IDENTIFYING THE FOUNDATIONAL STRUCTURES OF INFORMAL PHYSICS PROGRAMS TO SUPPORT PROGRAM LEADERS AND THEIR VOLUNTEERS

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ABSTRACT

Physicists, physics students, and community members engage with each other through a variety of informal physics programs. These programs differ in format, such as after school programs, public lectures, planetariums, summer camps, and other non-formal classroom environments. These programs also differ in the physics topics they cover, activities, audience demographics, frequency of events, and involved personnel. While studies have found that these programs have positive impacts on audiences and volunteers, we do not fully understand the organizational and programmatic structures of these programs or their impacts on those involved with these programs.

In this work, I apply an organizational theory framework to understand and analyze six functional aspects of informal physics programming: *Assessment*, *Audience*, *Institution*, *Personnel*, *Program*, and *Resources*. One finding is that the personnel have a central role in the functionality of these programs, however, program leaders often experience challenges because most of the responsibilities are placed on a single person. Program leaders state they want to do more assessment of their programs, but lack the time, resources, or experience to do so. Building off of my findings, I developed an empirical framework of key components. This framework identifies 12 key components of informal physics programming that program leaders have control over and that are important to the program's functionality. Identifying these components lays the groundwork for developing tools and resources that program leaders can use to support and improve their programs. Multiple of these components are centered around the recruitment and support of volunteers. Since these are voluntary positions, understanding the motivations of volunteers can help program leaders to better support their personnel. I interviewed alumni who had volunteered in informal physics programs as university students. I applied a volunteerism framework to understand their

motivations for volunteering in the first place and the impacts that volunteering had on their career pursuits. The findings of these studies help to identify the aspects of informal physics programs that are crucial for program functionality and how some of these aspects impact those who facilitate these learning spaces.

"THIS IS SO COOL! THERE IS SO MUCH SCIENCE IT MAKES ME GO AAAHHH"
-First grader who yelled at me when I visited their school with science experiments.

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1.1.1 People Engage with Science Outside of the Classroom

There are many different ways to engage the community with science. One seemingly obvious way is to teach science when people are in school so that they grow up to be scientifically literate. However, learners spend the majority of their lives outside the classroom [1]. As such, people continue to learn outside of their classroom experiences, leading to the creation of out-of-school-time activities.

In the United States, out-of-school-time activities have existed since the 18^{th} century, providing academic and social experiences, and have evolved over time to include more science learning opportunities [2]. Presently, the landscape of out-of-school-time learning for the sciences has grown for children and adults through a variety of opportunities like after-school programming, camps, museums, popular media, public lectures, citizen science, and more [1, 2]. In the present day, young adults are often engaging science content online through social media platforms [3]. While the methods for engaging the public with science differ in format, content, intended audiences, and frequency of events [4], audiences can build upon their scientific interest, identity, and knowledge [5, 6, 7, 8, 9].

There is a large decrease in interest in science among students around the time that they are in middle school [10, 11]. There is often a disconnect for students between the science they learn in school and its applicableness to their everyday lives [12]. This is partially due to the stressful environment of classroom spaces, which includes strict timelines and high-stakes assessments [1]. Students who struggle in the formal classroom structure have demonstrated competence on the same subject material in out-of-school contexts, in part due to their ability to explore the content in a way that was comfortable and interesting to them; this is impactful for students who are from non-dominant cultural or lower socioeconomic groups [1, 13, 14].

Children are not the only ones who benefit from participating in out-of-class activities. Adults also attend science learning opportunities in their free time. For example, attendees of science festivals get opportunities to have direct conversations with scientists about more complex science topics [15]. It has also been shown that attending science centers, museums, aquariums, etc. helps to promote scientific understanding and action [16, 17].

1.1.2 Scientists Facilitate Science Engagement Outside of the Classroom

There is a widespread push for scientists and researchers to engage with the greater community. Arguments for doing so vary. As Thomas and Durant note, the range of arguments include benefiting individuals as society becomes more scientifically and technologically advanced, recruiting members to participate in the scientific community, inform governmental decision making, and lessen the divide between scientists and people who are not experts within that specific field [18]. Thomas and Durant note that these arguments imply different underlying motivations. In this dissertation, we will see some of these different motivations manifest in how physicists engage with the public.

To further promote that researchers should be engaging with the broader public, university mission statements often include points about commitment to outreach and engagement. For example, Michigan State University's mission statement declares that one of the ways the university will “advance knowledge and transform lives” is through “advancing outreach, engagement, and economic development activities that are innovative, research-driven, and lead to a better quality of life for individuals and communities, at home and around the world” [19]. The National Science Foundation (NSF) requires funding proposals to include a Broader Impacts Statement detailing how the project has “the potential to benefit society and contribute to the achievement of specific, desired societal outcomes” [20]. NSF lists public engagement as one of the ways broader impacts can manifest [20]. While there is a push for researchers and scientists to get more involved in public engagement, there is a need to understand the structures that are necessary for effective programming. To do this, we should first look at understanding the fundamental components of public engagement programs that currently exist.

While there has been a push for scientists to engage with the public, it is often presented with a deficit-lens that engagement is something that scientists do to benefit everyone else, and some scientists do not see the direct benefit for themselves [21, 22]. Scientists are often concerned about the “co-production of knowledge” and disturbed by the idea of science being “informed by the public” [21]. However, there are great benefits from having the scientists and the generally public meeting and sharing ideas with each other. For example, there is a push for reflexive engineering, where engineers consider engineering problems with social, economic, and environmental barriers in mind [23]. An example that Robbins provides deals with a team tasked with developing an irrigation system for a rural village. A traditional engineering approach is for the engineers to say “this is the answer” without considering the logistics of how the system will be monitored or maintained by the community once the engineering team leaves. A more successful approach is to have the farmers and other community members involved in the process, as they also have expertise on the soil, types of crops they will be farming, etc. [23]. That, however, requires communication and pedagogical skills, as well as experience working with and collaborating with community partners, which are all skills that facilitators of informal physics programs gain and improve upon in informal spaces [24, 25, 26, 27, 28].

There is also a long history of inequity in the sciences. For example, the physics community is about 80% male and 70% white [29, 30]. Participating in public engagement has helped many scientists, especially those from underrepresented groups, to persist in their careers and build their sense of belonging [31, 32, 33].

1.2 Terminology

The words and terminology used when describing the various learning environments that take place outside of the classroom vary across researchers and practitioners in different fields. Even within certain academic fields and across disciplines, people will use different words to describe the same thing, and the same word to describe different things [34, 35, 36, 37, 38]. Here, I will define some of the common terminology used, and how I will be using these terms throughout the rest of this dissertation.

1.2.1 Formal Learning Spaces

These are more traditional classroom settings. Typically, in these spaces, students are given a grade or course credit. In many instances, students are required to take the course and can not opt-out.

1.2.2 Informal Learning Spaces

In many instances, informal is considered to be the opposite of formal, in that the learning takes place outside of a traditional course setting. Sometimes these spaces are referred to as "free-choice" because learners can choose to opt in or out of participating, and choose the level of their participation, in these spaces [1, 17, 34]. Due to this and the absence of aspects like grades, the stakes are considered low for participants compared to formal learning situations.

When it comes to learning outside of formal spaces, there are often variations in terminology. For example, in the report, *Formal, Non-formal and Informal Learning in the Sciences*, non-formal learning is described as being organized in some way with no credit awarded while informal learning is never organized and not guided by a curriculum [39]. This report characterizes non-formal activities as being led by someone with more experience, with an example including guided programs at a National Park, while informal learning is driven more by the learner, such as learning from a casual conversation with a friend [39].

As a counter example, *The International Handbook of Physics Education Research* also defines non-formal spaces to have structure, like a personal development course, while informal physics education as without formalized structures. However, the handbook breaks informal physics down into four blocks [34]:

- Informal physics education (non-designed), where learning takes place in spaces that were not purposefully designed for learning to take place
- Informal physics education (designed), where physicists design activities for learners
- Public engagement with physics, where physicists and members of the public have beneficial interactions with each other

- Physics communication, where physicists provide activities and content through various forms of media like podcasts, books, etc.

The second and third points especially conflict with the previous definitions that informal is without structures. Designed informal physics education and public engagement have structures. The activities are often designed by a physicist and the content was predetermined in some way and the learner opt-ed into joining that organized activity. The organization and structures certainly vary in rigidness across programming, but there are structures nonetheless.

Another key point is that non-designed informal physics education and physics communication often, but not always, lack the direct interactions between the physicist and the learner. Designed informal physics education and public engagement often have opportunities for direct interactions between the physicist and learner.

For the purpose of this dissertation, I am going to analyze not-for-credit physics learning spaces where there is a direct interaction between the learner and the person facilitating the learning space. I will be referring to these as *informal physics spaces.* For example, one type of informal physics space is a science festival where attendees are able to converse and interact with the scientists who are facilitating science activities. This would be an informal space because the scientist and the attendees are able to have direct interactions with each other.

1.2.3 Communication and Popular Media

Other ways that scientists present scientific information with the public is through "science communication" and popular media. Some examples of these approaches include popular science books, podcasts, online videos, apps, and TED talks. In most of these examples, knowledge flows one way from the scientist to the audience. For example, with a popular science book, a scientist writes a book based on their expertise, and then a consumer reads that book. In that case, the reader has no direct interaction with the scientist nor is the scientist learning directly from the reader.

In some instances, there can be some interaction between scientists and members of the broader public. For example, scientists may use X (formerly known as Twitter), YouTube, TikTok, and other social media platforms to share scientific information [34]. Through these mediums, people can leave comments and responses for the scientists, which can lead to a form of online dialogue about science. The level of constructive online interaction varies dramatically.

The examples that I have provided are typically led by a single scientist rather than an organization of scientists. In this dissertation, I am primarily interested in programs where physicists and audiences are directly interacting with each other in real time through some form of a physics activity. For example, public lectures are ways that physicists present their research to non-physics experts. In this dissertation, I focus on how speakers were recruited, how venues were selected, what audience interactions look like, frequency of events, and other organizational decisions. I do not directly focus on how Physicist A gives talks on their own or how Physicist B writes books. As such, this dissertation does not directly focus on physicists who do science communication or popular media.

1.2.4 Outreach and Public Engagement

Outreach and engagement are terms that are often used interchangeably by some people while others define them as being different ideas. Physicists may say that they do outreach when in reality they actually do engagement while some physicists describe their work as engagement when they actually do outreach.

In the community engagement field, outreach refers to a one-way flow of knowledge from the university to the public [38]. In this physics context, this frames the physicist as the sole contributor of knowledge that the public audience is learning from, which can be very deficit-oriented in many cases.

Engagement implies that the community and the universities have relevant knowledge that they share with each other [38]. In the informal physics context, this implies that there is a back and forth collaboration between physicists, audiences, and community partners in creating events and activities that are meaningful and relevant to each party.

The physics community is adopting the term *public engagement* [40], however, it is important to reflect upon the use of the word *public*. The public is often, though not always, considered to be people who are not acting in the role of the expert [18], i.e. in physics public engagement, the public would be people who are not the physicists or physics students facilitating the activities. This form of framing in informal physics programs, however, pins physicists as not a part of the greater public. There has also been a history of framing "the public" as scientifically ignorant and in need of a scientific expert rather than as people with their own expertise and knowledge that they can contribute [41, 42, 43, 44]. While the "public"" aspect of public engagement may be deficit oriented, it is the direction that the physics community, leaning heavily on the *engagement* aspect to assume that physicists and non-physicists are both learners in these environments [34, 45].

1.3 Informal Physics Programs

For this dissertation, I will be focusing on programs that facilitate informal learning spaces centered around physics content and activities. Examples of these types of programs include public lectures, planetarium shows, open house events, science festivals, summer camps, and after-school programs [4, 34]. While we know about different styles of programs, there is no national database of programs, and details about these programs are difficult to find and sometimes inaccurate [4, 46]. There was a survey conducted by the American Physical Society's (APS) Forum on Outreach and Engaging the Public (FOEP) that asked members about their public engagement and outreach work [47]. Over 68% of APS members who took the survey reported engaging with the public with the most popular formats being public lectures, demonstrations, and educational programs [47]. While these are the most popular ways of engaging with the public, there is still limited information on the structures and other details of this type of programming (audience demographics, program size, number of personnel, etc) [4], hence my focus on informal physics programs for this dissertation.

While outreach and engagement are sometimes thought of as two separate things, the programs that I analyze fall in varying points of a spectrum between outreach and engagement. Multiple programs that I analyze are public lecture series where physicists give a talk about a physics topic, usually about their research. This type of program is more on the outreach end of the spectrum; however, some of these lecture series may implement aspects of engagement. For example, a public lecture program may provide opportunities where the physicists and audience members are able to converse with one another and ask each other questions. Also, feedback opportunities could allow audiences to have a voice and influence on the types of presentations. This type of program can collaborate with community partners, such as event venues, to develop programming.

An example of a program that is high engagement is an after-school program that partners with some teachers and hosts activities where students can create or design their own experiments. In this case, the physicists may have the content knowledge, the teachers have knowledge on working with K-12 students, and the students have more autonomy in their physics exploration.

Throughout this dissertation, I will primarily refer to these informal physics programs as engaging in public engagement; however, many of the research subjects interviewed in this work may be quoted as saying outreach. The reality is that each program analyzed in this dissertation rests somewhere somewhere within this outreach-engagement spectrum.

1.4 Physics Education Research: A Discipline-Based Approach

Even though informal physics programs differ from classroom environments, they are still educational learning spaces. Therefore, educational research practices are useful in understanding some of the structures and experiences within these programs.

Discipline-based education research (DBER) focuses on understanding and improving science and engineering education [48]. While certain skills and practices may be applicable across different science and engineering disciplines, there are also challenges and goals that may be discipline specific. Therefore, DBER studies utilize expert knowledge to complement and inform the ways of knowing in that context [48].

Physics education research (PER) is one of the original DBER fields, with its origins dating back to the late 1800s/early 1900s to address concerns about the quality of physics education [48]. The American Association of Physics Teachers (AAPT) was established in 1930 to address some of these concerns [48, 49]. However, PER as a field of research did not structurize more in the 1970s and 1980s when the first PER PhDs were earned and research groups doing PER began to form within some physics departments [50]. Around the 1990s and the early 2000s are when PER publications and the research community increased substantially [48, 50, 51]. While PER has primarily focused on formal learning spaces like classrooms, there has been a growing amount of research in informal learning spaces in physics.

1.4.1 Physics Education Research in Formal Spaces

The majority of PER work is centered around classroom instruction, which includes courses in K-12, two-year college, and four-year college settings, with the latter being the most studied [52]. PER studies on undergraduate physics courses typically focus on conceptual understanding, problem solving, curriculum and instruction, assessment, cognitive psychology, and attitudes and beliefs about teaching and learning [53].

PER studies have had pivotal impacts in classroom structures and learning outcomes. For example, the implementation of undergraduate learning assistants in the classroom makes undergraduate students more comfortable with sharing their ideas and getting feedback [54]. Students in courses where they are able to interact with learning assistants tend to score higher on concept inventories than students in classes without learning assistants [55].

Classroom structures have also evolved. Physics classes are moving away from traditional lecturing to design set-ups where students work together in small groups and the instructional staff, which may include the instructor, graduate teaching assistants, and undergraduate learning assistants, are able to more easily engage students on a personal level [56, 57].

1.4.2 Physics Education Research in Informal Spaces

A growing sub-section of PER is informal physics education research (IPER) [58], which primarily looks at physics education outside of typical classroom settings [34]. Informal physics studies have looked at the impacts on audiences, finding that the positive impacts on children include building scientific interest and identity in addition to overall content learning [5, 6, 7, 8, 9].

Many informal physics facilitators are university students [4]. Studies have shown that student volunteers build a variety of professional skills such as being able to communicate to different audiences and implementing varying types of pedagogical practices [24, 25, 26, 27, 28, 32, 33]. As informal physics spaces tend to be less structured than formal spaces, student volunteers tend to have more autonomy and agency in their work, which can contribute to building their confidence, physics identity, and participation in physics [32, 33, 59, 60, 61, 62, 63].

1.5 Research Goals and Structure of this Dissertation

While there are noted impacts on informal physics audiences and volunteers, there is still limited understanding on the structures of informal physics programs and the long-term impacts on volunteers. This dissertation contributes to the growing field of IPER by studying the important structures of these types of programs, particularly on the importance of personnel for the operation of these programs. My research questions include: *What are the important structures of informal physics programs? What do the roles of personnel in informal physics programs look like? What are the important aspects of programs that* *program leaders can control? How can program leaders help to support their personnel? How do the structures of these programs impact their student personnel long term?*

Chapter 2 provides the methodological and study design considerations made to answer these research questions. I used a case study methodology to compare and contrast informal physics programs that differ in format and content covered. I apply an organization theory framework to analyze the structures of programs and use a volunteerism framework to study the motivations of student volunteers in these programs. Chapter 3 looks at the core structures of informal physics programs, identifying personnel as playing a central role in these programs. In this chapter, we also find that program leaders have a desire to conduct assessment within their programs, but lack resources, experience, and time to carry that out. Chapter 4 is the development of a practitioner-friendly framework identifying the key components of informal physics programs. This framework is meant to serve as the foundation for the future development of assessment tools and resources that program leaders can use. Building off of the findings of Chapter 3, this key components framework identifies multiple key aspects for personnel. Chapter 5 analyzes the impacts of volunteering in these programs on student volunteers' careers and professional motivations. This chapter is centered around interviews with alumni who had volunteered in an informal physics program as a university student.

Chapter 2. Approaches to Study Design

As stated in Chapter 1, my research questions aim to 1) understand the structures of informal programs in a way to help better support program leaders, and 2) understand the impacts of informal physics programs on their student volunteers. In this chapter, I lay out the multiple frameworks and methodological considerations that inform the studies in the rest of the dissertation.

Chapters 3 and 4 focus on my research primarily on the program structures. In Section 2.1.1 below, I turn to the business literature and use an organizational theory framework, which has been used to study organizations like non-profits. Chapter 5 examines the motivations of volunteer alumni in informal physics programs. In Section 2.1.2 below, I describe a volunteerism framework that I use in the informal physics space to test its ability to measure student motivations in volunteering.

In Section 2.2, I describe key methodological approaches used in Chapters 3, 4, and 5. In Section 2.2.1, I describe my use of case study, specifically comparative case study, in order to better understand the similarities and differences between different types of informal physics programs. In Section 2.2.2, I discuss the multiple processes used to recruit research participants.

For the studies in Chapters 3, 4, and 5, I utilized interview, survey, and site visit data. In Section 2.2.3, I discuss the pros and cons of each of these forms of data. In Section 2.3, I present my published work on how these types of data can be used together to form a more holistic view of informal physics programs.

2.1 Theoretical Frameworks

As mentioned above, in order to answer my research questions, I applied a couple of theoretical frameworks to guide my research. Organizational theory has been used to study the structures of different types of organizations, including non-profit organizations. As described in Section 2.1.1.2, I use an organizational theory framework that has been contextualized to the informal physics context in order to better understand the key structures of informal physics programs.

In addition to studying the structures of programs themselves, I am also studying the impacts that programs have on their university student volunteers. To do this, I apply a volunteerism framework in the informal physics context by interviewing university alumni who had volunteered in informal physics programs. This provided some insight into the motivations that volunteers had for volunteering and the impacts that volunteering had on their careers.

2.1.1 Organizational Theory

According to Lawrence and Lorsch, "An organization is the coordination of different activities of individual contributors to carry out planned transactions with the environment" [64]. An organization is a group of people trying to achieve a set of common goals through collaboration and distribution of tasks, although each individual may also bring their own set of personal goals to the situation [64, 65]. Examples of organizations are non-profits, businesses, and government agencies [64].

Since organizations are ubiquitous in many societies, a field of research has developed to understand how organizations work. As defined in the in *Organizational Theory, Design,* *and Change* [66], "Organizational theory is the study of how organizations function and how they affect and are affected by the environment in which they operate." This theory is used to examine the structures of how tasks and resources are distributed to meet the organization's goals, the cultural norms and values of the people inside and outside of the organization, and the actions taken to achieve the goals of those inside and outside of the organization [66].

There are two levels of analysis in organizational theory: *intraorganizational*, which looks at the internal relationships and structures, and *interorganizational*, which looks at the relationships and environments external of the organization [67]. It is important to analyze both the intraorganizational and interorganizational levels as both influence each other and impact the organization's approaches and ability to achieve its goals [67].

To help understand what organization theory is used to analyze, consider a business as an organization. Within this business, the organization has its own goals that it is trying to achieve. Within the business organization, there are workers, managers, and so on who work for the organization; however, these people also have their own personal goals and relationships with the other people in this business. An action that a business takes to achieve its goals is to have labor contracts with its employees. Outside of this business, the organization can also be involved in a larger network of other business which has its own structures. The organization also needs to consider the relationships it has with other outside organizations, such as suppliers and distributors. An action a business can take is to subcontract with other organizations for particular tasks. Organizational theory is used to analyze these different types of structures, relationships, and operations because each of these components influence how the business works to achieve its goals [67, 68]. Table 2.1, originally developed by Jaffee [67], details the levels of analysis with this example.

Table 2.1: This table was originally published in Jaffee [67]. This table shows the people, structure type, and transaction between the organization and those it has relationships with.

	Intraorganizational	Interorganizational
Definition	Within the organization	Between organizations
Structures	Bureaucracy	Network of interorganizational relations
Relationships	Workers, managers, coworkers	Suppliers, manufacturers, distributors, regulators
Transactions	Employment contract	Market exchange, subcontracting

The goals of a business, however, are quite different from those of an informal physics program. For example, while informal physics programs may be concerned about money in terms of being able to buy supplies for their activities, their goal is not typically profit oriented. A type of organization that the informal physics programs more closely resemble is a non-profit.

2.1.1.1 Organization Theory to Describe Non-Profits

The list of types of nonprofits is long. Examples include, but are not limited to, research institutions, schools and universities, health organizations, humanitarian organizations, foundations, and advocacy groups [69]. A precise definition of non-profit organizations varies across countries and even fields of study. However, some core aspects are that non-profit organizations are self-governing, profits are not distributed to directors or other members in the organization, they are institutionally separated from a government (however they can still receive funds and other supports from the government), and there must be some voluntary or non-compulsory aspect within the organization [69].

Non-profit organizations have their own goals, as well as they have to consider the internal relationships and goals with their members as well as external relationships and goals with their stakeholders in order to achieve their goals [70], making organizational theory a useful tool in analyzing nonprofits. People who have an influence on nonprofit organizations include, but are not limited to, volunteers, paid personnel, collaborating nonprofits, community partners, public administrations, private companies, schools, universities, and the general public [71]. Each of these groups bring their own goals, contributions, power, and influence in what nonprofit organizations aim to achieve and how they work to achieve those goals.

In their meta study, Tayşir and Tayşir did a deep literature review on the dimensions of nonprofit organization effectiveness and the different ways that effectiveness has been measured [70]. They compiled a list of effectiveness indicators from their literature review and asked nonprofit organization board members and leaders to identify which dimensions were most important to them for measuring the performance of their organization. From the responses of 69 nonprofit organizations, Tayşir and Tayşir identified six main dimensions of nonprofit organization effectiveness: Board (corporate governance), Managerial (strategic planning), Resources (fundraising and recruiting volunteers), Financial (budgeting and audits), Environmental (sustainability of technology used), and Program (stakeholder and client satisfaction of projects) [70]. While these six areas are presented as separate, they are closely related to each other and can influence each other. For example, if a nonprofit organization is unable to fundraise enough funds, their budget will be limited, which will impact the number of people they can hire and recruit to carry out their project tasks, and that can negatively impact their relationship with stakeholders and clients.

2.1.1.2 Organization Theory to Describe Informal Physics Programs

In Chapter 1, I discussed the breadth of informal physics learning activities. Informal physics programs share many characteristics that are also found in organizations. The programs have structures in the format of their activities, there are power structures among those running the programs, there are pressures and influences from outside sources like community partners, public members, and institutions —all of which impacts the goals and steps to achieving those goals.

Fracchiolla et al. used a nonprofit organization theory framework to analyze informal physics, finding that there are similarities between nonprofit organizations and informal physics programs [72]. Notably, they found that informal physics programs are adaptable to their changing funding sources, align their goals with their own mission statements and their funding partners, and have access to tangible and intangible resources like physical space locations and volunteers [72].

Some elements of a nonprofit organization framework do not completely make sense in the context of informal physics programs. For example, "board members" are not really applicable in most informal physics program spaces. In Izadi, et al., elements of the nonprofit organization framework were contextualized to be more relevant to the informal physics space [73]. In their contextualized framework, informal physics programs have six main dimensions: Personnel, Program, Resources, Audiences, Institution, and Assessment, as shown in Fig. 2.1. Definitions of each dimension are listed in Table 2.2.

Table 2.2: Definitions of each of the six dimensions of the organizational theory framework contextualized for informal physics programs. This table was originally published in Izadi, et al. [4].

Categories	Definitions
Personnel	The people involved with the functionality of the program.
	Examples: directors, presidents, volunteers, graduate students.
Program	Logistical and programmatic details of the organization.
	Example: content, structure, history, objectives.
Audience	The people that the organization is reaching.
	Example: local communities, K-12 students, college students.
Resources	The physical and financial assets that the organization utilizes.
	Example: donations, physical spaces, grants.
Institution	The umbrella establishment that the program is housed under.
	Example: Universities, National labs, Physics centers.
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.

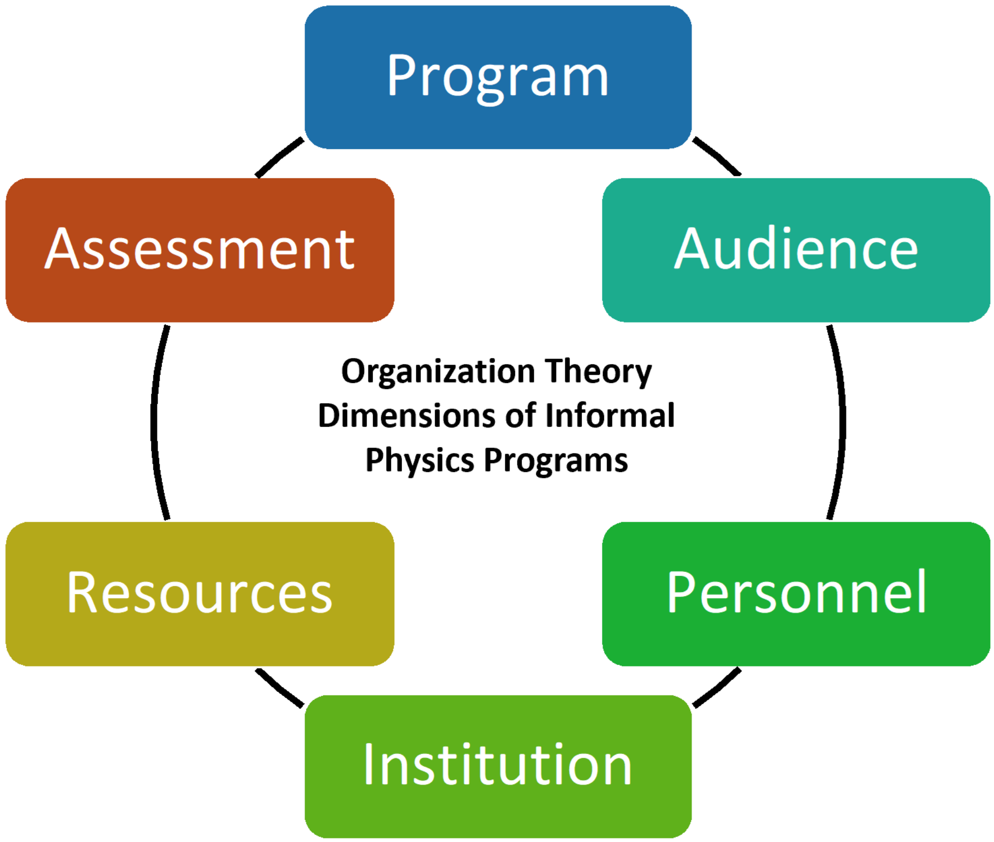

Figure 2.1: This figure shows the six dimensions the organizational theory framework adapted to the informal physics context. Definitions of each dimension are listed in Table 2.2. A variation of this figure was originally published in Izadi, et al. [4].

