiences off of the event altogether.

For the programs that did not report formal assessments, we do know from follow-up interviews that lead facilitators often have anecdotal evidence and other informal evaluation measures, such as gauging audience attendance from event to event, or observing audience vocal response and body language. Many lead facilitators also express a strong desire to do more formal assessments. In the informal STEM community, there are embedded assessment techniques that are often employed which practitioners in physics are likely not familiar with. Assessment seems like a key area of growth for informal physics practitioners going forward.

X. LIMITATIONS

There are of course a number of limitations to this study. While the development of the framework and instruments were done with a nationally distributed sample, the specific application and results presented are the product of looking at only one state. The methods for data collection created a total pool of 69 contacts from 61 programs in twelve different states; however, the response rate was not 100% for Michigan programs. We also likely missed some programs that exist and were not contacted. Thus our data represent a subset of the actual landscape in our test state. From personal experience, we are aware that more types of physics informal programs exist, and therefore our categories are not exhaustive.

Another key methodological limitation is that all our data are self-reported, including audience and volunteer numbers. The existence of the programs and recent events are corroborated by us from looking at the programs' websites and reviewing materials provided by the programs including publicly available documents, but the specific details are otherwise based on the self-reported information of the interviewee and not independently verified. Presumably, shortages of funding or lack of continuation of who manages the programs makes online information less reliable for more grassroots programs with higher turnover and less resources. Additionally, our study was only able to capture programs that are currently operational. We were not able to collect reliable information about programs that began and ended or are currently on hiatus.

Because of the small data collection sample size, we cannot extrapolate the demographics of participants to broader trends for the whole country. However, the demographics of the participants provide some context for the sample when compared to demographics for the physics community at large. We did not sample efforts from lone individuals, industry groups, and nonprofit STEM organizations that operate independent of physics institutions. Thus, we are not documenting some ways that audiences can engage with professional physicists. Finally, our survey and interview protocol cannot include the audience's perspective nor the perspective of other facilitators, such as volunteer physics students. As such, we do not capture the full experience of these informal physics activities.

XI. DISCUSSION

Informal programs can open the door to both public audiences and physicists to interact and engage using the medium of physics. In this work, we explore how organizational theory can provide information about the nature of informal physics programs. Our data across the six main categories of personnel, program, audience, institution, resources, and assessment show that informal education programs provide opportunities for sizable numbers of people to hear about current topics in physics and astronomy research, do interactive activities, and talk with professional physicists and physics students. Importantly, we find that undergraduate and graduate students are key groups of facilitators for these programs.

Overall, the main contribution of this work is a contextualized framework for describing and discussing informal physics activities. Talking about informal physics activities solely by program format does not tell a complete story about their complexities and impact. Further, looking at program data in aggregate allows us to better understand the breadth and depth of the opportunities that are available to particular audiences. Figure 13 shows a variety of specific dimensions of informal physics programs that are associated with six main components of the contextualized organizational framework. These dimensions represent a summary of our findings as well as the associated research questions presented in Table I. We propose these dimensions as useful guideposts for administrators, program lead facilitators, researchers and funding agencies to understand the multifaceted nature of informal physics programs. We also hope that they can be used to foster connections between administrators, researchers and practitioners, such as in collaboration on research, or advocacy for institutional support.

From our application of this framework to a test case state, we can also identify places where programs might improve and expand on connections with audiences. Some key takeaways are the following: Institution location and available resources affect the geographic reach of programs. Differences in geographic climate and population density may also affect program format, such as travel requirements to attend events. Audiences from marginalized and minoritized groups are not necessarily engaging in the programs offered. While all of the programs in our sample have some type of audience interactions built in, the majority of programs do fall under the presentation-style format, with limited contact time. Programs with the longest histories and more robust means of assessment are tied to national grants for large facilities or long-term institutional funding; newer programs or programs run by student groups may face additional challenges, and they may not have the resources to evaluate at a deeper level their impact on audiences.