In Chapter 3, I will use this contextualized framework to do a deeper analysis on the structures of informal physics programs. I will analyze all six dimensions with a heightened focus on the Personnel dimension to understand the roles of personnel in informal physics programs. Chapter 4 will expand off of those findings and look at the development of a framework that can be used by informal physics researchers and practitioners to evaluate programs.

2.1.2 Volunteerism Framework

As will be discussed in Chapter 3, the most prominent organizational theory dimension is Personnel. Given the central role that personnel have in informal physics programs, I am interested in the motivations of people who volunteer in these spaces. In Chapter 5, I test a volunteerism framework to understand why university students volunteered in informal physics programs and how it impacted their career pursuits.

In the midst of the COVID-19 pandemic, 23% of Americans formally volunteered through some sort of organization while over 50% of Americans engaged in some form of informal helping [74]. Prior to the pandemic, those numbers were even higher [75]. Examples of formal volunteering include public health efforts, support food banks, and mentoring students, while examples of informal helping include doing favors for neighbors such as lending a hand and watching each other's kids, all of which can benefit the greater community [74].

There are also benefits for the volunteers themselves, for example, improved physical and mental well-being, job and career opportunities [76]. In addition, volunteers gain leadership and communication skills in addition to building upon other specialized skills that they can use in their own work place [77]. These benefits also influence some of the volunteers motivations for volunteering in the first place.

People may volunteer in the program or activity for different reasons. Clary and Snyder present six motivational categories for volunteers as described in Figure 2.2: Values, Understanding, Enhancement, Career, Social, and Protective [78, 79]. This framework originates from work in psychology and was tested in a variety of volunteering contexts like public health, business, and student work [78]. Listing six categories does not imply that they only volunteer for one of these reasons. Volunteers may have multiple motivations of varying weights that influence their involvement. In addition, if a volunteer stays with a program or activity for a while, their motivations for doing so may evolve over time.

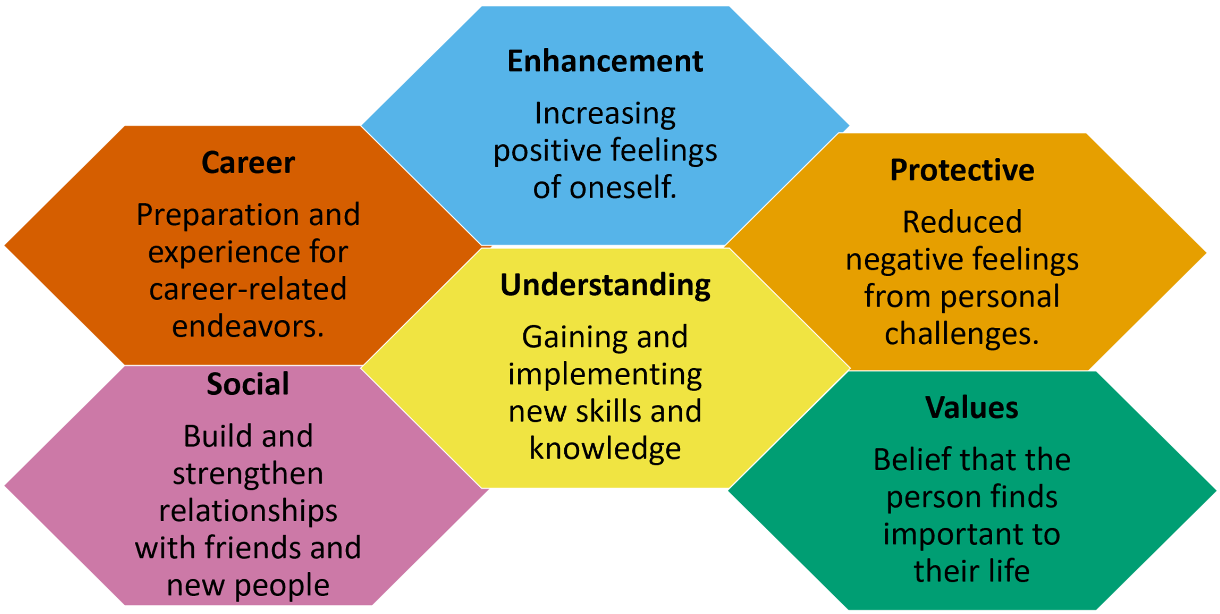

Figure 2.2: This figure shows adapted definitions of the six volunteerism categories [78, 79, 80, 81, 82, 83]. This figure originally appeared on a poster presentation at the 2023 Physics Education Research Conference in Sacramento, CA [84].

While this framework originally aimed to describe volunteerism more broadly, these motivational categories may need to be adjusted or adapted to the specific context that it is being applied to [78]. For example, this framework has been used in a variety of scientific contexts, but there were changes to the category names or some additions based on the situation. Wright, et al. applied this framework to a bird conservation citizen science program to study the relationship between volunteers motivations and their satisfaction within the program [80]. Similarly, Domroese and Johnson studied the motivations of volunteers in the Great Pollinator Project and how well the program met those motivations, ultimately making adjustments to their program protocols and training procedures [81].

Bruyere and Rappe found the same types of motivations in the framework to be present in their study of volunteers in multiple natural resource and land management organizations, but they also found another category unique to their specific context in which stated that a motivation for them to volunteer was to "get outside" [82]. This is important to note because going outside is a context-specific motivation that is not relevant or applicable to other forms of volunteering.

Like in the Bruyere and Rappe report, it is important to also apply this framework to other disciplines, like informal physics programs, to identify context-specific motivations. It could be that some types of motivations are less relevant to informal physics programs, and there could also be additional motivations that are unique to informal physics programs. In Chapter 5, I apply a volunteerism framework to identify and analyze the motivations and career pursuits of alumni who had volunteered in informal physics programs as university students.

2.2 Methodological Considerations

To answer my research questions, I used qualitative research approaches to understand the nuances and decision making that takes place within informal physics programming. In Section 2.2.1, I describe the methodological considerations I made in my research. I utilized comparative case study to analyze programs of varying format, audiences, and physics content to identify commonalities across different program types. To gather data for these case studies, research participants were recruited through convenience and snowball sampling approaches as described in 2.2.2. I collected and analyzed survey, interview, and site visit data, with each form of data providing a different perspective of a program as described in sections 2.2.3 and 2.3.

2.2.1 Case Study

Until around the 1970s and 1980s, education research was primarily quantitative [85]. Around this time, the use of case study in the USA and UK became more prominent as a reaction to the research community's and policy maker's bias for statistical analysis [85, 86]. Case studies provide a valuable context a nuanced perspective of a studied situation [87]. For example, a quantitative study may show what someone did, but a qualitative case study can provide context for intentions and motives [88].

What makes a case study is up for debate though as definitions vary across time and researchers [85]. Yin, whose background is quantitative research, views case study as a research method that can be used to explore, describe, or explain the item being studied [89]. Yin also applies traditionally quantitative views of validity checking in case studies, however, some critics argue that such validity checks are oversimplified for the complex nature of education research, and thus require different definitions for quality research [85, 89]. As Hamilton and Corbett-Whittier note, Merriams definition of case study has evolved from the description of a phenomenon to defining the case as a clearly bounded unit [21]. As a third example of a differing view on case studies, Stake views case study as a way to evaluate or learn about a specific person or program [90, 91].

There continues to be debate on whether case study is a method, methodology, or research design [85]. For my work, I apply the framing used by Hamilton & Corbett-Whittier and Elliott & Lukeš who view case study as an "approach to research" [85] and a genre of research [86] that uses a wide array of data types to "capture the complexity of relationships, beliefs and attitudes within a bounded unit" [85]. Throughout my research, informal physics programs as my cases. I am studying the complex nature of these programs, notably the perspectives and relationships of the personnel facilitating within these programs.

The specific case study approach that I am implementing in my research is comparative case study. A comparative case study allows for phenomenon to be tied to its specific context while also exploring the similarities and differences across other cases [92]. My goal with using this approach is to be able to compare the similarities of these different types of informal physics programs and be able to make claims about these programs more broadly. For example, in Chapters 3 and 4, I am analyzing the key structures of informal physics programs. However, if I just analyzed a public lecture series, there are some phenomena that may only be relevant to the context of public lecture series and not other types of programs, for example after school programs. Therefore, I analyzed informal physics programs that differed in format, content, audience demographics, and type of personnel. As discussed in Chapter 1, I am only analyzing informal programs where physicists and physics students are engaging with audiences. I am not analyzing science communication and popular media work that individual physicists may do.

2.2.2 Recruiting Research Participants

This work could not have been done without the involvement of research participants. For the studies in Chapters 3, 4, and 5, there were several methods for recruiting participants as described respectively in each of those chapters. The main two methods used were convenience sampling and snowball sampling.

2.2.2.1 Convenience Sampling

Convenience sampling what the name implies, selecting participants because it is convenient [93]. A classic example of convenience sampling is in psychology and social science research, where the majority of research participants are college students [94, 95, 96]. In these fields, there have been arguments for and against using college students in these studies, but ultimately, the appropriateness of using these populations is dependent on the claims and research questions that the researchers are trying to make (for example, it may be inappropriate to conveniently use college students in a study and try to make broader claims about non-student populations as students may have differing cognitive skills or social relationships than older adults) [95]. That is not to say that convenience sampling is bad, the researcher just needs to clearly state the assumptions that they are making and the potential limitations.

Izadi et al., which my work is a continuation of, implemented a convenience sampling approach of surveying informal physics programs across the state of Michigan [4]. They surveyed programs across Michigan because most of that research team was based in Michigan and had some familiarity of the programs and could more easily travel to some of them. My work in Chapter 3 also looks solely at programs in Michigan. There are some limitations with only looking at Michigan programs. Programs in Michigan may not be representative of programs across the country. The needs, goals, and resources for programs could vary state to state. As such, additional participants were recruited around the country based on personal connections with the research team. Based on these personal connections, we were able to recruit participants running programs from across the country, which I report on in Chapter 4. A limitation from that is potential bias from the research members in analyzing the data. While I and the other researcher members attempt to minimize our bias, our knowledge and familiarity with various programs can influence the type of questions we ask and how we interpret participant responses. Our knowledge and experience can be beneficial as we can ask more detailed and probing questions, but it can also influence our interpretation.

2.2.2.2 Snowball Sampling

Often used in qualitative research, snowball sampling is when researchers ask some initial number of research participants to recommend other people who may be interested and meet the goals of the research project [97, 98]. A benefit of snowball sampling is that it is easier to access otherwise difficult to reach populations as there may be a level of trust between the research participants, however, there also comes a risk of selection bias as the sample is dependent on the researchers initial sample of participants [97, 99].

A snowball sampling approach was used in Chapters 4 and 5 in order to reach programs outside of Michigan. Some research participants were recruited through other means like at national and regional conferences, however, such approaches may overrepresent program leaders who were tenure-stream faculty with funds to be able to attend such conferences. As found in Izadi et al., program personnel are mostly university students and faculty members lower down in the academic hierarchy who may not have the resources to attend such conferences [4]. Therefore, using a snowball sampling approach helps to reach programs around the country that we may not have otherwise been able to reach.

2.2.3 Types of Data

For my research projects, I used a combination of survey, interview, and site visit data. Each form of data provides its own set of information and perspective on a particular situation, each with its own pros and cons.

Survey data is good for logistical information. As shown in Izadi et al. [4], survey data can provide information like the number of personnel in an informal physics program, the main jobs of personnel members, the content and topics covered by the program, program format, types of activities, how long the program has operated, number of audience attendees, etc. This type of data provides insights of what informal physics programs look like broadly. However, the survey information is limited to the knowledge and perspective of the participant filling it out. In addition, survey data provide limited insights on decision making within the program and do not easily allow for follow-up questions.

Interview data allow for more nuanced insights on decision making rationale. For example, in Chapter 3, I analyze interview data from program leaders in which the program leaders provide detailed explanations on how they choose program content and activities, the rationale on how tasks are distributed among personnel, the relationship between community partners, etc. While in an interview, we could ask the same questions that were in a survey, interviews already take a lot of time to conduct. By implementing a survey first, we can get logistical information more easily, and then use interview time more effectively to ask follow-up and clarifying questions to participants' responses. Similar to surveys, interview data is limited to what the participant says and then the researcher's interpretation of their responses.

Site visits are when the researcher visits the program to observe the program in person. I have visited and embedded with programs to witness how programs prep and organize their events as well as interact with the members of the program. Data from site visits include field notes, physical artifacts, and media (video, pictures, etc). Doing so provides context for the scale and operation of the program being analyzed. Unlike surveys and interviews, site visits are more so limited to the observations and perspectives of the researcher.

All three of these types of data have their strengths and weaknesses. Collecting and analyzing all three types of data creates a more holistic view and understanding of informal physics programs. For a more detailed description of this, see my published work in the following section (2.3). The findings of that work can be found in section 2.3.5.

2.3 How Site Visits can Help us Learn More

I have used site visits in my work to gain further perspective and first-hand observation of how some of the programs I am analyzing operate. I have found site visits to provide valuable information that complements other forms of data like interviews and surveys. The rest of this section was published as an article for the 2020 Physics Education Research Conference Proceedings [100] and is provided here verbatim with only formatting changes. The author order on this article is Bryan Stanley, Dena Izadi, Kathleen Hinko.

2.3.1 Introduction

Informal physics learning environments refer to learning spaces outside the traditional classroom setting. This may include programs such as a science cafe, a physics open house, or a demo show. Physics education research has demonstrated that the local context and implementation of curricular materials in classroom settings critically affect the impact of those materials on students. For example, a variety of factors such as faculty buy-in, the presence of LAs, backgrounds of students, and if the chairs and tables in a classroom are movable, all can affect the way students experience curricular transformations [54, 55, 56, 57, 101]. Our project seeks to characterize the even more diverse variables that are in play in the local context and implementation for informal physics environments. Without this information, we cannot diagnose ways to improve the learning experience or design different formats that more meaningfully engage audiences.

The landscape of informal physics learning environments is complex as programs can vary drastically in their structure, activities, contents, and engagement [46, 72, 73]. Due to the complexity and richness of the landscape, it is difficult to evaluate the functionality and effectiveness of the programs. While informal efforts are often the public face of their host institutions, there is limited understanding compared to the more studied formal learning counterparts. It is necessary to study informal learning environments more rigorously as these programs and activities not only impact the public, but also those participating in the programs. Without a clear understanding of the resources, structures, and environments of the programs, we are limited in our abilities to critique and evaluate the programs and their impacts.

This work is part of a broader project to study the landscape of informal physics in effort to better understand the key factors that play into the effectiveness of informal programs. The general goals of the project are to determine what aspects are important in an informal program and how those factors are connected with each other. Understanding the challenges that programs encounter, as well as the internal and external dynamics of the programs, can provide insight on the functionality of these programs. To study some of these factors, we have already implemented and analyzed surveys and interviews with program facilitators. This study builds off our previous work that collected interviews/surveys about program logistics from the lead program facilitators [73]. From that work, broad organizational themes emerged as program, personnel, audience, resources, institution, and assessment, as well as finer sub-codes for each category. These data, however, are limited to the perspective of the lead interviewee.

Here, we aim to address the limitations of the interview/survey data by expanding our methodology to include site visits to informal physics programs. We hypothesize that data collected from site visits will complement the interview/survey data by revealing emergent sub-themes that were otherwise filtered out. Thus, the analysis we present here will further guide the methodology of the broader landscape project. We seek to characterize the factors that are important to how an informal physics program functions by looking at a site visit from an organizational theory lens. We draw from the business literature on organizational theory, which breaks down the different operational aspects of organizations. Taking an ethnographic approach, we collected field-notes and artifacts, and recorded other interactions during a site visit to a large informal physics program in the midst of running its annual community-wide event. From these data, we looked to see if new emergent themes came up by using organizational theory as guideposts. Then, we examined the content of these emergent themes, focusing on how these new data complement the already collected interview/survey data. We find that site visits provided significant insight into how personnel, resources and audience were important during informal physics program events in ways that were not salient from the interviews and surveys. For the broader project, this research shows that site visits will be critical into establishing full profiles of how informal physics programs function.

2.3.2 Contextualizing Organizational Theory for Informal Physics Programs

Programs may have multiple different goals and objectives they want to achieve, for example, wanting to focus on specific content or increasing engagement of certain age groups. The individuals participating in these programs may share the same goals, but their priorities or reasons for participating may also differ, for example, improving teaching abilities or experimental skills [70]. We take an organizational theory perspective to better understand the functionality and dynamics within these programs. Organizations operate under their own structure, and their performance is influenced by a multitude of components such as resources, the working environment, and the social relationships both internally and externally of the organization, and power dynamics within these relationships [70, 102]. Organizational theory looks at the connectedness and weighted emphasis of these components' impact on the organization [102]. Informal physics programs have complex dimensions in terms of how the personnel and facilitators interact with each other and their audience.

As established in previous work, we believe that informal physics programs have many similarities to non-profit organizations [72]. Similarities include, but are not limited to, having the key components of personnel, stakeholders, program, and management; however, some of these terms need to be more appropriately reframed in the context of informal programs [102]. We have adapted these broad categories to an informal context. The six broad categories of factors that affect an organization's performance are: personnel (the people involved within the organization), programs (activities and logistical details), audience (the people the organization is reaching), institutional connections (the entity that the program is housed under, like a university or national lab), resources (financial and physical utilities), and assessment (self-evaluations by the organization) [102]. By contextualizing organizational theory in this space, we aim to create a multidimensional evaluation of informal physics programs.

2.3.3 Case Study

In this paper, we focus on a case study of an open house style event held by a program we will refer to as "House Physics", which is housed in a large western R1 university. Site visits are more resource exhaustive for the researcher than interviews/surveys. We are taking a case study approach to guide our site visit methodology for future site visits. Before the site visit, the lead facilitator of House Physics, who is a physics faculty member, was interviewed by a member of the research team about program goals, basic logistics, activities, history, and recruitment and training of student volunteers. This interview was a little over an hour in length and had been previously analyzed for themes with the organizational theory constructs [72].

House Physics is a traveling physics outreach program that visits schools with hands-on experiments that undergraduate interns built. We chose this program as a case study for several reasons. First, two of the House Physics co-directors had participated in an earlier phase of the broader study and contributed interviews about House Physics. (In subsequent data collection, we split the single long-form interview into a combination of a survey and shorter interview) [73]. These interviews had been analyzed with a version of the organizational theory framework and a preliminary list of sub-codes were developed for each of the six main categories. From this analysis, it was clear that House Physics is a robust organization: it has a large number of university students helping with the program, it has long-term institutional support, and it undertakes many educational physics activities each year. However, its large size and scope as an informal physics organization made it difficult to determine a holistic picture of its organizational features from a few interviews alone. We determined that a site visit would allow us to explore the nuances of how, for example, volunteers interacted with audiences or with the program director, or the role of physical resources, like equipment.

House Physics holds a free annual open house event on the university campus. We decided to use this event and a subsequent planning meeting as the key events to collect data from on the site visit. The event consists of several ballrooms filled with hands-on science experiments, demo presentations, fundraising sales booths, and spaces for their science partners. The open house is advertised to the general public and has an attendance of about 8,000 to 10,000 people. House Physics has three co-directors who are physics and astronomy instructors at the university, two additional employees, and about 15 undergraduate interns. Some of the undergraduate interns are physics majors, but most of the volunteers are from a variety of other academic fields. For the open house event, there are about 50 volunteers who were partners or former interns, as well as approximately 125 undergraduate volunteers who were the current students of the directors' physics courses. Another important consideration is that the first author of this paper was recently a former House Physics undergraduate intern with the program. His close acquaintance to the House Physics co-directors and many of the House Physics volunteers allowed him to have access to the program events, behind the scenes activity, and have rich conversations with the program personnel.

2.3.4 Methods

For the site visit, the first author embedded with the House Physics group for two full days. The first day was the open house event and the second day was one of their weekly preparation days. He observed and took detailed field-notes of the open house events, including the opening meeting, volunteer training, and demo presentations. Similarly, he documented the prep day activities, including meetings, experiment building, and video production. Notes included observations of the social dynamics and interactions within the program, descriptions of informal interactions with personnel members, and documentation of programmatic and logistical details [103, 104, 105]. Photographs of the events and other artifacts such as flyers and program maps were also collected [103, 104, 105].

He also conducted semi-structured interviews with two of the co-directors using an interview protocol based on the broad organizational theory categories during the visit. One of the directors, who identifies as a white female, also serves in an astronomy teaching role at the university. The other director, who identifies as a white male, also serves in a physics teaching role at the university. The interview with the latter director is a follow-up to an interview originally conducted prior to the site visit.

Data analysis began with a single coder coding the field-notes and interview data in MAXQDA, using the thematic categories developed for the overarching landscape project: personnel, program, institution, resources, audience, and assessment [73]. In addition, the coder explored emergent sub-codes and themes in just the field-note data, later discussing with the research team to consolidate into more concise labels. The developed sub-codes were compared to those developed for the pre-site visit interview data to provide insights on the additional dimensions that a site visit brings to understanding a program.

2.3.5 Findings

From our analysis we have two main results: 1) we found over a dozen sub-codes describing key aspects of this program that were otherwise undetected or unverified via interview with the lead facilitator, largely in the category of personnel, 2) we observed a number of instances where the theme of 'personnel' overlapped substantially with other categories, such as 'resources' and 'audience', demonstrating the complex interwovenness of these categories.

The sub-codes generated from the interview and survey data tended to be more programmatic, such as learning about a personnel member's responsibilities, the physics content topics, or funding. The site visit, however, revealed the ways in which informal physics programs function as a social enterprise with respect to the main themes. For example, sub-codes emerged as to how personnel interacted with each other and how the program and personnel utilized available resources. We found that the majority of our emergent sub-codes centered around 'personnel'. Here we describe some of the key personnel codes in more detail.

2.3.5.1 Emergent Themes in Personnel

One aspect we are interested in is the social dynamics within informal programs. In our interview with the House Physics lead facilitator, he talked about how the team dynamic plays a role in guiding the creative agenda and identity: "The other thing which we do is we definitely are a team. When we meet we just meet around a table, and mostly we don't have presentations, mostly we have just brainstorming, like okay, here's what we have in mind for this year, what kind of projects would people like to see? What kind of focus would we like to have?...So they're really very much part of the team, and I think they get that. I want them to really own it."

In the existing codebook, that would be coded as a socio-cultural aspect of the personnel, but there are limitations in what this tells us. From the site visit, we saw more specific details that could not be extracted from the interview. We were able to witness program facilitators repeatedly *recognizing personnel members*. For example, the facilitators mentioned several times in multiple group meetings to the undergraduate volunteers that they are the ones who make the program successful. Sometimes, recognition was given on a more personal level, such as when an intern made a new physics demonstration, and the group gave praise toward it, and the lead facilitator asked if they could use it for their event. There were repeated actions like this observed that inspired a potential new code regarding the recognition of personnel by the facilitators.

Another new type of code also emerged by observing personnel on site. By sitting in on the weekly prep meeting (as described above by facilitator) and by observing personnel interactions throughout the activities, we observed multiple group aspects such as *socializing* and *working in groups* as emergent sub-codes that were otherwise absent or minimized in the interview process. For example, there were moments where personnel members were sitting around a table building a demo together while also laughing and sharing casual conversations about non-work related topics.

When the researcher had direct interactions with the program personnel, the volunteers were willing to converse in informal conversations, often with personnel members initiating the interaction. These interactions provided different data points than what could be extracted with a long, formal interview. They were brief and more conversational, which brought in a broader range of perspectives from within the program and allowed for much of the discussion to be driven by the members' point of view. This led to additional emergent sub-codes such as *reflecting on past experiences* they had in the program. From both outside observation and one-on-one casual conversations, many members reflected on past events they participated in, how those experiences stuck with them, and how that influenced their future goals and aspirations. One former intern talked about how the skills they learned from building demos transferred over to their current job. Another volunteer talked about how they decided they wanted to pursue education after participating in the program.

2.3.5.2 Overlapping Codes with Personnel

We also observed multiple cases where emergent sub-codes overlapped personnel and another of our themes. One of the most prominent that we saw was the relation between ‘personnel’ and ‘resources’. With the current interview codebook, there is a broad label for the *personnel’s role in the program*, which refers to the member’s tasks and duties. However, this code does not give insight into how the personnel complete these tasks. During the site visit we found an abundance of personnel members interacting with physical resources and were able to observe how these interactions take place. These interactions manifested in many different forms. We observed the personnel members transporting, setting up, and taking down event projects. Repairing projects was an activity that volunteers engaged in during the open house and the general workday, as well as interns creating and building their own projects. From the interview with the director prior to the site visit, we extracted information on personnel roles and physical resources as separate categories.

Another crossover theme was between ‘personnel’ and ‘audience’. From casual one-on-one conversations and sitting in on group meetings, we observed instances of personnel members recounting interactions that they had with the audience. For instance, in the weekly prep meeting that occurred after the open house, the personnel members reflected on their experiences at the event, with several members recalling interactions with families and other visiting groups. One volunteer talked about the positive conversations they had with a senior citizen group that attended the open house. From an interview, the personnel and the audience are looked at almost as separate contexts, but the site visit helps show the overlap.

The information we can extract from the interviews on the interactions between these two categories are broad and general, so the codebook is limited in identifying these overlaps. Such limitations make it more difficult to fully describe the program characteristics. Direct observation during the site visit allowed for codes across multiple themes to appear connected in a larger context. From the site visit, we observed how the personnel interacted with the audience, such as through casual one-on-one conversations. We also have an emergent sub-code of the personnel members reflecting on their interactions with the audience and sharing these stories with other personnel in both socializing and work meeting settings. We can see the interaction of the personnel and resources, but also the social interactions between members, where a lot of these emergent sub-codes seemed to blossom.

2.3.6 Discussion

2.3.6.1 Benefits of a Site Visit

In this paper, one goal was to test a methodology for conducting site visits to informal physics programs. In our other work, we found that interviews with lead program facilitators can provide long, detailed information of the program in about an hour time frame [73]. However, since the operation of a program is complex and we are limited to the single perspective of the facilitator, these nuances are not readily apparent and may serve as confounding factors in the success and challenges of these programs. Taking an ethnographic approach for the site visit allowed for a large amount of rich data to be collected. The facilitator interviews present more of 'what' the program does. What are the key points that we know about the program? We can learn what the top-level programmatic details are, what the main roles of most of the personnel members are, who the majority of the audience is, and what the funding sources are. Through a site visit, we are able to see more of 'how' the program does all these things and how these themes connect with each other on a much finer scale. We are able to have brief, informal conversations with other personnel members to get their perspectives on the program, their role, and their experiences, in a more natural setting than with a longer, formal interview. In future research, we can more carefully analyze the importance of these codes and what role they might play in the success and sustainability of programs, even seeing if this occurs in other programs.

The key takeaway in this work is that we were not able to get these types of data from doing a singular, formal interview with the lead facilitator. Arranging longer, more formal interviews with as many personnel members as we had casual interactions with during a site visit is not easily feasible, especially for larger programs. The interview data allowed for a deep look through a single perspective at each of the overarching themes that we have established. The site visit allowed for many perspectives on just a few of the overarching themes, in this case, primarily 'personnel' with previously unseen overlaps with themes such as 'audience' and 'resources'. This finding suggests that neither formal facilitator interviews nor site visits should replace one another when studying informal physics programs, but rather these two approaches are best suited to gather different types of data that complement each other when studying these programs.

2.3.6.2 Limitations with Data Collection

There are some challenges that arise with conducting a site visit, the most prominent being the actual data collection. Informal physics programs vary considerably, so the ease of information collection and the type of information can vary. For an all day event with over 100 personnel members and 10,000 visitors spread throughout an entire building, it is not feasible for one person to document every detail.

With a large scale event like this program, there appeared to be minimal interruption in the flow of the event as the research could sit in the background and blend in with the crowd to observe. From the lead researcher's prior experience with the program, the event appeared to run naturally like past events, giving little indication that the program or the personnel were acting more rigid while being observed. The invasiveness of the sight visit should be handled with care. Site visits to smaller programs could potentially have higher risk of disrupting the event. Another possible limitation could be with visiting programs that we are less familiar with, which could impact data collection.

There needs to be a plan beforehand on key aspects to attempt to observe. Having interview data before the visit helped to highlight key details to look out for that the facilitator deems as important aspects of the program, such as how people share in a group meeting. However, there also needs to be flexibility in the plan for the researcher to appropriately adjust to the active surrounding environment to collect crucial data as they appear. During the open house, there were several times that the researcher was moving from one location to another to observe, and was stopped by personnel members who wanted to discuss their experiences in the program. While the original goal in that moment was to observe audience interactions, it was difficult to pass up the opportunity for a brief conversation with a participant willing to reveal their rich perspectives on the program. There needs to be a balance between the researcher following their plan to observe specific components, as well as being flexible enough to react in the moment to what is happening around them.

In future work, we intend to conduct more site visits to expand on these themes and enhance the site visit methodology. We will also refine our emergent sub-codes to expand our codebook through rigorous analysis and discussion. The more finely tuned codebook will be used to compare more thoroughly with our interview data to aid in examining key themes and subtle nuances within these programs. In the broader project scope, we aim to find indicators that most impact the sustainability and success of informal physics programs. We hope this methodological process helps those interested in examining their own learning spaces consider how their data sources can work together for more holistic understanding. This work is funded by NSF AISL #1423496.

Chapter 3. Central Role of Personnel in Informal Physics Programming

This chapter was published as a journal article in Physical Review Physics Education Research in 2023 [106] and is provided here verbatim with only formatting changes. The author order on this article is Bryan Stanley, Dena Izadi, Claudia Fracchiolla, Kathleen Hinko.

3.1 Introduction

People can learn physics in many different spaces outside of traditional classrooms. Learning that occurs outside of the classroom space is referred to as "informal," "nonformal," or "free choice" learning [34, 107, 108, 109] in the field of education. In informal education settings, whether and how to engage in learning is determined mostly by the individual, and learning goals for the facilitators and/or the audience members can include excitement and identity growth along with scientific content and practices. Examples of informal education activities that are focused on physics content include, but are not limited to, afterschool programs, summer camps, public lectures, online videos, podcasting, physics festivals and open house events, planetarium shows, online games and apps, and demonstration shows [4, 34, 110]. Physics faculty, undergraduate students, graduate students, and postdoctoral researchers often volunteer or act as lead facilitators in these spaces [111]. The physics community more commonly uses the words "outreach," "public engagement" and in some cases "science communication" to describe how they interact with nonphysicists in informal educational environments [34, 40]. In this paper, we use the term informal physics programs to describe organized activities for public audiences that are led by physicists.

Studies in physics education and science education have looked at the impact of these programs [112, 113]. Ours and others past studies have focused on audiences, especially children and mixed-age groups, and have established positive impacts on building interest, identity, and content learning [5, 6, 7, 8, 9]. There is also research looking at the physics students and physicists who participate. Studies have shown that physics students volunteering in informal physics programs are able to build communication skills and improve their pedagogical practices with various demographics of audiences [24, 25, 26, 27, 28]. In addition, these spaces often provide physics student educators with agency over activities, which can increase their confidence and abilities to adapt their pedagogical practices quickly [24]. Some of our previous studies have also looked at the impact that facilitating these programs has on university students' physics identity and sense of belonging in the physics community [59, 60, 62, 114]. In particular, ours and others past studies have shown that students who volunteer in informal programs can gain a sense of autonomy, build relationships with their peers and faculty, connect their formal learning to the real world, and see themselves in their fieldall of which can strengthen their participation in their respective fields [32, 33, 60, 63, 114, 115].

It is clear from existing research that both audiences and physicists can be impacted by their experiences participating in informal physics learning; however, we do not know how the structural design, organization, and operation of informal physics programs affect these experiences. Collectively, informal physics programs encompass a large range of audiences, formats, and content; as such, programs are organized and function in a variety of different ways. In prior work, we characterized the structures and features important to informal physics programs by adapting an organizational theory framework to the context of informal physics spaces. This contextualized framework has six categories that encompass the main functional elements of an informal physics program: Assessment, Audience, Institution, Personnel, Program, and Resources (described in the following section) [73]. Previously, we reported on logistical information for aspects of each categoryfor example, sizes of audience, number of volunteers, and the type of physics contentfor a case study of a single state [4].

In this study, we go beyond program logistics and take the next step of framework development to gain a deep understanding of how the different categories affect each other. To investigate connections between framework categories, we collected extensive interviews with informal physics program leaders about their program design and operation. We then analyzed each interview for emergent program elements within each framework category and looked for areas of overlap. As described in the Sec. 3.4, we observe the prominent role that personnel, the physics students, staff, and faculty involved in the educational activities, have in these programs. Based on this finding, we then shifted our analysis to focus on how the personnel influence the content, activities, and audience interactions of informal physics programs.

In this paper, we present an in-depth case study analysis of three programs selected from a broader dataset we have collected. These programs have different formats, physics topics, and audiences, and they showcase diverse and effective ways that personnel are integrated and integral to the program. We present the cases of a physics and astronomy public lecture series for adults held at a local bar, a weeklong summer camp for high school students at a research laboratory, and an undergraduate student club doing astronomy open houses for general public audiences. Our findings show the important role of the personnel of informal physics programs and the influential connections they have with the other organizational components of audience, resources, and program content and activities. Ultimately, understanding the complexities between framework categories will allow researchers and practitioners to identify areas to improve informal physics programs, especially in being inclusive, in being equitable and accessible, in supporting physics students who participate, and in connecting more strongly to the community and home institution.

3.2 Framework

This work is part of a bigger project to understand the landscape of informal physics, identifying common themes, successes, and challenges that are present among the many diverse styles of programs [58]. Some studies have looked at aspects of the landscape, such as the 2015 American Physical Society (APS) Forum on Outreach and Engaging the Public (FOEP) survey and the SySTEM 2020 project in Europe; however, those studies focus on the content, types of activities, and the audiences that the physics community engages with, and not at the physicist facilitators or the ways programs are structurally organized [47, 116].

In this study, to gain an understanding of how the different organizational structures of informal physics programs are interrelated, we draw on our prior work contextualizing an organizational theory framework to informal physics spaces [72, 73]. Organizational theory originates from the business literature and describes the internal and external relationships present in organizations. Organizations, including nonprofits, consist of various social groups, each with their own goals, training, and contribution to organization [66, 69]. Aspects like social and cultural relationships, power dynamics, monetary resources, physical resources, and external partnerships all influence the functionality of the organization [70, 102]. Nonprofit organizations and informal physics programs share some common characteristics: they often have short-term or grant dependent funding, they depend heavily on volunteers, and their planned activities are flexible to the needs in local communities. When adapted for informal physics, the dimensions of the contextualized framework consist of six broad categories [73]: Personnel, Program, Audience, Resources, Institution, and Assessment, defined in Table 3.1.

Table 3.1: Defining the dimensions of the informal physics organizational theory framework.

Informal physics dimensions	Definitions
Assessment	The form of evaluations that the program conducts.
Audience	The people engaging with the content and activities.
Institution	The larger organizational entity that is affiliated with the program.
Personnel	The people involved in the programs functionality.
Program	Logistical aspects of the content, activities, format, and other administrative details.
Resources	The financial and physical items of the program, as well as partners that program works with.

Using this framework, we identified parameters that differentiate informal physics programs, such as the size and demographics of the audience, the number of volunteers, pedagogical practices, physics topics, and connections with institutions [4]. We are able to analyze the complex dimensions of informal physics programs as they pertain to how the lead facilitators, volunteers, and audience members interact with each other, the supplies and funds, and relationships with other organizations. We also found the goals and objectives in informal physics spaces may differ among programs and the participants. Some programs prioritize awareness or understanding of a certain topic while others aim to boost engagement among specific age groups or demographics. Volunteers may share similar goals as the program, but may also have their own priorities, such as building communication skills. Similarly, audiences may have their own goals in attending.

Building off of the work we did to analyze the parameters within six framework categories, we continue using organizational theory to study the interconnections between the categories. The dimensions of any organization necessarily intersect and feedback into each other - in this study, we seek to map key places of overlap for the specific context of informal physics programs. As described in the Findings section, we find connections between all six main categories present in our framework. Early on in our analysis, we observed the prominence of the Personnel theme as well as the high level of connectedness between Personnel and the other categories. This prompted further study into understanding the Personnel and their connections to other organizational categories.

3.3 Methods

Building off of our prior work of adapting an organizational theory framework for informal physics settings [73], we designed our study to identify how the six framework categories affect each other. For our study design, we collected data from a wide variety of programs. These programs differed in formats, personnel involved, and audience demographics. The informal physics dimensions are broad and each program might have a different way of being organized. Looking at multiple program variations can provide insight that can be useful for not just one type of program (for example, summer camps), but be applicable across different types of informal physics programs.

We interviewed lead facilitators to gain information about the program structures. Lead facilitators are the people who make operational and design decisions for the program. As a part of a larger research project, we have collected many forms of data about informal physics programs, including surveys, interviews, and site visits [4, 100]; from this work, we have found that interviewing lead facilitators provides insight into the rationale and process for making these decisions. The decisions may involve the institution, partners, and resources that other personnel members may not have knowledge about. For example, a volunteer may not know how advertising works, how community partners are contacted, or where funding is acquired. Lead facilitators work directly with volunteers, institutional administrators, community partners, and event audiences. Formal documentation of these practices is often limited, however, depending on the resources available and the support of the host institution. Our prior studies have shown that knowledge of these practices is often contained within the lead facilitators personal experience or documents, so speaking directly with lead facilitators is the primary way to obtain information on these details.

As described in detail below, we designed a flexible interview protocol, tested and validated it, and collected data from a national sample. Our final dataset included 31 interviews with lead program facilitators. Given the rich and detailed nature of these interviews, we present a comparative case study analysis on a subset of these programs, which allows us to describe the intricacies and nuances within individual programs. This approach also helps us to compare similarities and differences between multiple types of programs in an attempt to create a broader understanding of the structures and challenges that are present across the cases [87, 89, 117]. Considering multiple programs helps to strengthen claims that can be made across multiple forms of programming, while also guiding investigation into the impacts of differing structures.

3.3.1 Interview Development

We developed a semistructured interview protocol that spans all six organizational categories. The development process went through several iterations to best gather detailed information about the program while also being aware of the time that the interviewee is volunteering to be interviewed. The initial phase of interviews was with eight lead facilitators from different programs with questions about the activities of their program, how the program began, how the program evolved over time, and other details about formats and relationships within the program. In this initial phase, lead facilitators were also asked for feedback on the interview process and questions themselves.

Interviews with this first group were 1.5-3 hours in length, in part due to the interviewees enjoying giving details about the history and events of their programs. We decided the interview format needed to be more streamlined, as it would be difficult to recruit more personnel to participate in long interviews; however, we still needed to collect logistical information to provide context. Thus, after this initial testing phase, we revised our strategy for interviews by (i) removing some questions from the interview and putting them into a survey and (ii) revising some questions for conciseness and clarity. Program facilitators took the survey prior to being scheduled for an interview. The survey took 15-20 min and was a mix of multiple-choice questions with optional comment boxes and some open-ended questions. Survey questions focused on logistical and numerical information, for example, the number of volunteers involved in the program, the number of contact hours with audiences, program location, and the physics content and activities. When a participant completed the survey, they were contacted by a research member to schedule a follow-up interview. Collecting survey responses in advance of the interview allowed the research team to prepare follow-up questions that explored the particular program. Survey question preparation, validation, and results were reported by Izadi et al. [4].

Second-round interviews with a condensed protocol were 45-60 min in length and followed a semistructured format (see Appendix A). Interview questions asked about the history of the program, the programs goals and objectives, the programs connection to its institution, background information of the interviewee, the structure of the program, the personnel involved in the program, the programs funding, the programs audience, activities and content covered, assessment the program conducts, the future of the program, and challenges the program faces. The interviewer would also ask follow-up questions based on the participants responses. Questions were asked from each category, but based on the content of the response and follow-up questions, not every single specific question from the protocol was asked of each interview participant.

Since the protocol evolved iteratively with feedback from the interviewees, we coded the full, condensed version to determine how much each framework category was focused on. Even though not every single question was asked of each interview participant, the percentage of questions that spanned each framework category was consistent across the interviews and the condensed protocol. The percentage of questions that called out each category is assessment 5%, audience 5%, institution 18%, personnel 27%, program 29%, and resources 16%. The larger focus on personnel and program is not surprising because in this study, we are interested in the operations and organization of these programs, and how all of the pieces of the program fit together. Because the tasks required to run the program are of course completed by humans, we necessarily asked lead facilitators to describe their roles and the roles of their volunteers in doing that work. For example, one question asks, "What assessment resources do you draw from?," which is coded as both assessment and also personnel, as it inquires about their involvement and rationale in carrying out assessments.

3.3.2 Data Collection

For data collection, we took multiple approaches to recruiting participants. We used a convenience sampling strategy by contacting lead facilitators from informal physics programs of which we had direct knowledge. We also gave talks on the broader landscape project at conferences of the American Association of Physics Teachers (AAPT) and American Physical Society (APS) and asked for participants. We also cold-emailed people who could be identified as the lead facilitator of informal physics programs affiliated with physics-degree granting institutions. A snowball sampling approach [46, 98] was used by asking participants to name any additional informal physics programs they might be aware of in their institutions or elsewhere.

In total, 31 interviews were conducted, spanning 7 states and 2 international programs. Michigan was the most represented with 13 interviews—due to the residence of several research team members, we had direct knowledge of higher education institutions and national laboratories within the state. Most of the interviews (27 of the 31) were conducted prior to the COVID-19 pandemic. The pandemic had many direct impacts on informal physics programs, thus interviews conducted during the pandemic included the original interview protocol as well as an additional COVID-focused interview protocol. Prior interviewees were emailed to schedule a shortened, follow-up interview focused on the impacts of COVID on their program. Analysis of the impacts of the COVID-19 pandemic on informal physics programs has been discussed in other work and is not analyzed in this paper [118].

3.3.3 Case Study Analysis

From the dataset, five programs were selected and analyzed as described below. The five programs were selected for their differing formats, content, activities, and program structures. All five programs are based in Michigan. Of the five programs that were selected, three were chosen as cases due to their detail-rich interviews.

Each interview was audio recorded and then transcribed through a web transcription service [119]. Using the qualitative analysis software maxqda, we analyzed the interview transcripts using the six main framework categories for coding. A single code unit was defined as the full sentences in which a response met the definition of a code or subcode, including a single sentence up to a couple of paragraphs, but not partial sentences.

Two researchers used the six framework categories as guideposts to explore emergent ideas from the interviews [73]. They independently coded these emergent ideas, compared them afterward, and discussed them with the research team. This process was done iteratively over multiple interviews, modifying the codes and themes until there was agreement within the team. As an additional validation measure, another researcher, who was not involved in the development of the coding system, was trained to code the five interviews specifically with those codes. They coded a subset of the interviews independently from the other researchers. Afterward, the researchers discussed and compared their coding of the interviews and made fine adjustments to the coding system. This was done iteratively across interviews until there was consistent agreement among the researchers when coding the interviews.

Once there was consistency among the coders, we began analysis on the frequency and overlaps of each code. An interviewees response often contained several codes simultaneously. For example, a response may talk about the interactions that a volunteer has with an audience member. That response would contain both personnel and audience codes. We used the MAXQDA software to count and analyze when multiple codes were present in the same statement.

3.3.4 Case Study Selection

Presenting a detailed analysis of a subset of our data allows us to describe the nuances of our current framework and identify instances of overlap between the six main organization theory categories. Specifically, this provides an opportunity to highlight the central role that the personnel play in connecting all the organizational components together.

The three programs that we are analyzing here are among the most common informal physics programs associated with physics departments and laboratories [1], but also provide unique looks at the informal physics landscape, representing different format structures and tackling different physics topics. The institutional support that each of these programs receive varies. Each program targets different audiences, ranging from young children to adults. These differences are beneficial for analysis because they highlight the important connections between aspects of informal physics programs that may be common across programs. Important to our findings, these three programs represent a variety of noticeable challenges and successes regarding the program personnel. Analyzing these three programs in more detail allows us to dissect the recurring personnel attributes that are present in all three programs and consider the aspects that are only present in some of the programs.

3.3.4.1 Pub Physics

Pub Physics is a monthly public lecture series hosted at a local bar. Andrew, a faculty member from a large, public university is the lead facilitator of Pub Physics. For each event, two visiting guest presenters are invited to give a public talk about their research, typically related to astronomy or astrophysics. The presentations are followed by a Q&A and trivia session where audience members have the opportunity to ask questions and engage with the speakers and content. While the program aims to reach an adult audience in a downtown setting, away from the university, there is a small fraction of the audience who are members from the facilitators department and university. Graduate student and postdoctoral volunteers from the astronomy department assist Andrew with program logistics and audience interactions.

3.3.4.2 Camp Physics

Camp Physics is a weeklong summer camp for high school students. Ben is the lead facilitator of Camp Physics, which is held at a large research facility. During this program, the youth participants engage in specialized physics-themed activities and presentations organized by Ben and his team of faculty, postdoc, graduate student, and support staff volunteers. Youth come to campus at the beginning of the week and stay overnight in the campus residence halls until the end of the week.

3.3.4.3 Physics Club

Physics Club is an undergraduate student organization housed in the physics and astronomy department at a public, research-focused university. Physics Club has many goals in strengthening the physics and astronomy community within and beyond its department. Its informal physics efforts are led by two elected undergraduate officers. The officers recruit their undergraduate program members and department students to volunteer in their events which include open house events, planetarium shows, and visits to schools. These events involve demonstrations and astronomy-related activities that volunteers and audiences engage with together.

3.3.5 Limitations

There are limitations to our dataset and analysis. For example, although the three programs that we chose to describe here differ in format and content covered, they are not representative of all forms of informal physics programs that exist. In addition, the data for each program are from the singular perspective of the lead facilitator. While interviews provide a snapshot of the facilitators perceptions of programs, we do not have direct knowledge of the experiences of the audience or other personnel members. For this reason, when talking about the audience, we do so from the perspective of the personnel's interactions with them.

Considering the experiences and identities of the researchers is also important when considering potential biases in the study design. Each researcher brings in their own positionality which can and does influence multiple parts of the research process. The interviews presented in this study were conducted by a White female immigrant. Other authors who contributed to the analysis are a Latina woman, a White woman, and a White man. For example, this can affect how comfortable participants may feel when speaking with us in interviews. In addition, we as researchers also have our own biases which can influence how we ask interview questions and how we analyze and interpret their responses. As authors of this paper, we each have our own experience participating in or facilitating informal physics programs. Our experiences in informal physics programs are beneficial because we already have some understanding of how these spaces operate; for instance, our past experiences also allow us to ask probing questions about specific aspects of informal physics programming and structures. However, it could also influence our interpretation of the data, such as overly focusing on certain aspects of running programs, we have personally found a valuable or potential bias toward program leaders that we sympathize with around challenges.

3.4 Findings

3.4.1 The Prominence of Personnel

In our initial analysis, lead facilitators did not discuss the six framework categories in equal amounts. Figure 1 shows the percentage of how much each framework category was coded for each program with respect to the programs total number of codes. The proportion of each category that appears among the three programs follows similar patterns. The personnel category was most discussed among the interviewed lead facilitators, though all six framework categories are present in the data.

As expected, lead facilitators often discussed multiple categories in a single response. Many responses included categories that were not explicitly asked about for their respective question. For example, two program-related questions that we ask are, “Could you give us more information on the physics content or concepts that your program aims to cover?,” and “Has the content changed over time?” Lead facilitators gave responses that discussed how the content of the program is selected, which often includes the academic background of the personnel and the interests of the audience. In addition to discussing multiple categories in responses, lead facilitators explanations varied in length for each question depending on how many details they wanted to share. These factors explain the difference between the percentage of codes in Fig. 3.1 and the percentage of codes that we asked about in the interview protocol. While we asked questions about personnel and program the most, lead facilitators talked about personnel more than we asked about it. Even in questions explicitly asking about other categories, lead facilitators often talked about personnel in their responses.

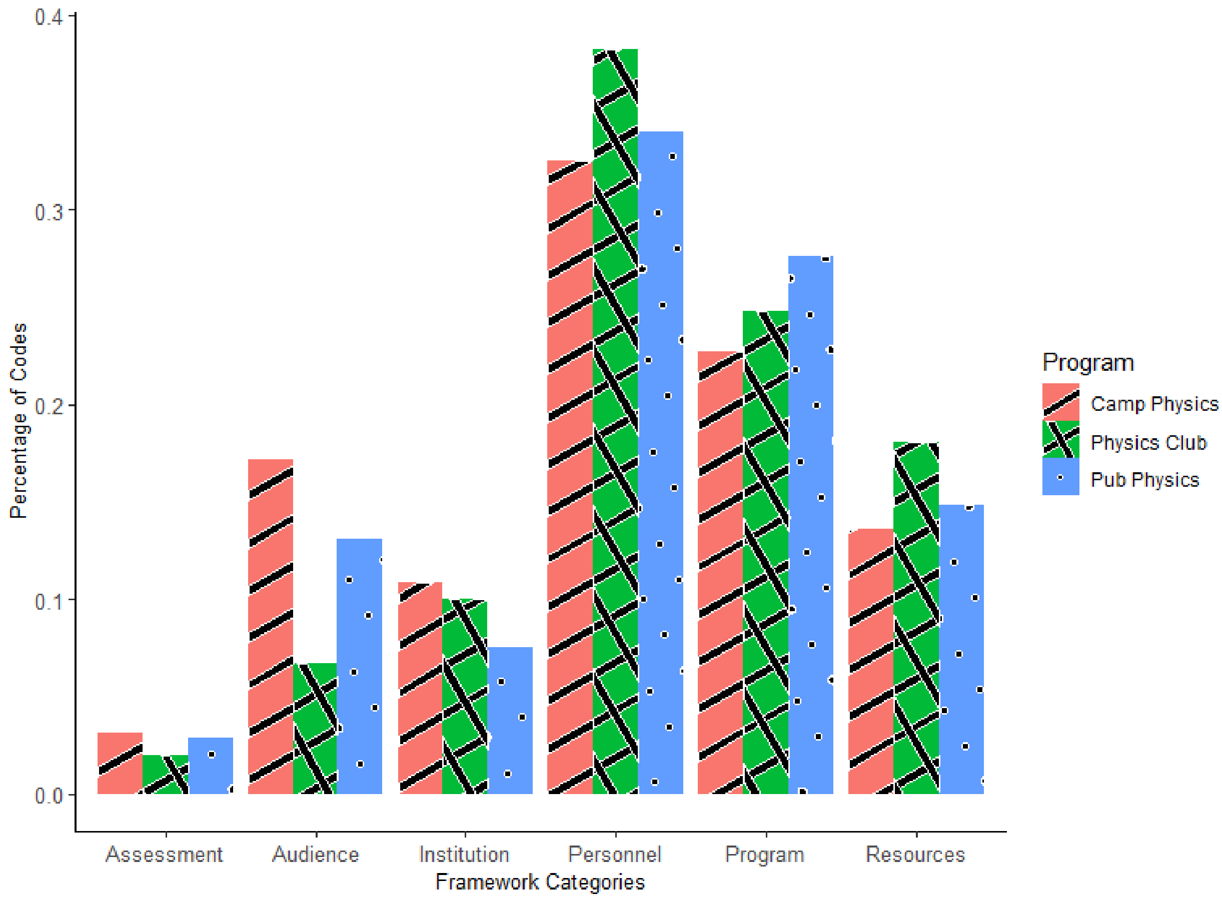

Figure 3.1: This chart represents the percentage of codes present for each framework category across all three case study programs. For example, for all codes in the Camp Physics interview, 3% of those were assessment, 17% were audience, etc. In comparison, for Physics Club, 2% of its codes were assessment, 7% were audience, etc. We found personnel to be the most prominent for all programs, accounting for roughly a third of all codes within each interview. Camp Physics, Physics Club, and Pub Physics had 286, 149, and 344 total codes, respectively.