It is important to note that COVID-19 resulted in much upheaval for informal physics programs. Personnel were not all available on campus to plan activities, audiences were not allowed to congregate in large numbers or touch equipment, many venues were closed, and budget cuts hit institutions. During the pandemic, we followed up with program leaders from our data set and investigated the impact of COVID-19 and its related restrictions on their operation and performance. Our COVID-19 study suggested that programs that stayed in operation relied largely on the efforts of individual directors or facilitators to make substantial adaptations [17,18]. In addition, strong ongoing

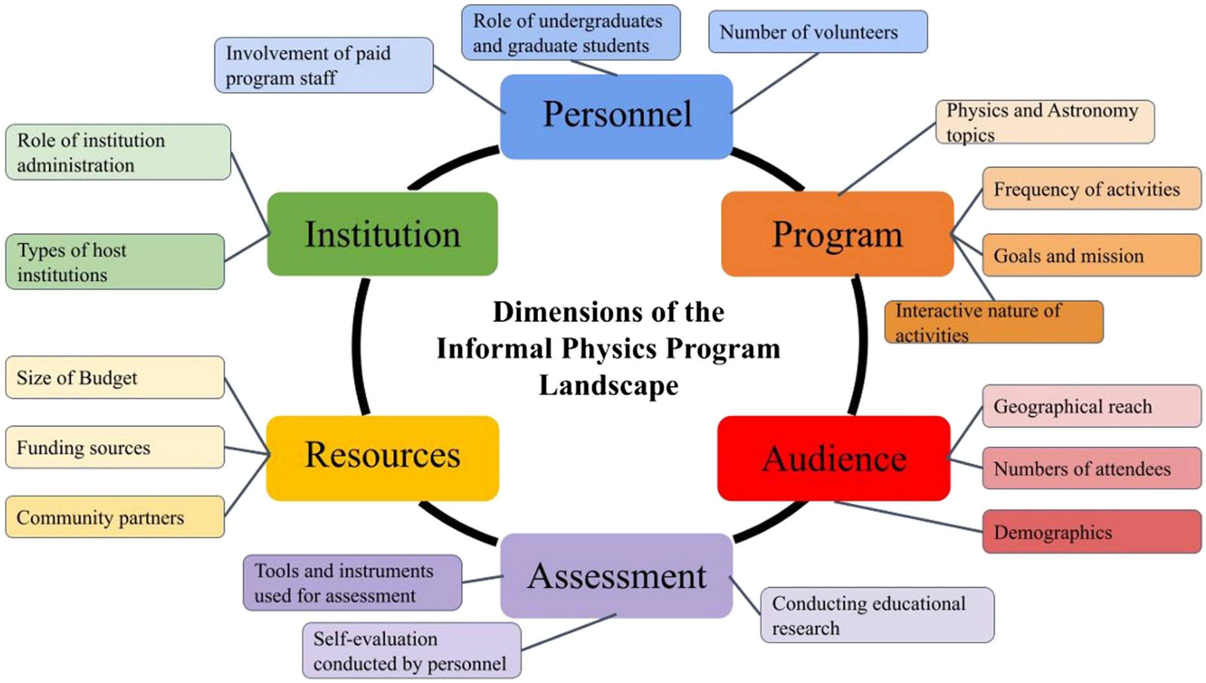

FIG. 13. Landscape dimensions associated with six main components of the organizational framework for the informal physics programs. These dimensions can be useful for practitioners, researchers, and administrators to make connections with other programs and to situate their work in multiple ways.

institutional support played a significant role for maintaining program activities during the pandemic.

XII. FUTURE WORK

It is clear that informal physics programs are operating throughout the country, and they are a substantial educational enterprise of the physics community. In future work, we plan to collect data from additional programs across the country to add to the types of program formats, to look for themes of content and connect them to geographic location, and to do more cross-program comparison. We are also looking at interview and observation data qualitatively to explore the complexity and challenges that informal physics programs contend with across all the framework categories [54]. In preliminary work, site visits have already shown to be useful to gain insight into the nuances of program functionality [50].

Finally, it is crucial that we connect this research to current practice. The informal physics practitioners who have participated in this study are not just subjects, they are people who want to contribute to the research itself so they can have a better understanding of how their efforts are situated with respect to other informal physics programs. They also want to understand how to better connect with audiences, how to create physics content that is meaningful, and how to measure the impact of their programs. We are thus developing practitioner-oriented materials to communicate the findings of this study. Such materials can allow programs to leverage their participation in the study towards their institutions, funding agencies, and other stakeholders.

Note that if you are involved in an informal physics or astronomy program and would like to contribute to our study, the current survey is available in Ref. [55] https://sites.google.com/msu.edu/informalphysics.

ACKNOWLEDGMENTS

We would like to thank all of the lead facilitators of the informal physics and astronomy programs who participated in this study. This paper is part of the project supported by NSF AISL No. 1713060.

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