While codes from all categories were found to overlap with each other, we found instances of personnel overlap the most with the other categories. Figure 3.2 shows how much each category overlapped with the other categories for each program. The width of the lines connecting each circle is proportional to how frequently those categories overlapped; thus, a thicker line represents more overlaps. For example, personnel-program overlaps accounted for 30% of all overlaps in the Pub Physics interview while audience-assessment only accounted for 3%. This difference is represented in the figure by the personnel-program line being 10 times as thick as the audience-assessment line. Personnel is also one of the most mentioned in conjunction with other categories alongside the audience and program categories. Overlaps of categories with and between institution, resources, and assessment occur less frequently in the data. A table with overlap frequencies can be found in Appendix B.

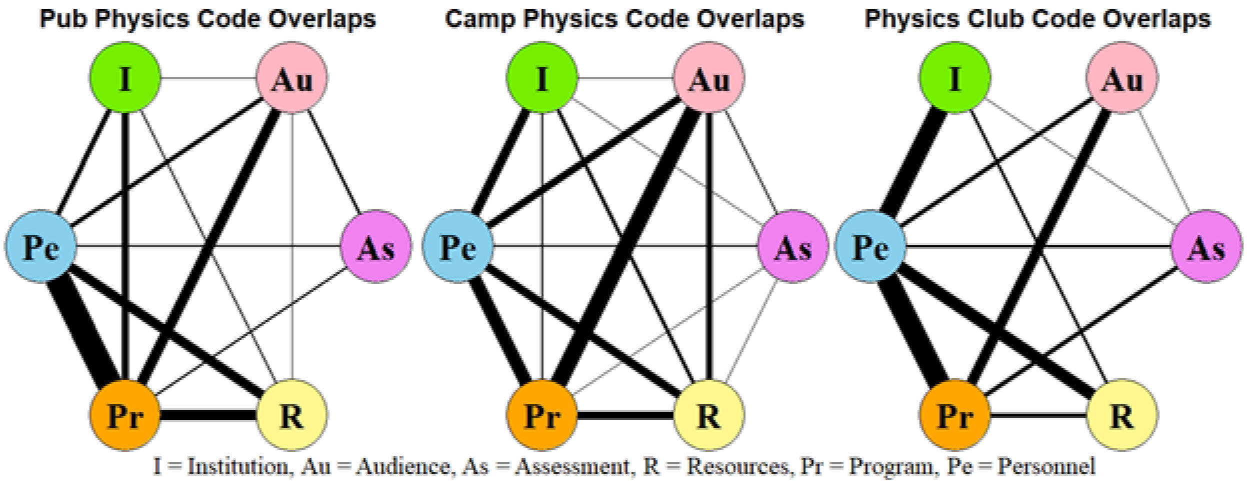

Figure 3.2: These charts show overlaps between framework categories in our interviews. Each line connecting two framework categories means that there was at least one overlap between those categories for that program. The thickness of those lines is scaled by the percentage of overlaps coded in that particular interview between those two categories.

We find the personnel category to be foundational and central to the informal physics programs in our dataset based on being the most coded and most overlapped framework category. These initial quantitative results guided our qualitative analysis toward how people spoke about personnel and the other categories. With a heightened focus on the personnel of informal physics programs, our research questions shifted: Who are the people in the program and what are their roles and tasks? How are roles and tasks distributed among the personnel? How do the personnel interact with audiences, their institutions, and resources? How do personnel engage with assessment? What are the challenges that personnel incur?

To answer these questions, we looked carefully at the comments surrounding personnel and the associated overlapping codes. Looking across programs allowed us to identify key themes, which we discuss in the following sections.

3.4.2 Personnel Roles and Tasks

We want to know more about the physics faculty and students who take on the responsibility of organizing and facilitating these activities and programs. What are their personal academic backgrounds, connections to physics, and prior experiences with public engagement? What role do they currently have at their home institutions? Characterizing the personnel is critical to understanding the training and prior experiences personnel bring to their work in the informal programs, their interactions with the audience, and who influences the content.

3.4.2.1 Who are the Personnel?

The lead facilitators of these three programs have varying academic ranks ranging from undergraduate students to university faculty. The volunteers in the programs are also a combination of undergraduate students, graduate students, postdocs, staff, and faculty; however, each program has a different ratio of personnel from these groups. In addition, the majority of these personnel members are dedicating their time to these programs on top of their regular work and school responsibilities.

Pub Physics is led by Andrew, a university lecturer, who has a Ph.D. in astrophysics. His main job is teaching multiple classes at the university each semester, and his role in Pub Physics is not part of his regular duties for his lecturer position. He had been involved in public engagement efforts when he was a graduate student and postdoctoral researcher and wanted to continue with similar efforts when he started his current position. He did not find other public engagement opportunities to be aimed at adults, so he built this program to cater to that audience. Andrew recruits speakers who are typically faculty, postdocs, and graduate students from the host university or from out-of-town institutions. The speakers are not recurring volunteers each month. Recurring personnel members consist of about three volunteers who are either graduate students or postdocs in the astronomy department. They assist with program logistics and operations.

Physics Club's outreach efforts are run by two yearly elected undergraduate co-chairs. Carly is the undergraduate facilitator interviewed for this study. There are a couple of faculty advisors who oversee the program and public engagement efforts, but it is the public engagement co-chairs who handle most of the organizational work and planning. Volunteers for the programs public engagement events are other undergraduates from the institution. Throughout the academic year, the number of undergraduate volunteers for events ranges from about 25-50 students. The volunteers are primarily involved in interacting with audiences through physics activities and demonstrations.

Camp Physics is led by Ben, the public engagement program coordinator at a large research laboratory. Ben differs from the other two program facilitators in that his paid job is to organize informal physics events and activities. Ben earned his Ph.D. in physics and currently organizes this program and works on other public engagement projects for the laboratory; he does not have other teaching or research responsibilities. For the camp, there are some business support staff from the department who help with program logistics. There are also approximately 15 short-term volunteers who are all graduate students, postdocs, or faculty members from the laboratory who assist with developing the content and activities.

There are several interesting outcomes to having programs be facilitated by personnel that span academic ranks. Helpfully, activities can be informed by the perspectives and knowledge of a considerable range. For example, Pub Physics has faculty speakers who give a talk about their work on cutting-edge research topics, while graduate students who understand those topics are speaking with audience members during the event and translating from their point of view. However, personnel at different academic ranks vary in the amount of time that they can dedicate to working in the program depending on other school and work commitments. For example, Physics Clubs program leaders and volunteers are full-time students in classes, some of whom have other jobs like working in research laboratories. For all personnel, except dedicated staff hired only to do public engagement, these people have other commitments as part of their professional physics work and connection to their institution, such as taking classes, teaching classes, doing research, etc.

3.4.2.2 What are the roles and tasks, and how are they distributed?

We find that there are many different specific tasks that are necessary for programs to run. The types of tasks that personnel members carry out span the other framework categories that describe informal physics programs. The personnel are responsible for developing content and other program-related activities. Part of the programmatic design that personnel take into account is how to interact with the audience. The personnel members may request support from the institution, sometimes requesting physical space, funding, or other resources.

While programs differ in personnel and program formats, the types of roles and tasks that the personnel carry out are often similar. In Table 3.2, we have grouped the specific tasks according to common themes and documented the main tasks for each of our three case study programs. These include both tasks that require physics content knowledge, like designing hands-on activities, and more logistical and management tasks like making sure the venue is available. Each program we looked at had several of each type. Tasks related to physics content knowledge include giving presentations, designing physics activities, and engaging with audiences with demonstrations and activities. How a personnel member carries out these tasks may depend on factors like their academic rank. A program's format and structure can also dictate the tasks that a personnel member carries out. For example, the Physics Club leader selects the demos that their undergraduate volunteers will do while the Pub Physics leader allows their guest faculty speakers to give a presentation on a topic of their choice. Here, the specific tasks that personnel carry out are different and the volunteer's level of agency varies based on the academic ranks of the personnel as well as the format and structures of the program.

Logistical and management tasks may include scheduling events, advertising events, and communicating with partners such as venues, sponsors, community groups, or research specialists. These tasks tend to fall onto the lead facilitators; however, these tasks are sometimes overlooked by administrators when recognizing the work of lead facilitators. Coordinating with local venues for hosting events and designing promotional materials are examples of time-consuming tasks that are necessary for holding events that audiences will come to. As we will discuss later, tasks like communicating with partners make up a large portion of the lead facilitator's preparation time.

Table 3.2: Common program tasks and who in the program carries out these tasks.

Program tasks	Pub Physics	Camp Physics	Physics Club
Giving a presentation	*Guest speakers*, typically faculty at other institutions	*Laboratory faculty* presenting on their work	*Undergraduate volunteers* answer audience questions after planetarium show
Designing or choosing activities	*Grad student* organizes trivia	*Grad students* & *postdocs* design experiments	*Lead facilitator* chooses demos
Engaging audience with demos and activities	*Lead facilitator*, *grad student*, *postdocs* answer questions during trivia	*Grad students* and *postdocs* interact alongside experiments	*Undergrad volunteers* present with demos
Recruiting volunteers	*Lead facilitator* sends emails through astro department; *Lead facilitator* emails with guest speakers	*Lead facilitator* puts ad in weekly newsletter, and recruits via personal contact; *Lead facilitator* talks with faculty member guest speakers	*Lead facilitator* buys and set-up posters, sends messages in a group chat
Advertising events	*Lead facilitator* designs flyers, promotes on social media, sends to audience email list	*Lead facilitator* shares info with teachers and schools who pass along info and promote the program	*Lead facilitator* buys promotional materials
Communicating with partners	*Lead facilitator* works with venue for space, organize drink tickets for speakers, gift certificates for raffles	*Lead facilitator* talks with resident halls a year in advance; *Support staff* organizes catering	*Lead facilitator* communicates with mega-organization for organizing regional events
Maintaining connection with institution	*Lead facilitator* communicates with department newsletter organizers	*Lead facilitator* communicates with department newsletter organizers and direct interactions with laboratory faculty	*Lead facilitator* communicates with faculty advisor

It is worth reiterating that these efforts are often in addition to the personnel's other responsibilities with their regular work and school commitments. For some programs, the necessary time commitment for the personnel may be low, but there are more long-term commitments for other programs, which can cause strain. As noted with Camp Physics, volunteers may only need to dedicate part of one day in the summer to the program to carry out mostly predetermined tasks. Contrast that with Pub Physics and Physics Club, which host events year-round. Carly from Physics Club mentions that it can be difficult recruiting volunteers during the summer or if there are conferences or department trips. Pub Physics hosts an event every single month, so with the volunteers and guest speakers all working in academia, their work commitments outside of the program will be heavily influenced by the time of year that it is. Also as previously noted, many of the personnel are university students and postdocs, so there is naturally a turnover rate every couple of years as personnel graduate and move on to new positions.

We also find that these responsibilities tend to fall on one or a few people. As shown in Table 3.2, many of the common tasks are taken on by the lead facilitator. Many of these tasks, such as communicating with partners and advertising events can require a substantial amount of time and resources. The overloading of responsibilities on a single person can lead to challenges in carrying out certain tasks and hinder the program's functionality and sustainability. It is important for the program to consider how it is distributing its tasks among its personnel, but also to take into consideration how the personnel are distributing their own commitments within and outside of the program.

3.4.2.3 Recruitment and Retention

A program's ability to recruit and retain volunteers is critical given that there are many tasks and responsibilities that need to be completed. We find, however, that some programs have challenges with recruiting and retaining volunteers, which leads to many tasks being left to the lead facilitator. In some instances, the connections and level of support with the institution contribute to the program's ability to recruit volunteers like students and faculty from the department.

For Pub Physics, Andrew primarily recruited personnel by asking faculty, postdocs, and graduate students in the department. He was able to recruit a couple of volunteers to assist with social media management, recording talks, coordinating with speakers, and other logistical tasks; however, there were challenges in rotating tasks and responsibilities among the small group of volunteers. As Andrew notes, "It would be nice if we comfortably had upward of six people regularly involved or a larger group where the duties would rotate. It would be nice if—for April I know that I have these two people that are in charge of finding speakers and then for May it's a different two people and there's some sort of rotation. So it's not a monthly burden so maybe if I could get another 10 people to commit every other month type of thing would be really nice. I've yet to find that level of support consistently." Without a full group of volunteers, most of the responsibilities have overwhelmingly fallen onto Andrew, which can be difficult to complete on the side of his regular job. One of the most difficult tasks to complete is recruiting guest speakers. He started by recruiting members of the department to give talks, however, the department is relatively small. A combination of limited responses to his requests and not wanting to repeat speakers led him to quickly run out of speakers. Once the program became more established, Andrew was able to recruit speakers from outside of his department, however, doing so was still challenging. Andrew said, "I would say the thing that I spend most of my time doing is freaking out, and not having a presenter, and trying to figure out what to do, and my event is a week away, and I still don't have anyone lined up. And so I don't have—the advertisement says to be announced, or whatever." Without a speaker, there is no event. Even if the speaker is recruited at the last minute, it hinders the ability to advertise the event or to organize other activities like the trivia session that is related to the talk. Limited advertising can limit the audience size, which can in turn impact the hosting venue that is selling food and drinks. This recruitment challenge related to personnel has direct and indirect impacts on the program, audience, and resources.

Physics Club reports similar challenges of volunteer shortages. Physics Club has other types of activities than just public engagement, so to recruit volunteers for specific public engagement events, Carly will send out emails to the program's members through emails and group messaging apps. Since the program's members are primarily undergraduates from the same department, there are common time conflicts among the volunteers. "We had an open house, but the majority of our members were out of town on a department-sponsored trip. So the people who are most active are gone. Everything went okay, but it was shaky for waiting to hear—because I was also out of town—waiting to hear if everything went smoothly." The event ended up running okay, but as Carly notes, "knowing the people aspect of things is something I don't think we've quite handled yet." This again signals the importance of communication with partners as well as the institution. Something to consider is if program facilitators and partners or institutions communicate with each other when planning their events to make sure they are not losing personnel or audiences to events occurring at the same time.

A notable difference between Physics Club and Pub Physics is that the Physics Club lead facilitator role is elected every year, thus the leadership changes relatively quickly. Due to this, there are some inconsistent program processes over the years, which can cause some procedures to falter or have to be recreated with each leadership change. For example, one of the challenges that Carly inherited was the volunteer sign-up. "There was very little organized structure to knowing exactly before an event started, knowing exactly who was going to be there." A couple of days before an event, there would be a message sent out to a volunteer list to recruit people. "What I would like to see our outreach cochairs change this year is getting more of a signup sort of thing. I want to know exactly, going in, how many people we have coming, and exactly where they're going to be." This allows Carly to plan how to distribute tasks among the volunteers, how long event preparations may take, travel logistics, and other arrangements that may need to be made.

Camp Physics did not report the same challenges with distributing tasks among its personnel. Ben will recruit volunteers through the laboratory's weekly newsletter while also talking to faculty in the laboratory. The laboratory also has an outreach committee, so once a year, Ben will contact the committee to recruit graduate student volunteers. "In the end almost nobody has to do all that much. So it works out pretty well. I'm the only one who's there the whole time" says Ben. One reason for this is that Ben distributes smaller and more discrete types of tasks to various groups of volunteers. For example, the support staff are responsible for coordinating housing and catering for the youth participants. Other volunteers are responsible for preparing the activity space by gathering name tags and other supplies. Graduate students and postdocs are responsible for developing and facilitating activities, which mostly entail carrying out or modifying activities from previous years. In Camp Physics, each volunteers responsibility is a singular and well-defined task.

We can see from Camp Physics that task distribution can affect recruitment and also that institutional support can play a role in this process. Since each personnel member has their own dedicated task and the time commitment is relatively low, recruiting volunteers has not been as challenging. While Ben advertises for volunteers in formal ways like the laboratory newsletter, he comments that his success is, "...mostly, it's personal contact. I will talk to a faculty member myself, that kind of thing. We have an outreach committee over there, and every year, I say, 'You know what? We really could use some grad students to help out, and we could probably use a postdoc.'" Here, there are fewer challenges with the connections between personnel, resources, institution, and program.

3.4.3 Program Content and Activities

An important finding is that the personnel and their academic backgrounds directly impact the type of content and activities that are part of the programs. Other important features that can influence content and activities are the agency of volunteers, availability of space, physical and financial resources, interactions with audiences, and institutional support. For example, Pub Physics personnel currently or have previously worked as researchers in astronomy, astrophysics, or related fields. Similarly, Camp Physics volunteers are researchers who utilize their laboratory space and resources to conduct related physics activities. Physics Club utilizes a mixture of planetarium space and resources provided by the department as well as undergraduate volunteer knowledge from their coursework and research experiences.

In some cases, volunteers' academic backgrounds can be highly influential to the programs' goals because volunteers find it easier to go into the content more in-depth and more passionately. Camp Physics focuses on physics topics related to the laboratory's primary research area. Program activities use the equipment that is available at the laboratory. The recruited volunteers are faculty, postdocs, and graduate students who all work at the laboratory, so they bring their expertise to their presentations and activities. As Ben notes, "I kind of sketch out, 'This is the array of things that are going to happen.' But the individual experiments and talks and things, [the volunteers] pretty much have free reign...they're probably going to talk about their own experiments with their own equipment." Camp Physics leans into how the personnel bring their own expertise to the activities and encourages them to relate the content to their own work.

However, sticking to a particular theme that the personnel may be comfortable with can also challenge a program. As mentioned, Andrew from Pub Physics earned a Ph.D. in astrophysics and therefore has the interest and expertise in that field. Pub Physics guest speakers are free to choose the specific topic they present as long as it can loosely be tied to astronomy. As Andrew notes, "the idea is basically the talks that we try to find have some connection to astronomy research, even if thats a very tenuous and weak connection." Some connections may be made through computing, machine learning, and particle physics, with some attempts or comments on how it can be useful for astronomy and astrophysics. Other volunteers also bring their own physics content knowledge into the activity structure. For instance, after each talk, there is a trivia session that one of the graduate students or postdoctoral volunteers puts together based on the speaker's presentation. Sometimes volunteers bring other types of knowledge to program activities. For example, one of the Pub Physics graduate student volunteers was interested in the live streaming of the event. While she was a volunteer for the program, she used her technological knowledge and experiences to record and stream events online.

Physics Club also has had to adapt to the varying content knowledge of its volunteers. As an undergraduate organization, volunteers are sometimes majors outside of physics or astronomy, so there is a larger variance in the depth of physics background among the personnel. This can lead to varying degrees of autonomy among the personnel. For example, Carly is the one who selects the activities from a database of available demos. Typically, the volunteers are there to operate or assist with the demos. The volunteers have some individual freedom in how they answer audience questions, but they do not have the same level of creative or content input on the activities as the volunteers for the other two programs. The institutional support also impacts Physics Club's content as the department provides the program with funding, a meeting workspace, and some physics demos, as well as access to the planetarium where they can host planetarium shows and open house events. With the institutional support and access to these resources, Physics Club is able to put together astronomy-themed shows, events, and demonstrations.

Another factor in content and activity design is from feedback, communication, and interactions with the audience. For example, Camp Physics used to run physics activities with home-made detectors. Participants questioned why they were using a simplified version of the same equipment that was available in a world-class laboratory. The program took the audience feedback into consideration and switched over to using actual detectors and laboratory space at the facility. For Pub Physics, Andrew says that roughly 80% of the topics covered are astronomy or astrophysics related to astronomy because that is something that a lot of the public is curious about. "It's a great opportunity to get people in the door even if in the end what they end up learning is more about computation or geology...If it's astronomy [laughter], it's going to be pretty reliable [to attract audience members]." Similarly, Physics Club has different themes to draw interest and excitement. Themes may include Star Wars, planets, or black holes to encourage audience members to return again for a different event.

For these programs, personnel influences the program's content and activities based on their knowledge and academic background. In addition, the interactions that the personnel have with the audience and the institution can also impact the types of activities and spaces that the activities take place in.

3.4.4 Personnel Interactions with the Audience

For all informal physics programs, the way that personnel interact with audiences impacts the audience's experience and engagement with physics content. In our cases, we find personnel and audience interactions in the three different programs happen as presentations, demonstrations, Q&A, one-on-one interactions, social media, live streaming, guided activities, and tours. These types of interactions are influenced by program structure and design and impact different audiences in varying ways. For example, personnel members may interact with children differently than adults. We are interested in how program personnel connect with the audience based on program design and why lead facilitators made those design decisions.

3.4.4.1 Personnel Recruit Audiences

Program leaders recruit and advertise their events to audiences through social media, flyers, word of mouth, and contacting schools. Andrew promoted Pub Physics events via social media, email lists, and word of mouth. Event turnout was large so he did not change that approach for several months. As Andrew notes, "I would say, 90% of the crowd knows us through [social media platform]. What I've been wanting to do is trying to figure out better mechanisms for getting the people that aren't on [that platform]." Andrew then added another social media platform that he believed is more common in younger crowds, which resulted in some new followers. However, if social media is the main form of advertising, then only certain audiences are most likely to learn about the event. Andrew has considered expanding to flier-based advertisements but is uncertain about their effectiveness. With physical flyers, one needs to consider where they are posted. Andrew often does not promote

Pub Physics on campus. According to him, the university has plenty of opportunities to learn science. While Andrew appreciates when a university faculty member does show up to express support for the endeavor, he also wants to make sure that he is not catering primarily to academics.

Ben has made connections with teachers in his local community through a teacher program that he also runs. The teachers Ben has connected will spread information about Camp Physics to other teachers and community members: "It used to be that [previous program leaders] advertised solely by mailing posters to schools [around the state] and thats how it got done before I got here. And then I was like, 'Why are we mailing all the stuff? It seems like a huge waste.' So with these connections that we already have, basically, [teachers we know] help get us people." Camp Physics, however, is limited in the number of students due to laboratory space. Camp Physics has an application process because there are more interested students than available spaces. With an application process, one needs to think about who they are accepting. Camp Physics aims to expose students who already have an interest in science to some physics topics that they likely will not see in school. In reviewing applications, Camp Physics tries to limit how much they are weighing the schools and opportunities that are available to students. For example, looking at the number of science classes or extracurriculars that students take may privilege students in certain schools or districts. In recognition of this issue, the Camp Physics application considers activities that the student pursues on their own, such as the types of science books they are reading or science videos and shows that they are watching.

The personnel make decisions to attract certain audience demographics, such as kids, adults, people unaffiliated with the institution, people of a particular socioeconomic status, or gender. We find that some decisions that personnel make to attract their target audience include the avenues in which they advertise, such as flyers versus social media or on campus versus off campus. The personnel also takes into consideration how resources like location and amount of physical space can impact the audience.

3.4.4.2 Opportunities for Audiences to Ask Personnel About Physics Content

We find multiple different opportunities for audience members to ask physics-related questions and learn together with their peers. One opportunity for audiences to ask the personnel questions is through a dedicated question and answer (Q&A) session. All three programs have some form of a Q&A session built into their event, either during or after the presentations.

Pub Physics dedicates some time after each speaker for the audience to ask questions. In addition, after all the guest speakers have given their presentations, Andrew will open up a broader Q&A session. It is not uncommon for physics and astronomy graduate students, postdocs, and faculty to attend Pub Physics as audience members. Knowing this, Andrew will say, "Can the physicists, astrophysicists, and astronomers come up to the front of the room." Those who are interested will go to the front of the room and answer astronomy-related questions from the rest of the audience.

While audience members are able to ask physics-related questions to the personnel in Q&A sessions, the formalism may make some audience members uncomfortable with sharing their questions, much like a student asking an instructor a question in front of a large class. To help mitigate the stress of asking questions, Camp Physics allows time after the faculty member's research presentation for the high school student audiences to form small groups to develop questions. Each group then asks their questions together. The benefits of this format, as Ben notes, is that the high school students get time to formulate their questions and help each other understand concepts that they may not have figured out by themselves. Also, "people who might not ordinarily raise their hand in class might get a chance to sort of have their questions answered. So that's kind of a signature aspect of our program."

Pub Physics also creates opportunities for audience members to ask questions to the personnel without having the entire audience watching. For example, a graduate student volunteer will run trivia during the breaks between speaker presentations. During this time, Andrew will walk around the room from table to table. "I come up, and they [audience members] are talking about science. And, 'Actually, we have a question for you. We can't figure out how thing X works that they're talking about.' I walk them through that and explain it to them. So I get the opportunity [to] have informal science discussions in [that] science education outreach [space] ... me-to-three people or me-to-six people."

From these examples, we can see that the program's activity design creates a connection between the audience and personnel. For some audience members, the casual interaction creates a space where they may feel more comfortable asking their physics questions to the facilitator or their peers. The facilitator is also able to have more personable conversations with the audience.

3.4.4.3 Finding Personal Connections Between Personnel and Audiences

In our cases, lead facilitators are aware of barriers to inclusion that can affect audience participation, including how audiences interact with personnel. Some factors that can negatively affect audience-personnel interactions are perceived differences in background, race, age, or academic degree. One way the programs try to mitigate barriers to these interactions is by implementing structures that promote more personal connections between the personnel and audiences.

When Andrew moves around the room after a speaker's presentation at Pub Physics, he is doing more than just answering physics questions from audience members. As he puts it, "I try to ask people like, 'Why are you here? Are you having a good time? What would you like to see at future events?' And make it feel like they're not just a blind face in the crowd that's there for two hours. So I know a bunch of the regulars' names at this point, the ones that show up from time and time again. So I try to make it—I try to instill some level of community." With an audience size of about 100-200 people each month, and an email list of about 180, there are many repeating audience members who Andrew and the other personnel interact with each month.

Camp Physics runs for a week with the audience of high schoolers spending the nights in the resident halls. With the physics activities running during the day, this allows for social events for the youth in the evenings. The personnel are invited, but not required, to attend the social events, and "a lot of them [the graduate and undergraduate students] just come in the evening and hang out," according to Ben. Also in the vein of being casual, Ben notes that the evening activities are "an excuse to sit around with the students and our people and just chat and ask anything you really want to at this point." It is a low-stakes space where personnel and audience members can casually interact with each other and discuss anything, even if it is not physics related. Ben says, "[the high school students] being around each other but also having all that time with faculty, staff and students here. That's their number one consistently rated aspect of the program." Similar to Andrew at Pub physics, Ben from Camp Physics makes claims about long-term connections and experiences that their audiences take with them when they leave the program.

At the center of Physics Club is the idea of building an inclusive environment for anyone interested and passionate about physics and astronomy. For example, Physics Club hosted three separate events with the Girl Scouts, seeing 100-150 girls over three nights. Since this was an audience of younger kids, Carly says, “I try to remember to bring stuff for them because we have stickers and all sorts of posters, color pages, things like that here. So I try to remember to bring that sort of stuff there so that theres something they’re taking home. ...I know that being a woman in this department can be difficult, but if we can start making that cultural change early or just fostering that value system, I think that’s really important.” There is a gender inclusivity factor that Carly and Physics Club work to create with their events.

For some sessions of Physics Club’s open house events, the audience may be “purely undergraduates, and then I would say it’s pretty representative of what this university looks like in the sense that it is predominately white...[with representation from] international students a little bit as well.” Since Physics Club is composed of undergraduates as well, there is an effort to connect with their peers through passion and excitement. Carly says, “If it’s people that are really passionate about it, I think [the public engagement co-coordinator] and I are, it comes across and we can encourage other people to do it.” Carly works to ‘tell people that you don’t have to be an astronomy major to spend your Wednesday nights just hanging out with us,” emphasizing that Club Physics events are spaces where casual and scientific interactions can take place. Physics Club tries to consider the needs of its audience to create an environment that fosters welcomeness and support on and around physics.

3.4.5 Resources and Institution Connections

The functionality of informal physics programs often requires some level of support from their institutions and community partnerships. Partnerships and institutions may provide resources such as financial support or physical items like supplies and space. The availability of these resources plays a vital role in the program's ability to run its events and activities. For example, access to a venue can impact audience-related factors like number of attendees and the audience demographics. Programmatic attributes such as the style of activities, content, and planning can be influenced based on resources.

3.4.5.1 Partnerships Provide Resources

While programs are often viewed as single groups or entities, their event operations often require collaboration and coordination with partners. Building partnerships is key for programs because partners can provide necessary resources. Partners can include donors, community organizations that the program works with, teachers or schools, and businesses that host or sponsor events. For example, Pub Physics partners with local bars and venues to host their monthly events. Pub Physics' events depend on having these spaces available. When one of the venues went out of business, Andrew had to find another venue that would host them and could accommodate their audience of up to 200 people.

Building partnerships, however, takes time and effort. Personnel, often the program leader, regularly work and communicate with partners to build relationships and trust. For Pub Physics, Andrew is responsible for communicating with the venue about planning event dates, providing drink tickets for the presenters, and raffle prizes for the audience. At one point, one of the venues would help with marketing the event by creating promotional images and advertising on social media. Transitioning to another venue, Andrew has taken on more of the promotional roles, though the current venue does provide prizes and raffles during the event. Andrew spends about a full work day each month dedicated to emailing people, coordinating which month works for the speakers, coordinating with the venue, and advertising the event.

For Camp Physics, Ben is responsible for coordinating with on-campus partners like the residence and dining halls to house students for the week and to accommodate participants' dietary needs for Camp Physics. As Ben notes, "I used to do almost everything myself. Now we have some business support people that I can say, 'We would like catering on this day and this day. We're going to eat in the residence hall the rest of the days. This is the kind of thing we need. Here's all the allergies we need to be aware of.'" This freed up Ben of some necessary tasks such that he could focus on other responsibilities.

3.4.5.2 Choice of Program Location and Fees

An impact on audience attendance is program location and the cost of attendance. Pub Physics events do not have an admission fee, making it more financially accessible for some audience members. Since the events are hosted in a bar, Andrew encourages audience members to purchase food and drinks to support the venue, but there is no purchase requirement.

Transportation is a challenge the programs encounter. While program leaders take into account transportation for audiences to attend the program's events, there are some limitations that occur. Pub Physics has been hosted at a couple of different bars over its history. One location was in a downtown area, which led some people to attend because they happened to be walking by at that moment. Other venue locations do not necessarily have the same foot traffic and require different forms of transportation to attend. Camp Physics does not fund transportation to attend the camp, and the camp is too far for some students to walk to. Camp Physics is able to provide campus housing during the week nearby the camp, but being able to arrive on the first day of the camp can be a challenge. In some instances, some teachers have encouraged students to apply to the program, and if they are accepted, there are some community resources that are provided to assist with the transportation.

There are many factors that come into play when personnel determine the location and cost of their program. Physical resources may influence the event location, but the location can influence who is able to attend. Funding is a limitation for some programs, so personnel have to make decisions that take into account the financial resources to keep the program sustainable, while also considering the impacts that those decisions may have on the audience.

3.4.5.3 Institutional Connections and Challenges

The support and input from personnel and the institution can impact some of the events and organizations that the lead facilitators need to plan for. Programs often serve as a public face for departments, universities, and laboratories that they are housed in. While programs may be representing their institution, the level of institutional support varies. Institutions may provide funds, physical space for events and preparation, or volunteers, however, some challenges may arise as well.

Camp Physics has reported strong support from the large research facility that it is housed in the form of volunteers and funding. As discussed earlier, when Ben needs volunteers, he will advertise through department newsletters and talk to faculty and students directly, with many of them volunteering for multiple years. Among those repeat volunteers are some of the facility's directors. "My boss is involved almost every year. And the chair of our outreach committee is involved almost every year...Our directors are pretty supportive of the outreach program. They're also pretty hands off. They're like, 'You do what you think needs to be done.' And people say yes when I ask them for things." The institution also provides financial resources. For one project, Camp Physics needed a sizable amount of funds. Ben went to his director, who then committed some funds and wrote a letter to other departments asking them to contribute as well. "And it completely worked. We had no trouble getting the money that we needed. So again, as long as the laboratory exists and our directors are the way they are, were not in trouble," says Ben.

Some challenges that Physics Pub experiences are with the resources and support that it receives from its institution. "Occasionally they'll [department] advertise [Physics Pub]. Yeah, I didn't—I never really got much in the way of actual support from the department either advertisement or financially supported, or anything like that." Andrew says that he was once awarded a department outreach award, but that was the extent of acknowledgment from the institution. "I don't even know how many people in the physics department knew I was doing it even though occasionally we would send out department-wide emails." Andrew asked a laboratory on campus to promote Pub Physics in their newsletter, but they declined because it was not explicitly related to their laboratory. Andrew's department would occasionally mention Physics Pub's event in the department's weekly announcements, but he had to constantly remind them to do so. This eventually led Andrew to say, "On top of everything else I was juggling, it just wasn't worth it." He then stopped emphasizing promotion within the department.

There are several instances where Physics Club and its home department are at odds with each other, straining relationships. As described earlier, there were instances where Physics Club events were scheduled during a departmental trip, which rendered several undergraduate volunteers unavailable for the club's event. In addition, Physics Club is a due-paying member of a regional organization at the request of the department, which has caused some tension with the program. As Carly states, Physics Club is not active in the regional organization as it is more catered to nonstudent groups and has some internal conflicts. However, part of the Physics Club's budget has to be used to cover a membership fee for the regional organization. "Personally, I disagree that we should have to donate to that or build it into our budget. I don't think it's something the department should be sponsoring, but we do it." It is worth noting the power dynamics that are at play in this case. It may be more challenging for student-led programs to confront the faculty of their institution compared to programs facilitated by other faculty.

The personnel and institution connections within informal physics programs can have big impacts on programs' functionality. Some programs are paying the salaries of the lead facilitators, who are hired as professional physics educators for the institutions. Other programs do not provide monetary support for the lead facilitator directly but may support the program costs in other ways; thus the institution can rely on the interest and availability of the lead facilitator to keep the program operating while maintaining an association with the program that may be useful for cultural capital or grant agencies. In some cases, programs live on the fringe of institutional support, as seen with Pub Physics. Andrew finds volunteers through his other work at the institution, though the institution itself does not necessarily support the program. It is also clear that the relationship to the program impacts other framework components, such as resources. Impacts with resources may include financial support, the types of partners the program works with, or supporting and recognizing personnel members.

3.4.6 Assessment

In our findings, the assessment framework category was the least coded. We find that within the interviews, the terms evaluation and assessment are being used interchangeably, which is partially due to the researchers deliberately using both words to be inclusive of the different ways that program leaders might think about these topics. We asked interview and survey questions using both, for example, “Is there any evaluation associated with your program, event, or activities?” and “What instruments and tools do you use for your evaluation or assessment?” This approach lets the interviewees interpret and speak from their understanding of evaluation and assessment. While evaluation and assessment are related, there are some differences. Evaluation is focused on whether programs are meeting their objectives; grants, similar to the ones that Ben earns for Camp Physics, require some evaluative process about outcomes—for example, Ben tracks the number of students who participate and then go on to be science, technology, engineering, and mathematics (STEM) majors in college because that is a goal of his program. Assessment looks at impact as well but may be used by facilitators to adapt their programs. For example, program leaders may be interested in why certain people do or do not engage with their events or activities. At the time of the interviews, assessments were interpreted by the interviewees and interviewers as primarily formal. When answering questions about assessments, lead facilitators would typically describe whether or not they facilitated something like pre and postsurveys or written feedback forms.

A main finding is that all programs were not performing as much assessment as they wanted partially because their personnel have limited time, resources, and/or experience carrying out formal assessments like surveys and feedback forms. There were two key reasons for this: (i) some aspects of the program are difficult to assess due to the voluntary, informal nature of the interactions and (ii) program leaders do not necessarily have the knowledge and resources to carry out intensive assessments. For example, Andrew would like to know more about who the Pub Physics’ audience is and why they are attending but, “I just don’t know what the right questions are, the right things to be asking...I would like to know some way of figuring out why people return or why they don't return. Are we alienating people?...I'm thinking a lot of ideas. None of them are concrete because...I don't feel like at the moment I have any great resources to turn to for that." While Andrew hosts Pub Physics away from campus to avoid a crowd of predominantly academics, and the event is free, he lacks the resources and time to assess his advertising and event practices in the way he would like. While he does like casual conversations with the audience and observations, these informal assessments do not provide as much information as he would like to inform his practices.

Camp Physics has some resources to carry out surveys and conversations with youth participants, however, as Ben will admit, "I'm not really well equipped to do assessment. I have a degree in physics. Educational assessment was never my thing." In the past, Ben partnered with an education researcher to study the impact of the program on students' STEM pursuits after high school. Ben and the educational researcher analyzed past surveys and designed new questions to ask youth alumni who participated in Camp Physics. The results of the study were published, and Ben was able to present those to laboratory directors and funders. However, the research partnership came to an end. Ben still uses the refined survey questions and structures that were developed from the research partnership. The new survey results that Ben collects are now just used for internal program improvement.

While formal assessment may not be commonly implemented in informal physics programs, we noticed program leaders are still able to collect some amount of data that informs their program decisions. Examples include casual conversations with audience members to better understand their experiences and needs, observations of audience demographics, and noting audience engagement in activities. When it comes to understanding the Pub Physics audience demographics, Andrew wonders, "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...But if we're not getting diverse individuals in the room, then there's no way of assessing why they are or are not coming." Carly of the Physics Club will reflect on how she felt the program met some of its goals, such as working with female and low-income families. "Low income is something that I don't think we really achieved this year. We did do some outreach events with students in [city], but more could've been done with that." Carly notes the location of the Physics Club may impact the types of audiences they interact with since some of the locations that the Physics Club could go already have other groups and institutions that do similar public engagement events and activities.

Carly also uses formative feedback, particularly in how to effectively communicate complex physics topics to younger audiences. Carly notes that this is a communication challenge that many of her volunteers experience. "You know these complex physics concepts. Explain them to an eight-year-old now because she wants to know what Hawking radiation is or how black holes work from the conservation mass." Reaching audiences can be difficult in the first place, as well as actually engaging with them in a meaningful, supportive, and informative way. Carly chooses topics that she thinks audiences may connect with and that often requires adjusting how she and the volunteers explain that concept.

While program leaders encounter assessment challenges due to limited time, experience, and resources, they still have an interest and desire to carry it out. Andrew from Pub Physics says, "I'd like to develop an assessment to see if people are enjoying the events, learning things from the events, understanding the messages we're trying to send about the importance of scientific literacy." Andrew is interested in learning about already developed tools or at least working with others to develop one. "I dont know much about the literature, and so are there common assessments that are used for informal education? Or if not, maybe we could develop one." Ben also notes that collaborating with researchers in developing assessment provides some professional benefits. "I had zero background in anything educational when I got [this position]. So I had to pick it up...But a lot of what I've done is by finding the expert...If you find somebody else who's doing it [assessment]—because you can get a publication out of it or—at the very least, it's going to benefit them to some extent."

3.5 Discussion

3.5.1 Personnel are a Central Part of Informal Physics Programs

Our findings show that personnel are instrumental in developing program materials, interacting with audiences, managing resources, connecting with the institution, and conducting assessment. Figure 3.3 is a general visualization of how the framework categories connect with each other. Personnel is the central category connecting to all others, and the diagram provides an example of each interaction as informed by our data. In addition, the double-sided arrows symbolize a two-way interaction between the categories. For the sake of our visualization, resources and institution were combined as they are closely related to each other. Assessment is not explicitly included in Fig. 3.3, however, we find that assessment arises when personnel members (primarily program leaders) are evaluating or considering one of these five categories. For example, assessment occurs when program leaders are observing how personnel and audience interact or collect audience feedback.

Due to the connectedness of the framework categories, we find that if there are challenges in one category, those can disrupt some of the other categories. This was discussed earlier in the paper with Pub Physics where confirmation for volunteers (personnel) to give talks occurred late, which made it difficult to have advertisements with full event information (resources) to attract people (audience) to attend the event. Understanding the connections between framework categories can be useful to identify areas to strengthen the program. In the following sections, we will discuss in more detail how themes appeared in the data and the implications that arise.

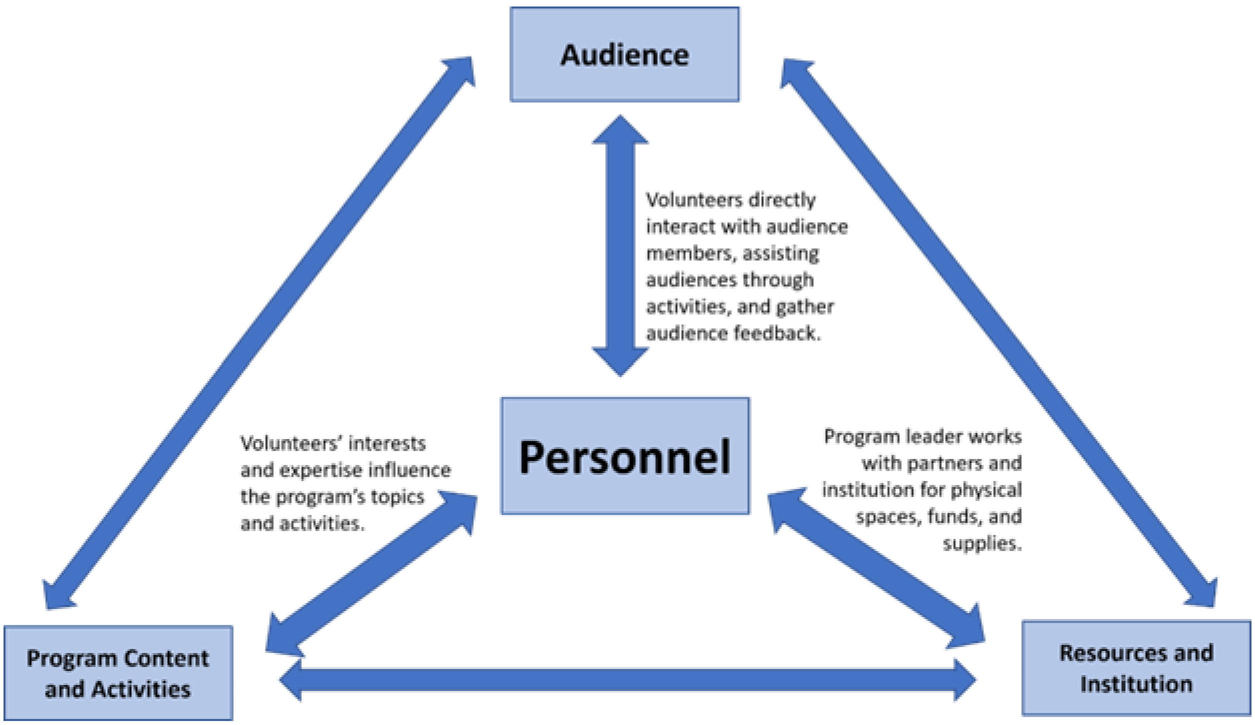

Figure 3.3: A visualization of how the framework categories connect with each other. Connections with the personnel are accompanied by generalized examples extracted from the interview data. As discussed, institution and resources were closely connected to each other and not as prominent, so they were combined for this visualization. Assessment is not explicitly included, however, we find that assessment arises when evaluating and observing one or more of these five categories, and those observations are often conducted by the personnel.

3.5.2 Issues of Access, Inclusion, and Equity

Thinking about how to improve access, inclusion, and equity of informal physics programs in the context of personnel is critical because not only does it involve those who volunteer in these spaces, the personnel are strongly connected to the program and audience. The personnel and who makes up the personnel have the power to influence these issues in the other categories.

The personnel and the programs they lead are a part of and inform the culture of physics. The lack of more explicit recognition and support is already signaling issues of equity and inclusion in physics as a field and the practices that physicists do. As we have shown, many roles and tasks fall onto a few people. In addition, the majority of the personnel are on the low end of the hierarchical chain in their institution. For example, undergraduate students volunteer and sometimes run informal physics programs, but they have limited time, resources, and power within their institutions. The personnel in these programs are contributing to the physics community, so it is important to support the students and faculty who are involved in these programs.

Addressing issues of access, inclusion, and equity with personnel can help address some of those same issues with the audience. The decisions that program leaders make with advertising, program design and location, fees, interacting with audiences, and other program structures impact who attends the programs events and their experiences at the events. Personnel need to consider how they connect with and attract audiences, including the accessibility of the program to audiences.

Representation within personnel is important for considering aspects of inclusion with both personnel and audiences. About 80% of those who earn a degree in physics are male, and over 70% are white [30, 29]. The universities in which the programs we analyzed are housed have demographics similar to the national averages. As program volunteers are recruited from these departments, personnel demographics and backgrounds may not necessarily be the same as the intended audience. There is sometimes difficulty in recruiting volunteers given the many commitments students and faculty have, and there arises a tension in presenting a more diverse face of physics without also overburdening members of marginalized groups with participating in informal physics events alongside their other commitments. Making sure that the personnel are supported in these programs and in their institutions can help address representation, which in turn can impact the audience as that is who they directly interact with.

Personal connections between the personnel and the audience are important as this builds trust and interest between the two groups. This is especially true with getting and maintaining an interest in physics among a younger audience. Carly specifically comments on this based on her experience of being a woman in the department, and why she brings stickers, color pages, and similar items to the Physics Club events. It creates a connection with the younger kids and allows them to bring a part of the physics back with them after the event.

Program leaders can also consider how they are creating spaces for interaction between the personnel and the audience. For example, a stage in a physics lecture might automatically create a separation between the physicist and the audience; additionally, if the stage is higher up than the audience seats, this can reinforce a hierarchy of knowledge. However, if personnel members are moving around the space and sitting with the audience, casual conversations and social interactions among personnel and audience members can take place, which may create a sense of community among the personnel and audiences as well as a more comfortable physics learning environment for all participants to express themselves. In these spaces, audience members get exposure and personal connections with professionals and their work in the physics field, which could impact the interest and academic and career pursuits of younger audience groups.

Assessment is a tool that can help program leaders understand the experiences of all participants and make decisions that affect those experiences. Assessments can help identify, measure, and address challenges and successes that each program has in regard to its audience and personnel. However, there is a need for resources to help program leaders with assessments. Not all forms of assessment are the same and sometimes there needs to be creative assessment methods due to the voluntary and sometimes short-term nature of informal environments. For example, it can be difficult for a program leader to assess why audiences are attending their program. A way to assess this issue can be from casual conversations that personnel have with those in attendance, which can provide some form of feedback on what the audience would like from the program. However, as noted earlier by Andrew of Pub Physics, it is easier to get that feedback from the folks who are already in attendance. It is difficult to assess those who are not present, which affects how much programs can know about reasons people are not attending or stop attending events.

3.5.3 Considerations for Assessment

As noted by the lead facilitators of these programs, there is a need for assessment tools in informal physics programs to evaluate and monitor many aspects of their work. Given the importance of personnel members in these programs, checking in on their experiences and satisfaction in the program can be crucial in retaining volunteers and helping develop their physics identity and interest in participating in informal physics. There is also a need for an assessment on connecting with audiences for many similar reasons as assessing the personnel: attracting and retaining audiences, reviewing the intended audience versus the audience that actually participates, adjusting practices as necessary, as well as building identity, understanding, and interest in physics. We suggest that the broader physics education community of researchers and practitioners work on this issue to produce more research on assessment in informal physics programs.

Based on our study, we propose that lead facilitators might be able to self-assess their programs across organizational categories. In our study, program leaders told us about what they evaluated or wished they could evaluate in their programs; in Table 3.3, we rephrased a selection of their responses into the forms of questions that other practitioners might ask. For example, practitioners could consider what are the tasks that need to be completed within the program, and how these tasks can be distributed among the volunteers such that the tasks play to each person's strengths and interests, while also not overburdening any one person. This could include communication with the volunteers, asking them what they perceive their roles to be, providing appropriate training and support mechanisms for volunteers, and making sure that the team is in agreement on what needs to be done and by whom.

The purpose of Table 3.3 is to inspire questions that practitioners could consider when assessing aspects of their program; this is not meant to be an exhaustive list nor will every example be relevant to all programs. Additionally, informal physics programs do not implement assessments in the same way. A question that works for one program may not work for others.

Table 3.3: Examples of questions that personnel members can consider when addressing interconnecting aspects of their program. Each row corresponds to the double-sided arrows in Fig. 3.3, representing the connections between the framework categories.

Connecting framework categories	Example areas for assessment
Personnel-Audience	Do audience members feel comfortable asking questions or conversing with personnel? What is the audience feedback on the speakers? Are volunteers equipped to address audiences questions?
Personnel-Program	Are tasks and responsibilities distributed among volunteers such that no one is overburdened? Are volunteers adequately trained on building activities or communicating with audiences? Do volunteers have agency in designing activities?
Personnel-Resources and Institution	How much time are personnel able to dedicate to the program relative to other work responsibilities? How organized are activities and supplies for volunteers to locate? Do the personnel report success and challenges to the institution?
Audience-Program	Are the activities engaging for the audience? Are the physics topics presented at an appropriate level for the audience? Did the audience learn physics content or practices?
Audience-Resources and Institution	Is the physical space an appropriate size with enough seating? Is the event cost or location a limitation for the audience? Are youth audiences more likely to attend that institution for college?
Program-Resources and Institution	How does content connect to the research of the department? How much department funds are being spent? For example, Buying supplies, paying personnel Is prep space and equipment provided and accessible at the institution?

3.5.3.1 Future work

There are still many understudied aspects of informal physics spaces. We suggest that there could be room for collaborative partnerships between practitioners and researchers to better understand the needs and functioning of informal physics spaces. There would need to be clear communication between practitioners and researchers on what the goals of these relationships would be, whether that is to better understand the landscape of informal physics, understand certain aspects of the program or audiences, and/or build the skills for practitioners to assess their own programs. We hope this work encourages partnerships between researchers and practitioners and that our framework guides future studies.

Our overarching goal is to develop a model for the organization of informal physics programs. This work helped us to understand facets related to the personnel and their connections with program content and audiences. Throughout this paper, we found that program leaders working with their institution administrators is important for financial resources. Program leaders are in charge of program design and implementation. Volunteers are also in charge of interacting with audiences. Going forward, we are working to identify specific key components within each of the informal physics organizational theory categories that practitioners can and should focus on to strengthen their programs. Identifying these key components will allow us to craft more relevant and targeted assessment questions that program leaders can use to reflect on and assess their own programs. The central role of personnel in informal physics programs will be a significant influence on the development of the upcoming key components model.

Chapter 4. An Empirical Framework for the Key Components of Informal Physics Programming

This chapter has been submitted and is currently under review as a journal article. The author order on this article is Bryan Stanley, Dena Izadi, Jessi Randolph, Lily Boyd, Claudia Fracchiolla, Kathleen Hinko.

4.1 Introduction

Informal education programs provide opportunities to teach and learn physics and astronomy in creative ways outside of the constraints of formal classroom spaces. They can have a positive impact on content learning, interest in physics and astronomy, and physics identity development for both audiences [5, 6, 7, 8, 9] and facilitators of the programs themselves [33, 32, 59, 60, 61, 62]. University students make up the majority of program volunteers [5] and also benefit from building a sense of community and gaining professional skills like communication and pedagogical practices [26, 27, 28, 32, 33, 32, 59, 60, 61, 62, 120].

The lead facilitators of these programs are often university students, staff, or faculty. In prior work, we have found that most of the leaders of informal physics and astronomy programs, whom we refer to as practitioners, want to be able to conduct assessment and evaluation within their programs. However, program leaders often have limited time, resources, and experience for such work [106]. The wealth of research from the physics education research community over the past decades show the importance of understanding the impacts of the learning environments that physicists create, not only to promote learning, but also to prevent harm from being propagated to marginalized communities [121, 122]. As the aim of a significant fraction of informal programs is tied to broadening participation efforts, it is even more important to engage in systematic and careful program design, evaluation, and assessment [123, 124].

Partnerships between informal physics and astronomy program leaders and physics education researchers have already created opportunities for assessment and evaluation that can be used to better programs and their community impacts. Initiatives like the Joint Network for Informal Physics Education and Research (JNIPER) from the American Physical Society (APS), with 160 members across 30 countries, demonstrates that there is a movement to promote more collaboration between education researchers and practitioners [125]. JNIPER hosts a variety of events to promote continuous learning and collaboration among researchers and practitioners. Events include a series of workshops and monthly coffee hours that cover topics such as evaluation and program sustainability. In these events, a main theme has been the desire for tools that practitioners can use to assess their program's effectiveness [126]. However, there is a major challenge to developing assessment tools that could be widely applicable because the logistical, management, and curricular aspects of informal physics and astronomy programs have not yet been characterized systematically. In contrast to the relatively standard operation of formal classroom environments, the landscape of informal programs is diverse and complex [4, 106]. Some types of programs may have similar organizational features, such as traveling physics demonstration presentations, but this type of program could have significant differences from another type of program, like a physics summer camp or an observing night. Therefore a necessary precursor to developing instruments that could be used across informal physics and astronomy programs is a categorization of the main organizational features of programs themselves.

The aim of this research study is to uncover and characterize the main aspects of informal physics and astronomy programs that are relevant to their operation and success and to share these results in a form that could be made useful to practitioners. To accomplish this, our study design uses a qualitative approach to framework development. We interviewed lead facilitators from a diverse array of informal physics and astronomy programs, and engaged in iterative coding of fine-grained aspects of program operation. Then we coalesced these fine-grained codes into key themes, and applied these themes to additional program data.

In this manuscript, we present the results of this study as an empirically-based framework that identifies the key components of informal physics and astronomy programs. This framework describes 12 components divided into 4 main categories that are a) important to programs' functionality and that b) program leaders have influence over. Our goal in this presentation is to present the many pieces of the framework in a way that applies to the multitude of informal programs while also being mindful of the quantity and grouping of the key components to still be digestible and useful for practitioners and researchers. Identifying these components sets a foundation for future development of assessment tools.

4.2 Developing a Framework

In the field of physics, frameworks, such as the Standard Model, serve as indispensable tools for comprehending the intricacies of nature, enabling us to characterize and understand fundamental phenomena based on empirical observations. In education research, frameworks play a pivotal role in understanding and categorizing different forms of public engagement initiatives within university settings. Frameworks provide a structured approach to assess programs and enable nuanced analyses of objectives, methods, and outcomes. For example, Doberneck, Glass, and Schweitzer work shows the lack of a common language for describing publicly engaged scholarship makes it hard for faculty and administrators to understand each other and for universities to demonstrate their social impact [37]. To address this issue they developed a classification system based on how faculty members themselves describe their work. This provides an understanding of what publicly engaged scholarship looks like in practice and the importance of context in understanding and assessing engagement efforts. Their framework facilitates nuanced analyses of objectives, methods, and outcomes, thereby enabling researchers to evaluate the impact and effectiveness of these initiatives.

Furthermore, public engagement and informal STEM education programs have a crucial role to play in fostering scientific literacy and interest in diverse communities. However, achieving equity and inclusion requires more than just access. Recent research emphasizes the importance of "meaningful engagement" that centers the voices and experiences of historically marginalized groups [127, 128]. Frameworks can provide structures and guiding principles for how to incorporate practices within informal learning programs to ensure accessibility and equitable practices. For instance, the YESTEM program offers a notable example by identifying four clear categories essential for cultivating equitable practices and spaces within informal learning programs [129]. The Michigan Public Engagement Framework describes the people, relationships, and contexts in public engagement spaces more broadly, moving toward a shared language among researchers and practitioners in different fields in order to identify crucial skills in public engagement work [130, 131].

Building upon this recognition of the need for robust frameworks, our research endeavors have delved into the operational dynamics of informal physics and astronomy initiatives. In our prior work, we leveraged Organizational Theory, particularly within the nonprofit sector, to systematically categorize programs, analyze their organizational structures, and pinpoint crucial components vital for their functionality [4, 72, 73, 106]. We developed a framework consisting of six broad categories adapted from nonprofit organizational theory. This framework serves as a foundational structure for understanding and categorizing informal learning programs [4, 73, 106]. A main finding was that program personnel, including program leaders and volunteers, play a central role in the functionality of informal physics programs [106].

However, our intention with this work is to refine our analysis to a mid-grain level —providing practical and actionable insights beneficial to program leaders, administrators, and researchers. This refined approach aims to bridge the gap between overarching organizational frameworks and context-specific details, offering valuable guidance to enhance the effectiveness and sustainability of these programs. In this work, we draw inspiration from an established framework utilized for assessing and enhancing physics teacher education programs, The Physics Teacher Education Program Analysis (PTEPA) Rubric [132]. This framework was designed as a self-assessment tool to empower physics teacher education program teams to engage in reflective evaluation and improvement processes in collaboration with key stakeholders. By leveraging this established framework, we aim to further refine our analysis to ensure comprehensive assessment and continuous enhancement of informal physics and astronomy initiatives.

4.3 Methods

For our approach to develop an empirical, practitioner-oriented framework, we decided to interview program leaders about the structures and history of their programs. We found from prior work that looking at online program materials or surveys did not capture the complexities of the operation of these programs [46]. Interviewing program leaders provided insights on the decisions, and the rationale of those decisions, on aspects of the program such as the content covered, audiences the program works with, and how resources are allocated.

For this study, we limited our examination of informal physics programs to programs where a team of physics faculty, staff, and/or students are engaging with audiences who are not professionally involved in the field. Examples of programs include, but are not limited to, summer camps, open house events, after-school programs, public lectures, and planetarium shows. A key feature of these programs is that the audience is able to directly interact with the program facilitators. For example, the physicists and audience members can converse with each other, asking each other questions and bringing their own expertise to the situation. Another example of engagement is working together through a physics activity. The programs that we discuss in this paper have affiliations with a university or a research laboratory. We did not include informal physics learning that might occur through popular media, such as podcasts, books, websites, TV shows, or social media.

4.3.1 Data Collection

To recruit participants for this study, we took several approaches. First, we used a convenience sampling method by contacting program leaders that we already had connections with. We also recruited participants at American Association of Physics Teachers (AAPT) and American Physical Society (APS) conferences. Finally, we cold-emailed program leaders who were affiliated with degree-granting institutions. As reported in Stanley et al. [106], we conducted 31 interviews, spanning 7 states and 2 international programs. Several research members lived in Michigan, and thus had connections and knowledge of institutions and research labs in the state. As a result, Michigan-based programs (13 total interviews) are the most represented in our data set. A total of 27 out of the 31 interviews were conducted prior to the COVID-19 pandemic. The pandemic had many direct impacts on programs. Prior interviewees were contacted to participate in a follow-up interview to discuss the COVID-impacts on their program. Analysis of the pandemic impacts on programs has already been reported on [118] and is not analyzed in this paper.

Prior to being interviewed, program leaders took a 15-20 minute survey that consisted of multiple choice questions with optional comment boxes and some open-ended questions. In the survey, program leaders answered questions about logistical aspects of their program such as audience sizes, number of volunteers, program format, etc. After completing the survey, participants were contacted by a research member to schedule an interview. Further information on the survey preparation and results are reported in Izadi et al. [4].

Interviews with program leaders typically lasted about 45-60 minutes and followed a semi-structured format. Interview questions asked about aspects of the program such as format, content, activities, institutional connections, funding, audiences, personnel, the program's use of assessment, and challenges the program experiences. The interviewer would ask follow up questions based on the response. Further details on the preparation and validation of the interview protocol are reported in Stanley et al. [106].

4.3.2 Data Set

We selected 15 programs from our dataset from which to build our framework. Our goal was to select a diverse sample of programs so that themes identified would be applicable to informal physics programs more broadly. The programs selected differ in format, physics topics covered, frequency of events, audience demographics, and the type of host institution.

The research participants are a mixture of tenure and non-tenure/instructional faculty, paid program coordinators, and university students. Each of these positions come with varying degrees of power and relationship within the administration of their institution. In addition, based on their job responsibilities, there are varying levels of support and expectations for engaging in informal physics. For example, in our data set we spoke with paid staff who are expected to entirely focus their program and also leaders of student organizations who are voluntarily leading their program on top of their coursework and other commitments. A table with details of each individual program is provided in Appendix C.

4.3.3 Key Components Analysis

A flowchart visualizing the steps of the analysis process is provided in Figure 4.1. Interviews were audio-recorded and transcribed using a transcription service. Transcriptions of each interview were qualitatively coded using the analysis software MAXQDA. Initially, five of the interviews were coded for emergent themes within the six categories from the adapted informal physics organizational theory framework. Further analysis of these five programs are described in detail by Stanley et al. [106]. From that work, we found that personnel have a central role in informal physics programs, as well as the importance of considering audiences, resources, institution, programmatic aspects, and assessment. However, a limitation of that study is the lack of actionable items for program leaders.

Two researchers examined the most prevalent emergent themes that arose from the analysis of the initial five programs (Programs #1-5). We coalesced these themes into a set of ten tentative components that we identified were a) crucial for the programs functionality, b) applicable across different types of programs, and c) program facilitators have influence over. Two different researchers then independently coded five new interviews (Programs

#6-10) for these tentative components. Each interview was coded one at a time and then discussed by the whole research team, resulting in iterative modifications to the components. Through this process, two additional key components were identified and defined. A new research member, who was not involved in the original discussions of the components, was trained to use the 12 components and coded an additional five interviews (Programs #11-15) independent of the other researchers. After coding each interview, this research member compared and discussed their coding with the rest of the research team, which resulted in further refinement to the component names and definitions. One researcher then applied this set of key components codes to Programs #1-5, so that all 15 programs had been coded.

In the next stage of analysis, we had three research team members, including a new research team member who was not involved in the development of the framework, look within each key component for themes. For each component, coded sections from all interviews were compiled, and then major themes within that key component were identified and discussed among the team. Descriptions of each component were constructed using data that spans all programs.

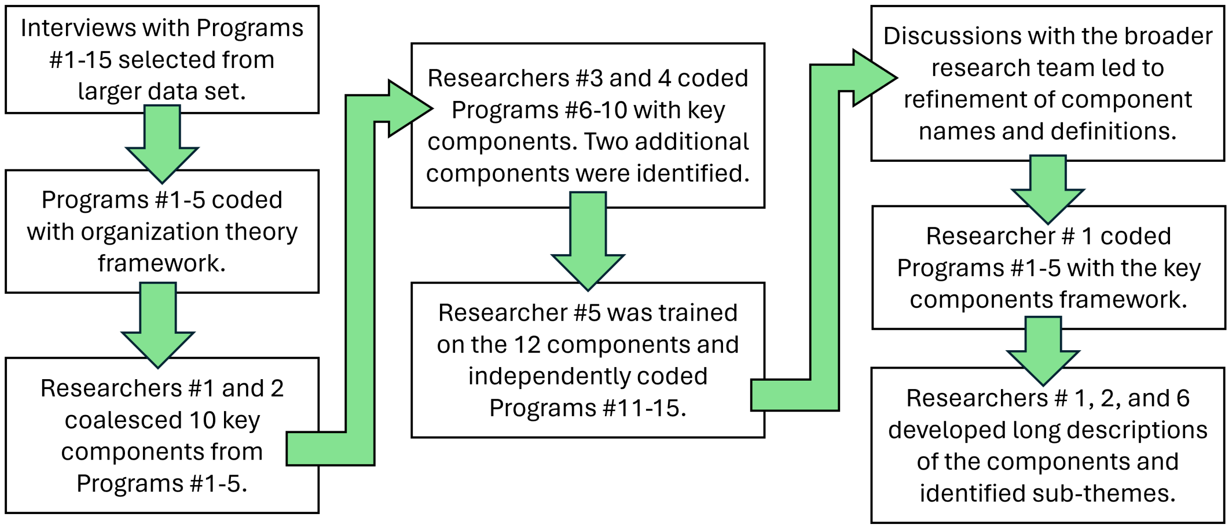

Figure 4.1: A visualization of the key components analysis process.

4.4 Key Components of Informal Physics Programs

As shown in Figure 4.2, we have identified 12 Key Components of informal physics programs. In the following sections, we describe the key themes and examples for each component. Stemming from our initial adaptation of organizational theory for informal education programs, we have grouped these 12 components into four groups that are thematically related. For example, one group contains the three components that are centered around program personnel. These groupings are identified in Figure 4.2. We will present each grouping as its own section in this paper.

We recognize that this framework has many parts and, furthermore, that these parts are interconnected. For example, one of the components is goals. Programs have many types of goals that they aim to achieve, and some of these goals may be closely related to other key components, such as wanting to support audience engagement within their events or wanting to provide professional development opportunities for their student volunteers. In this paper, we include details on all components and their interconnectedness to provide a comprehensive framework that is useful for practitioners.

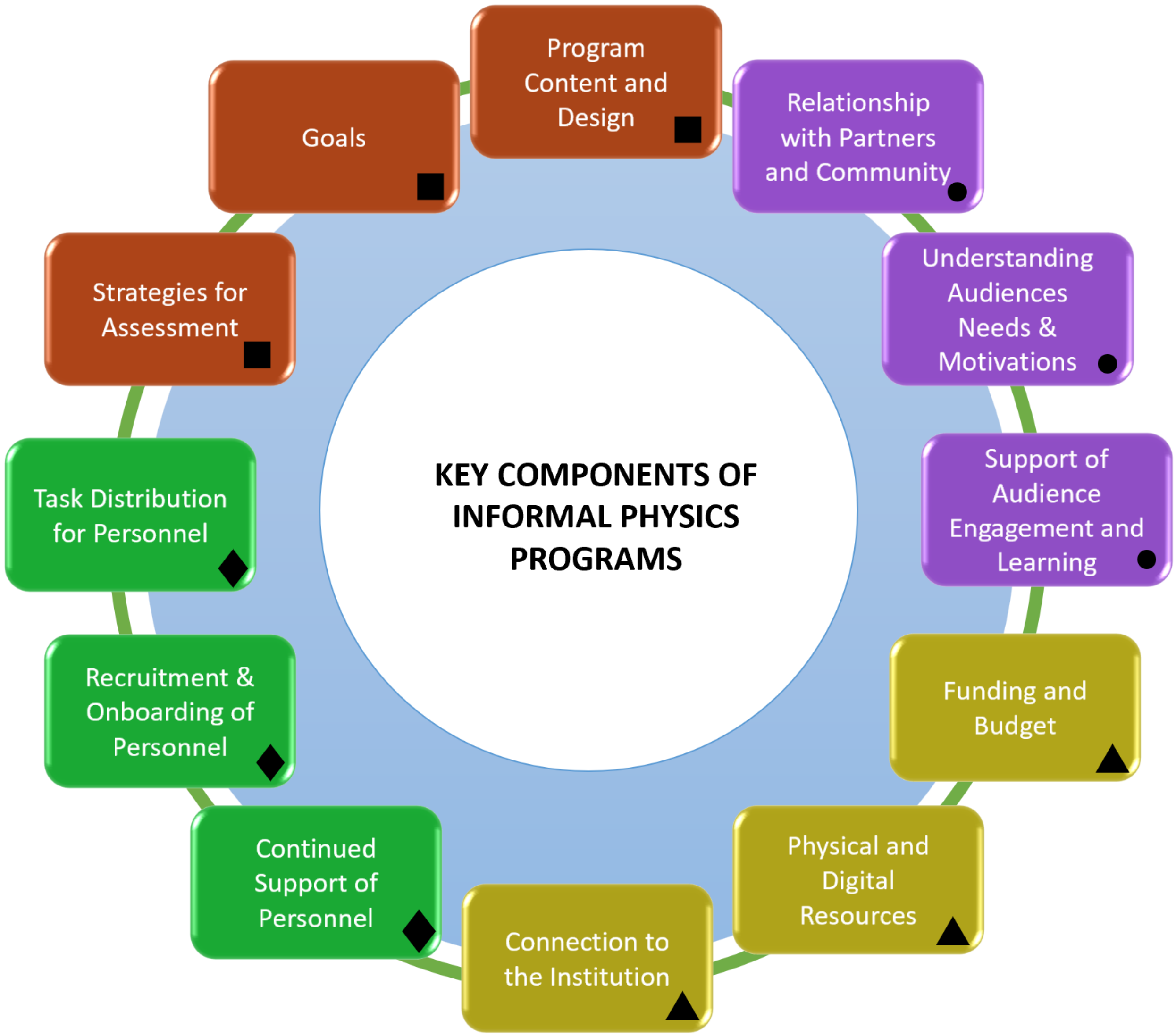

Figure 4.2: This is a visual representation of the 12 key components of informal physics programs. The components are grouped by similar themes and designated by color/shape icons (Program Goals, Design and Assessment in brown with a square icon; Personnel in green with a diamond icon; Institutional Connection and Resources in yellow with a triangle icon; Audience and Partners in purple with a circle icon). They are organized and connected in a circle to show the interconnected nature of the components.

4.5 Program Goals, Design, and Assessment

While there are similarities across different programs, we find that each program has its own set of goals that it is trying to achieve. Sometimes these goals guide the design of the program; sometimes the design of the program guides its goals. For example, one program may prioritize connecting with certain types of audiences such as kids. Another program may prioritize getting university students to volunteer in community engagement work. Some programs may put effort into creating activities that focus on a particular physics topic. We also find that programs use varying forms of assessment to help programs determine if they are meeting their goals and influence how they design their programs. We describe these ideas with the following components: *Goals*, *Program Content and Design*, and *Strategies for Assessment*.

4.5.1 Goals

Goals are what the program is working to achieve. Programs have many goals that are often centered around audiences, personnel, and content. We find that programs may prioritize their goals differently based on factors such as available resources, institutional connections, and community partnerships.

Goals play an important role in influencing the program content and design of a program. There are a variety of goals that may serve as the purpose and motivations of the program, establishing a "big picture". Practitioners leverage thoughtful design and adjustments to the other 11 components to accomplish these goals. While there is a plethora of possibilities for program goals, many programs are motivated by similar core ideas, such as curiosity, engagement, professional development, and inclusivity. Some of the commonly reported goals are described below.

4.5.1.1 Programs Seek Audience Curiosity, Exploration, and Engagement Through Their Physics Activities

Many programs have goals centered around wanting to create a safe and inviting environment for scientific exploration, curiosity, and discovery. Programs may offer opportunities to learn experimentally or actively engage in activities or discussions that can help forge positive experiences with and in science. They may also seek to share the importance of science with their audience. For example, Program 7 hosts weekly physics classes on the weekends for elementary and middle school students. To help address issues of imposter syndrome, Program 7 utilizes team-based learning. As the program's leader states, "By being able to talk about it in a group, it solidifies their knowledge. They feel like they're part of a group, they feel like they contributed, and it grows their confidence. And their ability to talk amongst their peers instead of just having the one-on-one dialog with the professor is a big deal."

Some programs want to offer opportunities for the general public to learn, experience, and engage with science that they may not otherwise encounter in their daily lives. Put broadly by Program 14, "That is what I see is the goal of what we do at the planetarium, is to teach people about the universe." Programs may also seek to incorporate and integrate science into modern culture. Program 10, a summer camp, shares, "We've lost science as part of our culture I think. It's been turned into this esoteric study that isn't part of our culture anymore, and so trying to bring it back into this is part of what makes us American or part of what makes us people is that we can make art, we can make music, we can do science, we can learn, but it's trying to think of it as more a part of their life than something in school or a possible job. So trying to bring it out of that academic sphere and more into their life."

We also find that programs connect science to art, history, religion, music, or other disciplines. This can offer audiences more entry points to engage with science and can encourage the exploration of the intersections of science and other fields. For example, Program 9 describes itself as "an eclectic mix of science, art and music. [There is] always a mix of education and entertainment that's pretty, pretty strong in our history and continues through today. We're definitely a very experimental facility. We have the freedom to explore various different types of projects and partnerships . . . looking at those intersections of art and science and, and other types of fields as well."

4.5.1.2 Programs Aim to Provide Professional and Scientific Development for Their Student Volunteers

In addition to supporting audiences, most programs in our data set seek to support undergraduate and graduate students by providing learning opportunities that teach students how to be professionals in the scientific field and effectively communicate science. As stated by Program 9, a planetarium, "We host faculty talks frequently, we interact with graduate students, undergraduates, [who] all make a core part of our team. And so we really see ourselves kind of as a learning facility, a training facility, for our students in terms of how to work at an institution."

Program 7, which hosts weekend physics classes for elementary and middle school students, has some of its classes run by more senior undergraduate students. The undergraduates are usually pre-service teachers or end up having careers in teaching. To support the program's goals of supporting student volunteers professionally, the program leader will then work with the college students in developing lesson plans and course goals.

4.5.1.3 Programs Work to Provide Inclusive and Communal Learning Spaces

We find that most programs center their goals around the curation of inclusive and equitable spaces in science. They may want to share physics with historically marginalized groups in science or provide various forms of support for students in physics. Programs may prioritize connecting to the surrounding community and supporting community development.

Programs may also combine a number of motivations and goals to formulate the broader vision for their program. For example, with their planetarium programming, Program 14 considers ways to give audiences opportunities for exploration, which includes "giving people the space to ask questions or to get their questions asked ... because I think people are naturally very curious, but you need to create an inviting space and safe space for people to ask those questions in the first place." Program 14's leader also notes that just answering people's questions is not enough. "I think some level of exploration [is necessary] and I also think having some ties to the real world ... I think understanding why we should even care in the first place is also a good key." Here, Program 14's goals are creating spaces where people can explore for themselves and get their physics and astronomy questions answered. In order to support that goal, the program considers how to do so in a way that is safe and supportive of exploration, and ultimately finds relevance for the audience.

The graduate student organization Program 11 describes the goals of their public engagement work as being two-fold. "I think, one, it's to encourage grad students to give back to their community because we don't do that enough. And I think, two, it's to share something that we think is beautiful with younger students." Here, Program 11 works to improve overall involvement of community-based work, something that they note is lacking among graduate students. The second goal is more focused on the impacts of that community work, such as sharing physics with kids.

4.5.2 Program Content and Design

Program Content and Design is about the topics that a program covers as well as the programmatic structures of their activities and events. Topics can range from broad to specialized areas of physics and astronomy. With program types ranging from public lectures to summer camps to science festivals, programs can engage with audiences with these topics through varying levels of interactiveness.

4.5.2.1 The Topics Covered Depend on Personnel, Audiences, Partners, and More

In prior work, we have found that the landscape of informal programs covers a multitude of topics including general physics, particle physics, biophysics, astronomy, astrophysics, and earth science [4]. As we discuss in the later components, how programs choose these topics can depend on a combination of personnel knowledge and experience, the audiences' interests, funding, and the goals of community partners and/or the institution. For example, Program 9 does planetarium shows on a variety of topics, but repeats some topics like black holes "because it always has high attendance." However, if they get "funding from, for example, [a specific funder] to do a show, then there might be constraints on what the show needs to be about." Program 8, which has guest speakers talk about their research, selects people who they think will give a good talk, but ultimately the speaker who is the one deciding what the presentation will be about.

4.5.2.2 Programs Structure Activities Around Physics Content Based on Their Audiences and Resources

One facet that makes informal physics programs unique is that they exist in many different formats with varying designs of activities and interactive opportunities. For example, if a program is working primarily with an audience of children, the program may design their curriculum to involve hands-on activities or demonstrations. For Program 15, "our design is that it's, it's active, and that's engagingwhatever the kid is doing is, is like tactile, right, they can work with the thing, they can manipulate the thing ... We like to have things where they can take something home, that's interesting. So like, making a rocket made out of a balloon. So they have like, these rocket races that they have with balloons."

Other programs design their activities around the space and resources that they have at their disposal. For example, planetariums like Program 14 already have defined physical spaces like a dome, but they can think about different ways to engage with audiences in these spaces. "We've worked with people in art history and design on getting content in the dome so people can be immersed in there ... we have this really amazing, awesome technology that allows us to teach about everything in the universe ... so how can we share that technology with other people? ... We know we can hook people in different ways. It might be the history. It might be the art. It might be the science. But ultimately, our goal is science education but it doesn't necessarily have to be the entry point."

4.5.2.3 Program Design is Influenced by Mobility and Accessibility Constraints

Programs also have to consider their audiences' mobility and access to these programs. Program 13 is able to travel to schools, so they have to consider activities and materials that can be packed and moved around while also being appropriate and engaging for the varying classroom and school spaces they are visiting. Other programs like museums, planetariums, and summer camps are more restricted to their physical location. In which case, they do not necessarily have to consider the transportability of their activities, but they do have to consider more about how their audiences are able to visit them. Some audiences may not have access to transportation or funds to travel to these locations, so programs have to take this into consideration of their design.

There are many other logistical factors that programs take into consideration, including the frequency and duration of their events, purchasing of materials, registration, and fees. As mentioned above, programs take into account their audiences' ages, needs, and the size of the audience when designing their program; however, as we will discuss in the other key components, the personnel have a large influence on the program design, as do partners, the institution, and access to physical and financial resources.

4.5.3 Strategies for Assessment

Strategies for Assessment is about how programs gather information about their operation. During the interview process, the researchers used the words assessment and evaluation interchangeably to consider the different ways that program leaders think about these ideas when gathering information about their programs. However, there are some key differences between assessment and evaluation. Assessment is often used by program leaders to consider how to evolve their program. For example, assessment may be used to understand people's interest in particular physics topics and thus inform how the program approaches future events. Evaluation instead looks at if the program is meeting certain measurable outcomes, such as determining how many youth participants go on to have a STEM-based career.

Research participants used assessment and evaluation interchangeably, so for the purpose of this paper, we will refer to both terms as assessment. Programs may use formal assessments like interviews and surveys with audiences to gather feedback. We find that some programs also use informal methods like observations or casual interactions with others throughout an event. Programs may collect this information to determine if they are meeting their goals, to provide data to their institution or for funding purposes, and/or to make adjustments to their program design.

4.5.3.1 Formal and Informal Methods of Assessment are Useful to Programs

We find that programs use feedback from the audience or personnel as a form of assessment. This feedback can be gathered formally through surveys, scheduled meetings, or other methods. For instance, Program 15 collected feedback by "having a board where the board had the tables labeled, and we would ask [audience members] to put a sticker on the board for the thing that they found most exciting or most enjoyable." Feedback can also be received informally through comments offered by the audience or personnel in person, written online reviews, or views on online videos. Most programs used a combination of formal and informal audience feedback, with surveys and in-person conversations being the most frequently reported.

Another assessment method utilized by most programs was informal observations and reflections, in which personnel take note of what seems to be working or not working, often through observations of and interactions with the audience, and ask themselves questions about how it can improve. For example, when Program 13 is hosting their demonstration shows for kids, the program leader will watch the kids in the audience to see their reactions. "It could be at the part of the show that's really exciting and sometimes it's the most mundane thing. [laughter] Or at least from your perspective, it seems like the most mundane. But there's that one moment where you just happen to see that spark [in a student]." These observations can inform the demonstrations and activities that they facilitate for their upcoming shows. Other assessment methods include collecting data, keeping records, conducting research, and receiving external recognition, such as awards. Attendance may also be used as a passive form of assessment.

4.5.3.2 Programs Use Assessment to Evaluate Their Audience Related Goals

Programs assess a wide range of topics depending on the goals of the program or purpose of the assessment. However, most programs reported assessing audience interest, excitement, and enjoyment, as well as the diversity of their program, personnel, and audience. Many programs also assessed logistics, such as the utilization of space and resources and scheduling or timing of events, and the sustainability of their program. Programs may assess whether or not audience and community needs or goals of the program are being met. For example, Program 8 assesses if they are meeting their audiences needs and goals through the use of surveys at the end of their events. Other types of assessment ask about reasons that audience members attend and participate in events, what they value about the program, how they heard about the program, and how easy it was for them to access the activities.

4.5.3.3 Programs Use Assessment to Inform How Their Program Should Evolve

Programs can operationalize the knowledge gained from assessments to make adjustments that allow the program to be more successful. For several programs, assessment responses were considered when hiring and supporting personnel, or when designing or planning future events. Programs also adjusted their design or materials to be more accessible and inclusive, or try to choose topics that would be interesting and engaging to the audience. Program 10 stated “I try to come up with really good activities. I think that’s kind of the crux. And I try to make sure that whoever’s leading the activity is excited about it . . . So I just try to choose things that you’re going to like, that’s I guess a lot of it.”

Programs also make adjustments to better align with their goals or to better fit the needs of the audience and community. For instance, Program 12 is a science museum. When the museum was originally being built, it was meant to be a children’s museum that was not science-focused. The museum leaders had done a survey of teachers in the area. The survey results found that while there were life-science museums in the area, there was not a museum that focused on physical science. Based on requests from local teachers, the museum pivoted to focus on physics content.

4.5.3.4 Assessment has Challenges but Overall is Beneficial to Programs

Some programs reported challenges finding the time, energy, or support to develop assessments. Programs that were able to create formal assessments sometimes struggled to get survey responses or engagement. It can also be difficult to create an assessment that is accessible to all audience members, and program leaders do not necessarily have educational research experience. Program 10 encountered this challenge when trying to develop a survey for children: “I put a bunch of words on a page and said, ‘Circle the words that sound like science, and put triangles around the words that sound like art’ And they can have both. But apparently, when I said, ‘Sounds like,’ some of the kids took that literally and were trying to rhyme words with art. And so I had to reword that because I have to use small words because I didn’t want to say, ‘What words would represent science,’ so I think I changed it to, ‘What words would you use to describe science or art?’ But yeah, and then I had five years of data that I was really excited about until I learned that the youngest kids were not understanding the directions."

Despite the challenges to creating and utilizing assessments, programs described benefits of assessment. For example, programs can use positive feedback and reviews to justify the need for the program to their department or sources of funding, and asking for opinions can help the audience feel heard and valued. The majority of programs describe how they use informal forms of assessment like observations and conversations with audience members, however, more formal forms of assessment, such as surveys and interviews, are less common due to constraints such as lack of time, resources, or experience.

4.6 Personnel

Personnel are the students, staff, faculty and others that support the program's operation from the host institution. These individuals are central to informal physics programs as they interact with audiences, they design and implement program events and activities, and they work with community partners. We have looked deeply at the relationships between Personnel and the other aspects of informal physics programs in related work; these are described in detail in Stanley, et al. [106]. Based on the number of tasks and responsibilities needed for these programs to operate, programs typically require a team of personnel. We find that there are many considerations that program leaders have to make in order to recruit and retain personnel in their programs. These ideas are described with the following components: *Recruitment and Onboarding of Personnel*, *Distribution of Roles and Tasks*, and *Continued Support of Personnel*.

4.6.1 Recruitment and Onboarding of Personnel

Recruitment and Onboarding of Personnel considers how program leaders can recruit volunteers to participate in the program and events. This includes thinking about the types of volunteers the program may want to recruit based on knowledge, skills, etc as well as advertisement practices. Program leaders also have to design training experiences for their personnel in order to carry out their tasks appropriately.

4.6.1.1 Program and Activity Design Influences the Type of Volunteer a Program Recruits

In many cases, there is a program leader, often a single person, who is in charge of many aspects of program logistics and management and also activity content and design. There often can be strain in the program with the majority of tasks being assigned to a single person (see additional examples in the Distribution of Roles and Tasks section). To overcome this, programs will recruit personnel members to help carry out some of the many tasks that need to be done to run the program. As we have found in past work, these volunteers are mostly university students, but also include faculty and staff [4]. Students, staff, and faculty each bring their own strengths and challenges, so programs make recruiting decisions on what best fits their needs.

If the program is designed around research presentations and laboratory tours, then a program will often need to recruit speakers. Programs may recruit faculty, post-docs, or sometimes graduate students to present given their experience and expertise. Staff and faculty may be more equipped to communicate with partners, requesting department funding, etc. The schedules of student volunteers may be more flexible compared to faculty and staff so that they can put more time into the program.

4.6.1.2 Programs use Multiple Methods to Recruit Volunteers

Graduate, undergraduate, and high school students make up a bulk of program volunteers. In some instances, students will inquire about working or volunteering in the program. This involves the student knowing about the program in the first place, which is usually by word of mouth or having previously experienced the program (for example, the program visiting their school when they were younger). In most instances, programs will still need to implement some form of recruitment method. A common approach is to email students, whether that is department wide or directed to a specific student organization. Program 9 will ask professors teaching introductory astronomy classes to advertise their planetarium program to recruit undergraduate volunteers. Programs may also create flyers. Programs attend or host on-campus events to recruit student volunteers. Recruiting additional volunteers, especially faculty and speakers, may include sending department emails and newsletters, asking individuals directly, or contacting those at other institutions.

4.6.1.3 Programs Provide Varying Levels of Training

As a part of the onboarding process, programs often provide training to volunteers on aspects like how to use equipment, explanation of content materials, event structures, pedagogical practices, communicating with audiences of varying ages, and more. Beyond the initial onboarding process, some programs have continuing training and development sessions for their volunteers. However, organizing these additional training sessions can be difficult due to scheduling conflicts. For example, Program 12, which has about 20 student volunteers, had planned hosting pedagogical workshops like, "[If] you plan to volunteer, we really need you to go to these, you know, we'll, you know, two one hour sessions on informal science pedagogy." However, that did not work out because of "timing and and, you know, scheduling all of these different people and so forth. But, it was something we had wanted to do."

Programs vary in how they structure their training processes. Some programs have meetings before events. Program 8 has presenters give a practice talk before their presentation. Programs like 9 and 6 hold multi-day training sessions, oftentimes at the beginning of the academic term.

In some instances, it is the program leadership who facilitates the formal training process. In other instances, there may be more of a mentoring relationship between the more experienced and less experienced volunteers. This can alleviate some of the labor burden on the program leadership.

4.6.1.4 Student Volunteers have High Turnover Rates and Busy Schedules that Affects Programming

An issue that programs' face is that there is often a high turnover rate of student volunteers because students graduate or become busy with other jobs or commitments. Therefore, student volunteers typically are not involved with the program for more than a couple years, in which case, programs may have to continually recruit and train new volunteers. Since students are also busy with other commitments and interests, many programs think about how to balance convincing students that it is worth dedicating time to the program while also accommodating students' busy lifestyles.

Program 11, which recruits primarily graduate student volunteers, works to convince students in the department that volunteering can be another fun alternative to participate in. "I've done a lot of thinking about, like, 'Okay. What am I asking from these grad students?' Because most people are like, 'I'm too busy.' . . . We have a lot of events that are on Friday nights, which is unfortunate because everyone's like, 'What? Why do I want to do that on a Friday night? You're crazy. I would never volunteer for that.' And so it helps to be able to explain a little bit further about why it would be fun to volunteer on a Friday night."

Students also have busy schedules with courses, jobs, and other activities that are rigid, which can impact students' ability to participate in program activities that take place during the week. Program 6, a demonstration show, has to work around this when working with other partners such as schools. "The only way we're able to do [our program] is if we can get a group of at least three [volunteers] that all have the same gap in their schedule and that it works with an elementary school. And so if the [volunteers] are available, then we can send them out to schools. But if we have eight [volunteers] that are willing to participate, but they don't have any overlaps in their schedule, well, we can't send out any groups."

4.6.2 Distribution of Roles and Tasks

Distribution of Roles and Tasks focuses on how responsibilities are split among the personnel. We find that responsibilities often fall on a single person, which can strain the program. Some of this strain can be reduced by considering effective and equitable ways to distribute tasks among all of the personnel.

4.6.2.1 Task Distribution is Dependent on the Type and Number of Personnel a Program has

Some programs host a single large event in a year while other programs have more frequent, smaller events. For programs that host single events, the program may recruit a few volunteers that work the entire event, or they may have many volunteers for smaller portions of the event. For Program 15, some aspects of their science festival program could run with four to five volunteers who worked all day, or they could "break it up, and you end up with like, eight or ten people for a table because you all do half day shifts." Working in shifts alleviated the time commitment and workload for each volunteer, however, that requires recruiting more volunteers for the event.

Some types of personnel have many different types of tasks while other volunteers have one type of task. For example, in Program 10, the program leader has many different responsibilities, particularly leading up to the event. "I create the registration forms, handle all the logistics of parents paying, answering parents' questions, getting the kids enrolled, splitting up the kids into groups, hiring the counselors, filing all the paperwork for that, doing the interviews, deciding which teams to hire, creating a schedule, deciding on all the activities, finding all the activity leaders, getting the space, buying the materials, ordering the food." When the event takes place, then the other volunteers come in to take on a specific role. For example, when 150 kids arrive at Program 10's summer camp, the program will "split them into 12 groups by age ... [Counselors will] take them to six different ... scientists, usually grad students and postdocs, who will then have one activity that they'll teach the group ... [grad students will] just teach the same activity to six different groups throughout the day."

As shown with Program 10, many different tasks, especially dealing with logistics, may fall onto one person. Program 13, a traveling student program that is run by a paid staff member, notes that "It's hard for faculty to help with how often these events happen ... It's not reasonable to ask a faculty member to try to have a schedule that's opened out to schools once or twice a week. That is literally a full-time job. That is why I was hired." There are a lot of tasks and responsibilities in running a program that can be overwhelming for someone who is volunteering in addition to their main job responsibilities. Having a full-time staff person can help alleviate some of that workload; however, that would require funding and likely institutional support as discussed in the *Connection to the Institution* and the *Funding and Budget* sections.

4.6.2.2 Leadership Roles are not Limited to Just the Program Leader

As discussed above, some volunteers are assigned a task such as running an activity multiple times, like Program 10's summer camp. Other responsibilities, which typically fall on the program leader, require additional levels of decision making. This includes event scheduling, designing activities, and hiring other personnel. Based on their role and power in the program, program leaders are the ones doing these tasks, or at least assigning tasks among the other personnel.

Other ways that leadership is built into a program is by allowing volunteers to have a role in the program's decision making process. For volunteers who are involved in the program for longer periods of time, some program leaders will give them larger responsibilities that involve decision making that impacts the larger functionality in the event. In Program 10, volunteers "have to learn leadership experience in terms of how to guide the kids. How to politely ask the kids to do something in a way that the kids will actually do it." In this case, volunteers have the ability to make decisions and learn from their decisions in running their assigned responsibility. Another example is Program 13's demonstration show, which goes on a multi-day road trip over the university's spring break to visit schools in rural areas. The program was limited on how many volunteers they could take on this trip. The program leader was busy with other responsibilities so they did not have time to pick which volunteers could participate, so they gave that responsibility to more senior volunteers. "I did relinquish choosing volunteers to [2 more-senior volunteers] who both have been on the trip more than once at that point. And so I had confidence that they would be able to choose good volunteers."

4.6.3 Continued Support of Personnel

Continued Support of Personnel is centered on how personnel are retained and supported in their roles in the program. This component is important as personnel participation is often voluntary and in addition to their main job and responsibilities. Program leaders can shape program culture, opportunities, and support for personnel members so that the personnel also benefit from participating in these programs.

4.6.3.1 There are Different Compensation Options that Programs Offer Personnel

Some programs financially compensate their personnel. For example, Program 8 is able to use their grant money to pay for support staff. However, funding can be limited for some programs. Program 7 can only pay some of their personnel members for their weekend class programming. "I pay the project leaders and I pay the mentors. And then if I have a young mentor . . . I usually have a volunteer mentor kind of role for them so that we can try them out before we actually hire them. And I can't hire that many mentors anyway because, like I said, the budget is pretty tight." In this case, the program financially compensates more experienced personnel with more leadership responsibilities. Other positions are not financially compensated and are more purely volunteer positions due to limited funding.

Program 6, a demonstration show, offers their student volunteers different compensation options. "[Volunteers] have the option of either taking pay for this, or we also have a program on campus [for students who] plan on becoming teachers, and they can get class credit for it." This particular option requires some support and buy-in from the institution.

4.6.3.2 Programs Mentor Student Volunteers to Build Professional Skills

Programs will check-in with their personnel and help them to improve their skills in the program. In Program 10, "we provide, I think, honest feedback about where they need to improve and what they're good at and stuff like that." Some programs, like Program 12, rely on volunteers who may not be physics majors. "Most [volunteers] don't have [a] physics background, but some don't have science backgrounds. And most of them aren't educators to begin with. And so we're helping them develop this expertise in facilitation and a comfort with physics."

Some programs consider professional development of their student volunteers as one of their goals beyond just engaging with the public. For Program 14, "We're here to teach the public and university students about the universe. But part of that is teaching students on how to be professionals in science communication as well, whether or not they end up in that career but that's part of the learning experience."

Part of the mentoring technique that we find programs utilizing is allowing students to take ownership of their work and have the power to make some decisions. For example, Program 7 allows more autonomy to their more senior students. "There's the project leaders who have been there for a while and know what they're doing. They get full control over what they want to run. I don't tell them what to do."

4.7 Audience and Community Partners

The goals and mission of programs include engaging with audiences, oftentimes engaging with a specific type of audience such as kids, adults, low income, etc. To effectively meet and work with these audiences, we find that programs take steps to understand their audiences and learn how to support their needs. Oftentimes, this involves working with other partners in the community. We describe these ideas with the following components: *Understanding Audience Motivations and Needs*, *Support of Audience Engagement and Learning*, and *Relationship with Partners and Community.*

4.7.1 Understanding Audience Motivations and Needs

Understanding Audience Motivations and Needs is centered around the initial steps that a program takes to identify the audiences they want to work with. There are several types of audiences that programs may cater their program to. For example, programs may be designed for adults, teachers, families, or kids. Program leaders have to consider that audiences have varying wants and needs from participating in a program. Understanding what audiences want from a program can help with advertising and attracting people to attend the program as well as designing appropriate activities.

4.7.1.1 Understanding Formal Environments Helps Create Appropriate Informal K-12 Programs

Some audiences attend a program's events because they want to learn physics knowledge or skills that they may not learn elsewhere. For example, each year, Program 8 hosts an all-day event for high school physics teachers from across the country on topics such as modern physics. Each year is a different topic so that physics teachers are "getting exposed to physics happening now ... they're having exposure to current research." Skills and knowledge from these types of events are often for teachers to apply to their current jobs, which may not necessarily be relevant for other adult audiences.

Some programs collaborate with formal learning spaces for youth audiences. This includes working with teachers and schools. There are local and national STEM education standards that students need to meet, so some programs work with teachers to develop content that meet those standards. Program 11 did this with their teacher partners by "look[ing] at the standards and in the demo closet and figur[ing] out an activity that we [could] do." Program 9 is "trying to be more aware of the Next Generation Science Standards (NGSS) and using those as at least, like launching off points." Schools take field trips to the Program 12 museum, so the program designs their activities to connect with different NGSS content with the goal that "teachers will be able to choose the field trip program right now."

For some programs, learning goals extend beyond science. Program 9 leadership reports that "we are learning more about the importance of social emotional learning, because lots of elementary schools are starting to implement social emotional learning in there as part of their curriculum, and so, you know, how can we help support that and more holistic learning in an environment like what we have?"

4.7.1.2 Reducing Barriers Allows More Types of Audiences to Participate

Having an awareness of the community that a program is wanting to work with can help it connect and engage with audiences. Some programs work with multilingual communities, so programs consider their needs when developing activity and informational materials. Where Program 12 is located, there is a push for more bilingual education in schools. Since this science museum frequently works with schools, they are also translating their materials for Spanish speaking audiences. Program 10 also takes language into consideration when advertising their summer camp as the program leader will "deliberately send flyers in Spanish and Chinese out to local communities because English is a second language in this area."

Program 14 realized that some of their programming can be "sensorily intimidating," which led them to explore and partner with different groups to develop sensory-friendly activities. "Our sensory-friendly programming came out of a desire to make the planetarium more accessible. We know that [our program] is a very sensory-rich experience in terms of loud sounds and the visuals and feeling like you're surrounded." One example is that some of their planetarium shows adjust their presentation style using more calming sounds and softer speaking voices to create a more relaxing show experience.

4.7.1.3 Physics Events can be Entertaining Endeavors for Audiences

Since some programs are designed for audiences to attend in their free time, programs consider what the appeal of attending may be for their audiences. Appealing factors can be the low price of attending and entertainment value. For example, college campuses have college-aged students who are often looking for things to do on a budget. Program 14, a planetarium, will put on public shows on campus and promote that "we're a really good cheap date which we emphasize to all of our college students." Some audiences look for things to do when the weather is not nice. Program 15 takes this into consideration when deciding the time of year to hold their festival events. "One of the things that we've learned to do is to hold it when the weather is crappy, right? Hold it in February, because everybody's inside." Programs also consider if there are other events, holidays, and competing activities. In some instances, parents may need something for their children to be involved with, in part for the childcare aspect. In some cases, programs may serve in place of daycare. This is the case for Program 10, where their camp was cheaper than daycare. This program also altered the fee process to be more flexible for lower income families.

4.7.2 Support of Audience Engagement and Learning

Support of Audience Engagement and Learning focuses on audiences who are currently at the program. Here, program leaders are interacting with audiences through the context of physics activities. Program leaders may get feedback from audiences and use that information to evaluate how to keep their events engaging, educational, and supportive for the audiences.

4.7.2.1 Social Interactions are Crucial for Audience Engagement

Programs interact with audiences in many different ways, but keeping audiences engaged often requires some form of audience interaction. Q&As are a common way that audience members can ask questions with physicists, especially programs that have presentation components. Public lectures often have dedicated times where audiences can ask questions to the speakers. Other interactions include assisting audience members with an activity or sitting down and conversing with audiences around a table.

Many of these interactions are driven by the program leaders and volunteers. Programs that have more hands-on activities tend to have a volunteer facilitator who can give direction, feedback, and answers to questions, but often in a fashion of a multiple-way interaction. At Program 15's festival-style event, "I have definitely seen some of the undergrads [volunteers] just like going through a 10 minute lecture on how craters are made. I'm just like, 'maybe you should take lunch now.' ... I think I did more of the Socratic dialogue ... and I think that's what a lot of people do ... good teaching is asking leading questions, regardless of the environment."

Sometimes the social interactions are more than just making connections between the audience and the personnel. There is a community building that can happen in the program space that comes from social interactions among the audience members themselves. Programs do that by allowing breaks between activities or having audiences work together on a task. As a result, some programs have repeat attendees to their events. According to Program 8,"There are teachers who've been coming back to [our events] for a long time."

4.7.2.2 Opportunities for Feedback Provide Insight on what Audiences Find Engaging

Programs often collect feedback from their audiences in order to adapt their programming to be more engaging. This can be in the form of surveys, feedback forms, or comments from conversations. For Program 10's demonstration show, the program leader asks kids in the program which activities that they like, "'And so that's really useful for me in planning the next year's [activities]."

Audiences have different interests and background knowledge, so programs take that into account in their presentations and activities. Programs encounter this especially when working with kids of varying ages. Program 11 notes, "How do we talk about physics with five-year-olds? Because people don't think about that in their day-to-day life. Cultural considerations are also important. For example, Program 10 explained how they work with kids from other countries: "I have kids that don't speak English sometimes because their parents might be here for a research phase. So I had an Italian girl. Luckily, [we focused on] hands-on activities. You don't have to understand, you just watch and follow along. She wrote a beautiful poem. We did poetry that year and so it was an Italian poem that sounded great."

4.7.3 Relationship with Partners and Community

Relationship with Partners and Community points to the important relationships that programs have external to their home institution that allow them to communicate with and understand their audiences. Additionally, many programs do not have the resources, funding, or space to operate their events alone. Programs work with sponsors or donors to help cover the expenses of their events. Local businesses or organizations help to provide a location to hold events. Local community groups provide knowledge and insight about working particular audiences, which can help with improving accessibility, relevance, and trust with audiences.

We define partners as anyone outside of the program's institution that a program works with. While this broad, there are some commonalities in the types of partners that programs work with. For example, in order to build a larger event that draws in bigger audiences, some programs collaborate with festival organizers or student organizations to host an event where multiple programs are participating.

Another type of partnership is one with an individual(s) who are serving in a liaison-style role between the program and its intended audience. In the case of working with specific cultural groups, this type of partnership is useful in understanding a group's norms, needs, and interests. For example, when Program 14 discussed how to make their program more sensory friendly, "we did that through talking to [multiple resource groups] in the area just to make sure we were doing it in a way that made sense for people." Another example of a liaison-style partnership is working with teachers. When working with schools, children are the intended audience, but the teachers and administrators are often the ones that programs work with on determining appropriate content and what works well for engaging students. As discussed in the *Understanding Audience Motivations and Needs* section, some teachers have certain science standards that they are required to reach, and these partnerships with programs can help to meet those requirements.

A third type of partnership entails logistics such as venue hosting for events, funding for the program, or sponsorships. These partners are often involved in operations, but not necessarily content or programming (though in some cases they are). A program may partner with a local business to host a physics event there and attract people to the business. For example, Program 15 hosts their physics festival event at a local children's museum. Program 1 hosts their public lecture series at local venues like pubs and restaurants.

4.7.3.1 Forming Partnerships Requires Time, Communication, and Understanding Each Other's Goals

A contributing factor to forming a partnership is understanding the program's own goals and the needs of potential partners. Programs may have a particular audience in mind, such as school children, so they may partner with schools. For example, Program 11 is a graduate student organization that visits schools, primarily working with K-6 students. Because graduate students have limited time, most of the schools that they visit are local.

Building and maintaining partnerships takes time and work to form trust. Oftentimes, partnerships stem from a relationship or connection with members of the community without the initial intention of forming an explicit partnership. For example, Program 13, a demonstration show, partners with another informal physics program in hosting some annual events. That partnership began "solely because I first made that personal connection with the people who run the program, before learning about the program." However, sometimes programs may push to advertise themselves and what they have to offer in hopes that it is of interest to other potential partners.

Advertisement occurs on social media, news and radio appearances, flyers, and emailing potential partners. As Program 14, a planetarium, notes, "if the news calls us, we'll be on the news. If the radio calls us, we're on the radio. If a school wants us to come out and do something, we'll do it because it's a way to also make sure that we are visible in the community and people remember that we exist." By increasing visibility, even if the program does not initiate the contact with a potential partner, there is a heightened possibility that that potential partner will contact the program.

4.7.3.2 Mutually Beneficial Partnerships Take Many Forms

Partnerships should be built from a mutually beneficial relationship. For example, when working with teachers, a program can meet its goal of working with kids while teachers may get their own state requirements met, and the students get an activity that is interesting to them. Program 11 explained, "Usually [the high school teachers are] like, 'Hey. Can we come to your classroom?' And then when I've emailed them back, I ask, 'Oh. Well, where are you going to be in the curriculum? We can try to do something that aligns with where you are. Or do you have any standards that you want us to hit?' And so a few of those teachers have emailed me back, and they said, 'Yeah. That would be awesome. We have two standards that– if you can hit these two standards in your activity, that would be cool.' And so that's going to take some time for me and the other coordinator because now we have to look at the standards and go look in the demo closet and figure out an activity that we can do." Program 15 stated: "[our partners] were really good about reminding us that the museum serves a lot of ages. And so the student groups are often really good at producing activities that were good for, like, you know, elementary school age, kind of and beyond, right, so like, second graders, first graders and kind of up, but they weren't really good at figuring out activities for two year olds, or four year olds. [Our partners] were really good at making sure to remind us that we needed activities for that and providing us with resources to make sure we were meeting that population."

It is also important to consider how long partnerships last. Partnerships can last many years, but they can also end, evolve, or splinter off. An example of a partnership that evolved is Program 10, which says, "We partner[ed] with another organization. Now they've taken it and spun it to better address their group of people. So it doesn't have the same structure but it's still a STEAM camp with a lot of the same ideas."

4.8 Institutional Connection and Resources

Institutions are the colleges and universities associated with their respective informal physics and astronomy programs. Programs are often hosted within a specific institutional unit, in most cases a physics, astronomy, or education department or center. The connection between the programs and their host institutions includes the resources that institutions provide, the institutional recognition of its members in the public engagement activities of the informal programs, and the personnel that are part of both the informal programs and also affiliates of the institutions. We describe these ideas with the following components: *Connection to the Institution*, *Physical and Digital Resources*, and *Funding and Budget*.

4.8.1 Connection to the Institution

In this component, we focus on how the connection to the institution affects programs and vice versa. While this component is referred to as *Connection to the Institution*, sometimes the nature of this connection is more of a relationship that is mutually supportive of both entities. In other cases this connection can be a source of tension, or sometimes both. Universities also provide resources, including rooms for events, facility maintenance, hosting of web servers, university insurance, and financial support for programs. We will discuss these in more detail in the respective components of *Physical and Digital Resources* and *Budget and Funding*.

4.8.1.1 Positive Institutional Relationships can lead to Financial, Resource, and Volunteer Support

One benefit of the institutional connection for programs is sustained funding over time and resilience in the face of budget issues. Multiple programs reported that during challenges from COVID-19, being connected to the department or university budget offered them protection from closure. This was especially salient in the cases of Programs 9 and 14, which are planetariums connected with large research universities. For example, Program 9, states: "Being part of the university, being part of this department that sees us as an asset, and something that they want to continually support definitely gives us a lot of stability. It's, you know, and like, right now, there's a great example during COVID times, you know, we have this larger backing department and university to kind of help make sure that we're not going to close down. If we were completely separate, that might not be the case."

Another benefit for informal programs of their connection to a department or center is access to physicists, astronomers, students, and facilities for research and teaching. For example, being connected to a physics department helps Program 15 recruit the large numbers of student volunteers it needs to run its open-house style event at a local museum. Program 10 uses physics research facilities to host middle school students for a summer program. The expertise of faculty and other researchers is also a benefit to programs - Program 9 commented on this, saying, "we have very direct access to how this field is changing and what we're learning in it and reputable sources who can help our presenters or our staff kind of learn these topics and make sure we're communicating them effectively."

4.8.1.2 Departments and Universities also Benefit from Working with Programs

In the *Support of Personnel* section, we discussed how programs can be professional development opportunities for students. The ability to offer this professional development opportunity is also a benefit to the institution. Informal programs provide a way for undergraduate and graduate student volunteers to be trained in science communication and to gain direct experience communicating with public audiences. Some form of training happens in all programs in our data set. In a few cases this professional development is formalized and recognized by the institution. In Program 12, student volunteers can achieve an official certificate in educational partnerships for working with the local community partner; this university-recognized certification can be listed as an item on professional documents. Other programs are connected to classes, offering a location or experience for students.

Programs also can be useful in recruitment of students to universities. For example Program 9 explains that bringing students to its planetarium "has been a pretty impactful way to highlight what happens at the university and the research that happens or just like creates a very memorable experience. So that's where we're, you know, trying to work with admissions a little bit more to utilize our space as an inspiring place to recruit more students."

Informal programs also support physics and astronomy faculty at the institutions. In several cases, individual faculty had leveraged the institutional connection with the informal program in broader impacts sections of grant proposals for other types of research. Large scale physics centers also relied on the success of their informal physics programs when reapplying for funding, such as with Programs 8 and 10. Programs also benefit faculty by giving them an outlet to share their work with the public and also connect with communities of which they are a part. For example, Program 15 explains: "And so I feel like, [this event] gave us that opportunity to do it as a department, right, as opposed to like, the University doing it, or the college doing or whatever it was, like, no, this is something we own something we're responsible for. And something that is, that is like really nested in the kinds of things that we do that demonstrate to the public that we are a valuable [resource], we're valuable, we're valuable to them." There is a sense that these programs can inspire some community goodwill that is beneficial to the institutions.

4.8.1.3 Power Dynamics can Create Tension Between the Program and the University

For some programs, however, their relationship with the university can sometimes cause tension or stress in terms of program design, implementation, and support. We note that this is especially prevalent in some interviews with student leaders as opposed to faculty leaders, in particular with situations such as requesting funding.

Multiple student led programs report tension in asking faculty and department administrators for financial support. The student leader for Program 11 explains their perspective in this way: “So they give us money, but it’s a fight to get money every year. So basically what we do is we put together a budget and then go ask for money, and then usually they say no, and then we go to the head, and then the head is like, ‘Okay,’ and then we get money. Every year they think– this is my viewpoint. I think, every year, they think that we’re asking for more money than we need. In that sense, I don’t think it’s as supportive as it could be.” Budget issues specifically can cause tension with programs and departments. For example, after COVID, Program 15 states: “You know, there’s no, there’s really no discretionary spending at the department level anymore. And so going and hitting up the chair for a couple hundred dollars is going to be a pretty hard ask now.”

Even programs that have a generally positive relationship with their university unit can sometimes face hurdles. Program 9 reports that sometimes planned activities are delayed for other university events, and recently they’ve had issues with university changes to parking: “now you have to pay all hours of the day, and that will significantly change our patron experience. Football games happen, and then you can’t get on campus.” They also have to conform to certain university policies, and so their signage is not as large or creative as they would like to draw in audiences.

4.8.1.4 Department Attitudes Towards Public Engagement may be Changing but still have Room for Improvement

Some program leaders report that program activities are becoming more integrated into the identity and activities of their respective departments or colleges. For example, Program 9 says: “I think recognizing the importance of outreach is also increasing over time. I would say that five years ago, it was not as appreciated as it is today by many faculty. So that’s where I would see that, [our program] overall, I think is being increasingly appreciated." The program leader also notes that as new faculty members are joining the department, they are incorporating the planetarium's work in their own classrooms. In addition, the program leader says that faculty are increasingly using the programs as a part of their public engagement work for grants. "I think all of those things are just sort of adding to this sense that community outreach is important, and that the department wants to make time and put energy towards that."

Program 15 talks about the growth of their program over time, stating "with more faculty involvement and interest, we, I think we start to realize that like, we can do this as a department and we can coordinate it together, and we can bring in, we can bring in more than, you know, introductory physics demonstrations, right, we can actually bring in really cool science and bring it into a space where families can interact with it and sort of develop a bit of an understanding of like, What does [our physics department] actually do?"

However, some program leaders, especially student leaders, express a desire for more support from faculty. Program 11 suggests that faculty in their department could do more to support the group that is responsible for the department outreach, saying, "I think faculty people like the idea of [this student group focused on issues of women in physics], and I think they use that as a token, like, 'We have a women's group in the department. We like that.' But they don't do anything in their day-to-day life to support that. They would never show up to [our groups] events . . . So I think they like to tokenize that we have a women's group and not be super supportive of it."

4.8.2 Physical and Digital Resources

There are two big categories of resources that are important for running programs - physical resources and digital resources. Physical resources was the most mentioned category. These are tangible items that are necessary for programs to run, and they are connected but separate from program finances which we describe in the *Funding and Budget* component. Programs also use digital resources to varying degrees. Digital resources include websites and apps for public audiences that must be maintained. Programs also use file sharing and storage to document and pass along digital copies of activities, photos, or other program information. Also, during informal education activities, some programs use digital tools others have developed, for example PhET simulations.

4.8.2.1 Community and Campus Venues Affect Program Content and Audience Participation

The resource common to all the programs in our sample was having a venue, physical space, and/or building where programs are held. Venues can be off-campus or on campus, or dedicated STEM education spaces (Ex. planetariums, museums). Off-campus examples include libraries, school cafeterias and gyms, conference centers, and outdoor areas. Venues constrain what types of programming can be done in specific rooms or areas. For instance, the size of a room limits the number of people who can engage in a program. The type of seating also limits ways for audiences to participate. For example, lecture-style classroom seating precludes activities that use table-top experiments.

Programs that travel to community spaces (e.g. physics demonstration shows) need to be flexible in order to accommodate different physical arrangements in varying off-campus venues. For example, low ceilings mean some demos cannot be done safely, lack of outlets may mean some demonstrations cannot be performed, and available seating for audiences can affect their ability to see equipment up-close. Because venues may have other events, program personnel might have limited time for set-up and clean-up, or have to pack in and pack out all equipment completely, which means any equipment must be transportable. Additionally, program leaders have to balance the other events at the off-campus venue; for example, they cannot schedule or create a new program whenever they want but must work with the venue staff as part of event planning.

Some programs host audiences at the host institution, i.e. on a college or university campus. Specific program locations are usually in classrooms, or other building spaces. An affordance of campus venues is having somewhat more control over the space, as program personnel are usually employees or students at the host institution. However, audiences must travel to campus for events, which can bring up issues of transportation, parking, and accessibility.

4.8.2.2 Permanent Venues for Informal Physics Programs have many Affordances

Museum and planetarium spaces allow program leaders to have significant control over the physical space, which in turn affects the ways audiences are able explore physics activities. These spaces can be designed to have signage, displays, and seating that prompt certain types of audience participation. For example, Program 12, which is located at a local museum, explains: "[the museum] doesn't have signs on the wall, it has signs like where the bathroom is, but it doesn't have signs on like what you're supposed to learn at it. So it's very open ended there." In permanent venues, program leaders have more control over the creation of new exhibits and content, which can allow them to expand their learning goals or reach different audiences. Program 9, a planetarium, described working on their lobby renovation as “creating the space to be a little bit more updated and have exhibits that are maybe a little bit more interactive.” Program 14 has been able to encourage audiences creativity by developing exhibits that incorporate art into physics and astronomy programming.

Having a permanent space can also be limiting. Many spaces have restrictions from university rules and often limited budgets. Venues like planetariums and observatories require specific staff for running telescopes or dome projection systems. Museum spaces may need staff trained for the preservation of a historical collection, or expertise in mechanical and electrical work for interactive exhibits. Permanent venues also require facility maintenance from use over time. These venues are difficult to maintain without specialized staff, which often require added costs for salaries and equipment. Some programs have to share their space with others. Finally, the size, shape, and technological parameters of the physical building can limit program changes and growth. Some programs need to expand to community locations to continue to grow programming and reach more people. For example, the director of Program 14 describes the limits of their venue: “I feel like right now, we are kind of hitting our capacity in terms of staff time and space really to do too much more. But I think where we do have the room to grow and where we would probably see the most change in five years is what we’re doing out in the community.”

4.8.2.3 Physics Equipment is Integral to Creating a Meaningful Experience for both Audiences and Program Personnel

Most programs use physics equipment and demonstrations for some or all of their activities. In many cases, activities are built around using equipment and demos. Program 10 describes:

"the focus isn't the materials, the reading materials, and the focus isn't the speaking. Those are just supplementary so that you can get on to using the equipment and supplies." Sometimes programs take physics demos for classroom use and adapt them to be appropriate for kids and safe for use. Other programs use sophisticated equipment to show off current research, such as microscopes. Museum and planetarium spaces can have big physical equipment connected to physics ideas. For example, Program 12, which is located at a science museum, describes one exhibit on quantum computing applications that has a giant light pegboard with pieces that audience members can put in it and move. In all cases, demos need to be updated, maintained, and sometimes replaced. Some activities use "at-home" or upcycled materials, which has been especially useful during COVID. For example, during COVID, Program 12 had kids create buildings out of cardboard and then drop them off at the museum.

Importantly, physical equipment is not just for use by audiences; a recurring theme is how much program personnel find enjoyment using physics equipment and demos themselves. The director of Program 10, a youth summer camp, states: "For a lot of [the program volunteers] it– and especially the older grad students or post-docs –it helps remind them of why they get into science in the first place. Seeing that excitement, playing with the toys when you get bogged down in research, sometimes it's good to step back and remember why you got into it in the first place." As an example, the student leader of Program 13 commented on their own enjoyment of a particular piece of equipment they use in demonstration presentations - a Theremin: "[I'm] the one who actually learned how to play it [laughter]." Program leaders report that student volunteers often choose activities or demonstrations that are on interesting topics, visually exciting, or showcase surprising phenomena. For example, Program 13 reports that electricity and magnetism demos are the favorite of their undergraduate student volunteers. Being playful with ‘physics toys’ and sharing that experience with audiences is a major source of fun for physics students in informal programs.

4.8.2.4 Resource Management is a Time-Consuming Part of Running Programs

General event planning is also a part of most informal physics programming. Food for volunteers and for participants, travel costs for personnel and for audiences (such as renting a bus), and consumables for demos can make up some amount of the program budget, or most of it in the case of Program 11. Some programs also spend money on t-shirts, stickers, flyers/posters, and related items for advertising and recruiting. Different programs may use specialized equipment like sound equipment or vans/vehicles for transportation.

One issue that comes up for program leaders is managing these resources. Lead facilitators can spend significant time on tasks like purchasing supplies, managing equipment, coordinating with venues, ensuring food is delivered, and planning for transportation. These aspects of event planning that are unrelated to physics content can be a challenge, as the Program 10 director states: “teaching in physics does not tell you how to run a summer camp, right? I don’t know what kind of food we order, where to have the kids dropped off, how to manage the kids so that the parents feel that they’re safe, all that stuff I had to learn on the fly.” Program leaders may feel tension between the amount of time they spend doing event management tasks and the time they spend developing physics activities or interacting with audiences.

4.8.3 Funding and Budget

The *Funding and Budget* key component is about the monetary funds that a program receives and how it utilizes them. Within the funding and budget component are fine-grained issues related to grants, donations, partners, and institutional connections. It encompasses how the program allocates the money they receive. This category also includes any changes in funding and budget over time or challenges that program leaders face on these fronts. Here we discuss the key themes of this component.

4.8.3.1 Programs find Sources of Funding from Local to University to National Levels

Some informal physics and astronomy programs are funded in part or entirely by national agencies, the most common being the National Science Foundation (NSF). Funding from NSF can either be independent STEM education awards, such as the Advancing Informal STEM Learning award, or it can be part of the broader impacts of a more traditional research project, where the educational and outreach activities make up a fraction of the overall budget. NSF grants can often provide substantial funding, in the hundreds of thousands or million dollar range. For example, Program 9 reports that "a portion of how we are funded is through grants. And that makes it very easy to be part of a university where, you know, faculty are receiving grants that require a broader impacts, outreach component, and then we can serve as that outreach arm for that project. So that's how we can achieve a lot of our funding." Another affordance of national grants are their flexibility, which allowed some programs to absorb some hits from pandemic. For example, Program 12 states, "the National Science Foundation has been very, very flexible and very, very understanding of

'Yeah, we know you're, you know, you're trying, you're doing what you're not quite doing what you thought you would do, but you're doing something and yes, keep paying your graduate students.' And so we were able to keep paying our graduate students, which was good." One challenge, however, of obtaining NSF funding is the amount of work and resources needed to put together a proposal, and an uncertainty of obtaining funding given the highly competitive nature of the NSF award process.

Programs also use additional funding sources including a) grants from professional organizations, like APS, or national foundations, b) smaller grants from local government and community-oriented organizations c) university, college or department level funding, and d) individual or business donations. Programs sometimes generate their own revenue from audience participants through ticket sales or program fees; however, in these cases, programs are typically aware that this can limit audience attendance and may be in conflict with their goal to be accessible to all audiences and thus keep the fees small.

4.8.3.2 Budgets are Significantly Impacted Depending on the use of Student Volunteers or Paid Staff

Personnel are the biggest chunk of budget for most programs unless it is all volunteer staffed. Programs with large amounts of funding, such as from government agencies, seem to have more personnel that are paid, such as part-time or full-time staff roles, which can amount to a full post-doc or higher level salary. Some programs have a model where students are paid for repeated work, but not for one-off events. Main expenses for programs aside from personnel are supplies and equipment, such as for demos and hands-on activities, food for kids or volunteers at program events, and transportation costs related to traveling to off-campus events. Some faculty noted that informal programming is relatively inexpensive compared to other educational or research activities in department budgets. However, this is typically true when the program relies on volunteers who work for free. For example, a comment from a faculty member leading Program 15, which operates with student volunteers and faculty committed to the program as part of their service: "I don't think we've ever had a money issue. Because it's pretty inexpensive to run? Sure. I mean, I think the most expensive items are the poster prints and the T-shirts."

4.8.3.3 Multiple Sources of Funding can Support the Stability of Programs

Stability for informal programs can look like being in operation without hiatus, the ability of a program to consistently offer a certain activity, or having enough personnel to operate reliably. An important part of how funding affects stability is the number of funding sources that programs have. Some programs have funding from only a single source this can provide a reasonable amount of stability, for example in the case of funding from a large NSF grant that is able to be renewed. However, single source funding, for example from a partnership with a local business or from only the department budget, can potentially lead to instability. For instance if the circumstances at the partner or host institution change and budget cuts are needed, the program may not be seen as part of the core function of the institution. New sources of funding can lead to new initiatives or the expansion of existing activities; however, these programs can retract if or when that particular source of funding ends. Some funding sources have built in timelines, like most grant funding, and program leaders must consider a plan for continuing the programming after a grant ends. A number of program leaders reported actively seeking funding from multiple sources, looking to incorporate more funding sources for program stability in the case that some funding is scheduled to end or ends unexpectedly. For example, Program 9 reports that "making our kind of sponsorship and donation space more robust is going to be important going into the future so that we can be a little bit more autonomous and sustainable."

4.8.3.4 Funding Cuts can be a Challenge

Grants that end and university budget cuts can both affect programs. When budget cuts happen, typically program cuts are to paid personnel positions and the amount of programming offered. For example, when Program 8's national grant funding ended, they were able to keep running but they had to cut funding for a postdoc and the one semester fellowship they offered to graduate students for participation. However, being seen as an important resource to the campus or community is a way to shore up programs against budget cuts. For example, Program 14: "the more we use the planetarium and the more we become a valuable asset to many people on campus and in the community, the less likely we would be a target for state budget cuts and things like that as well. So there is that ulterior motive in a way for doing this. The ultimate goal is I really want people to learn and have a really good time learning. But there is also this piece of it. If people are learning in a lot of different ways and we're valuable, then that provides us a bit of a safety net."

4.9 Implications

Thus far, we have presented on each of the 12 key components separately, highlighting key themes and examples for each. While we find that these 12 components are all important to programs, the level of importance and the manifestation of each component will vary across each program. Here, we present on how these components are connected to each other. We will also discuss how we envision program leaders and informal physics practitioners using this framework as well as future work.

4.9.1 The Interconnectedness of the Key Components

The reality is that these 12 components do not operate independently of each other. Informal physics programs are complex systems, and as such, these components have strong connections to each other. For example, a program leader may choose physics topics specifically to attract audiences. Perhaps the program leader used a form of *assessment* to get audience feedback on what *audiences find engaging*, and this leads the program to do more *astronomy related activities*. If that program makes the switch to doing more astronomy related content, then they will need to make sure that their volunteers are appropriately *trained* to cover such material. It could be that they would even need to *recruit* volunteers with an astronomy background. These components being closely connected to each other adds a layer of complexity for program leaders to consider when reflecting about their own programs. An additional complexity is that program leaders emphasize and prioritize each component differently.

4.9.2 Considering How Practitioners can Utilize this Framework

As discussed in the *Strategies for Assessment* component and in prior work [106], practitioners want to be able to conduct assessment to evaluate aspects of their programs, but often lack the tools, time, and resources to be able to do so. One of the goals of this key components framework is to identify aspects that are important across informal physics programs and that program leaders have influence over. It is important to do no harm in these programs. While using this framework can help in designing or improving programs and is well intended, it may not be as informed or knowledgeable as the program leader about specific aspects. These components can serve as guideposts that program leaders can use to evaluate different aspects of their program.

Identifying the important areas that program leaders should focus on helps to lay the foundation for the future development of assessment tools and resources, for example, reflective rubrics. As an example to help guide discussion on the creation of tools, we provide below sets of questions that accompany each of the key components. These questions are meant to help program leaders reflect upon their own programs and think about how they address key features of their own program. For example, below is a list of reflection questions regarding the *Support of Audience Engagement and Learning* component:

- What are the spaces where audience members can ask questions in my program? Is it set-up so that there can be a back and forth conversation?
- How do audiences interact with the personnel? With other audience members?
- What are the ways that audience members can give me feedback?
- What background knowledge does the audience have on the physics topics?
- Are my program materials accessible to audiences with differing needs? Are my program materials translated into languages that serve my audiences?

A more comprehensive list of reflective questions for each component is provided in Appendix D. It is worth noting that because of the interconnectedness of the key components, some questions may have relevance to multiple components. In addition, every program has its own set of unique features, so not every question will be relevant to every program. Instead, the idea is that program leaders can reflect upon the questions for the components that are most pressing for their own situation. We envision a couple different ways that practitioners can utilize this framework tool.

One approach is for the practitioner to go through each component and accompanying list of questions in Appendix D and reflect on their relevance to the practitioners program. This process can help the practitioner identify potential areas that they should make more detailed plans on improving on. This approach of going through each component and question may be especially helpful for younger programs, practitioners creating a new program, or practitioners who recently took a leadership role in a program. While potentially tedious, going through each component and question can help the practitioner to more broadly establish where the program is at and the direction that it wants to go.

Another approach for using this framework is for the practitioner to reflect on the aspects of the program that they think are going well and the aspects that they have challenges with. Upon their reflections, practitioners should think about the relevant components for that scenario, and then seek the reflection questions in Appendix D for those components. For example, a program leader may be able to easily get volunteers and the volunteers may be enjoying their time in the program; however, the program leader may also find it difficult to keep audiences engaged with activities. In this scenario, the practitioner may consider prioritizing their focus on the *Support of Audience Engagement and Learning*, *Understanding Audience Motivations and Needs*, and *Program Content and Design* components over the *Recruitment and Onboarding of Personnel.* This approach for using the key components may be more useful for program leaders who have had more experience leading their program.

4.9.3 Future Work

Program leaders are regularly thinking about how they can improve upon their programs. Programs are complex and there are many important aspects that program leaders have to consider with limited time and resources. The development and implementation of this framework is a way to professionalize the field of informal physics education and be used as a tool for advocacy for more support of informal physics activities. We are particularly interested in blending this framework with existing frameworks that look specifically at inclusion, diversity, and accessibility. We believe that this framework will guide and inspire researchers and practitioners to partner together in creating future tools and resources that can help program leaders to more easily consider changes to their programs. Communication is key for these partnerships. In this regard, it is important to consider feedback and reflections with the partners, consider the frequency of communication, think about the kind of input that is being asked for or given, and negotiate and be aware of the voice and level of input that each member of the partnership has.

Chapter 5. Using a Volunteerism Framework to Understand the Motivations of University Students who Facilitate Informal Physics Programs

This chapter was published as an article for the 2023 Physics Education Research Conference Proceedings [120]. The author order on this published article is Bryan Stanley, Kathleen Hinko. Some aspects of this published work have been expanded for this chapter.

5.1 Introduction

Physicists and physics students engage with public audiences through a variety of informal physics programs and activities like school visits, summer camps, open houses, public talks, after school programs, and more. Participation in these activities are often voluntary for both the participants and the facilitators. Many volunteers in informal physics programming are university undergraduate and graduate students [4, 106]. Some students volunteer repeatedly and for many hours in these spaces throughout their student careers, even though they are often not earning course credit or being paid [15, 33, 133, 134]. We are working to understand the nature of the deep and meaningful experiences that students are having. Studies have looked at the impacts on university student volunteers and have found how some structures of informal physics programs support physics identity development, sense of belonging, and career-related skills [32, 33, 59, 60, 61, 62, 63]. Students have different career paths, some of which are education related, and their experiences from volunteering can impact the careers they pursue.

Some studies have looked at the motivations of university students who volunteer in informal programs, noting themes such as positive experiences, sharing science, professional development, and teaching opportunities [63, 135]. In particular, some studies have used community of practice [59, 60, 61, 62, 136] and personas [137] frameworks to better understand the involvement of university students volunteers in informal physics programs. However, many of these studies analyze students as they are actively involved in their volunteering and do not look at the careers and long term impacts. Rethman *et al.* [33] found that current and former student volunteers reported an increase in motivational beliefs. Those motivations have strong ties to student excitement and development of interest and skills that are relevant to becoming a physicist [33].

Here, we interview alumni at various points in their professional careers about their past experiences volunteering in informal physics programs and how those experiences impacted them and their career paths. Our overarching research focus is on the different ways that informal physics programs can affect careers of volunteers. Our initial step in this preliminary study is to apply a volunteerism motivational framework to 1) see how it maps onto the informal physics space, and 2) understand how volunteers' motivations evolve from their first volunteer experiences in informal physics to their present lives. Before applying to our larger data set, we first apply this framework to alumni whose careers ended up in educational fields. For the scope of this paper, we aim to answer the following: How do informal physics program experiences affect volunteers who go into careers related to education?

5.2 Volunteerism Framework

For many facilitators, informal physics is not a part of their main job or responsibilities. For example, faculty may have teaching or research responsibilities while students may have coursework or other involvements. The work that most of the facilitators do in their informal physics programs is in addition to their main job or position [106]. We use the term student volunteer to describe the university students who are contributing to the functionality of these programs. In some cases, but not all, university students may be compensated for their involvement in their program, however, we still label them as a volunteer as their main position is being a student and their informal physics involvement is on the side.

Given that participation in informal physics programming is often in addition to one's current job and responsibilities, there must be some motivations for the volunteer to 1) volunteer in the first place, and 2) to stay in that volunteer position. The volunteerism framework aims to understand those two points for volunteers more broadly. Clary and Snyder define six categories that describe motivations for volunteering (*Values*, *Understanding*, *Enhancement*, *Career*, *Social*, and *Protective*), as described in Table 5.1 [78, 79]. Pulling from foundations in psychology, this framework was tested with volunteers in public health, hospital programs, psychology programs, and business, with populations of volunteers being non-students, students getting course credit for their service, and students not getting course credit [78]. While this framework is aimed for volunteering more generally, Clary and Snyder acknowledge that these categories may appear differently based on the type of activity the volunteer is participating in [78]. This framework has been used in scientific spaces, such as citizen science programs and environmental sciences, but was adapted with some contextual renaming or some context-based additions [80, 81, 82, 83].

For this pilot study, we want to test this framework in the context of informal physics programs to determine if it captures the motivations of student volunteers. Applying this framework to interviews with alumni helps to understand how those motivations connect to the volunteers' career paths. Because we are testing the framework, we are applying it to a subset of our data. Given that informal physics programs are inherently educational, we first apply this framework on alumni who had a career in education.

Table 5.1: Adaption of the motivational categories and their descriptions [78, 79, 80, 81, 82, 83].

Categories	Definitions
Career	Preparation and experience for career-related endeavors.
Enhancement	Increasing positive feelings of oneself.
Protective	Reduced negative feelings from personal challenges.
Social	Building and strengthening relationships with friends and new people.
Understanding	Gaining and implementing new skills and knowledge.
Values	Belief that the person finds important to their life.

5.3 Methods

For data collection, we contacted the lead facilitators of two informal physics programs: Traveling Physics and After School Physics. Both programs are housed at different large research universities. Traveling Physics is a traveling program that visits schools with hands-on physics experiments that were built by its team of primarily undergraduate student volunteers. After School Physics is an afterschool program that partners with multiple nearby middle schools and high schools. A team of undergraduate and graduate students and postdocs visit each school once a week to lead hands-on physics activities and explorations.

We contacted these programs about our study because 1) both programs have been around for decades, 2) both programs stay in contact with their alumni, and 3) the authors have previous involvement with these programs. Program leaders shared information of our study to their alumni contact lists in order to recruit participants to be interviewed. Connections with these participants snowballed to members from two additional programs who were also interviewed. In total, 25 interviews with alumni were conducted.

The approximately 30-minute interviews were semi-structured. Some interviews were conducted in person and some were done virtually on Zoom. We asked participants' about their past experiences in their program, their career after leaving their university, skills important to their current work, and memorable experiences the participants had in the program, with other volunteers, and with audience members. For analysis, both authors independently coded the interviews with the volunteerism framework using the qualitative analysis program MAXQDA. Code units were full sentences in which the response met the definition of a framework category. A code could be multiple consecutive sentences, but not partial sentences. Sentences could include multiple codes. After each interview, the authors compared codes, to which there was a high agreement, discussed any discrepancies and documented common themes found within each category.

For the scope of this paper, we are only analyzing participants who volunteered in either Traveling Physics or After School Physics and who ended up in an educational-based career, whether that was formal, informal, or a combination of both. We will present each participants' trajectory linearly, highlighting the different motivational categories that manifest throughout. The three participants we will discuss are "Amber," "Mark," and "Claire."

Amber began her post-secondary career as a student at a two-year college. After taking an astronomy course, she decided to pursue a degree in physics at a large four-year research university where she volunteered at Traveling Physics. Her job trajectory went in many different directions. She worked as lab coordinator, worked in the tech industry, returned to school to pursue a teaching degree, left the teaching program to open up her own business, returned to the tech industry, then hired as assistant director for Traveling Physics.

Mark earned his bachelor's degree in physics. As an undergraduate, he worked as a teaching assistant for the undergraduate labs. He went to graduate school to continue studying physics. As a graduate student, he volunteered at Traveling Physics. After graduate school, he worked at a university as a lecture demonstration specialist, where he teaches some classes and still participates in public engagement activities.

Claire was a neuroscience major as an undergraduate who wanted to go into education since early college. As an undergraduate, she volunteered in After School Physics. She is currently a middle school science teacher.

5.4 Applying Framework to Three Cases

Here, we will discuss the job trajectories of Amber, Mark, and Claire from when they volunteered in their respective informal physics program to their current position. We present each persons' story individually and chronologically, highlighting key instances where the participant mentioned one of the six motivational categories. We find that all six motivational categories are present across these three interviews.

5.4.1 Amber

As an undergraduate, Amber got involved at Traveling Physics because her tutor was a volunteer there and he told her that he thought she would enjoy volunteering with the program. Prior to volunteering in Traveling Physics, Amber had experience working with kids through nannying and daycare. Building from her enjoyment of working with kids, one of Amber's original motivations for volunteering at Traveling Physics was because, "I get to come in, inspire some folks, and maybe get some young people interested in doing science." *Values* like wanting to inspire young people is one of the motivators for Amber to get involved with volunteering, but additional categories also help retain her in the program.

As a student, Amber had jobs in retail and pizza delivery; however, "I was done doing jobs that were just doing jobs." She had *Protective* motivation for transitioning to Traveling Physics to reduce the negative feelings she had working at those other jobs. Instead, she wanted a job where she could use "my skill set that I thought I was good at. And so by joining [Traveling Physics], I could just concentrate on school but also enhance my physics learning. So I could go into, let's say, my E&M class, and I'm struggling with this electricity and magnetism concept, and I could come back into [Traveling Physics] and say, 'How does this work?'... So now I can move more into a career trajectory, versus I'm just doing jobs to pay the bills." Traveling Physics was providing Amber with *Understanding* motivations by helping her to build upon her physics knowledge and skills. In addition, she sees these skills and knowledge to be more helpful in lining up with her *Career* trajectory compared to her other job experiences.

After earning her bachelor's degree, she ran the undergraduate labs before getting a job in the tech industry. After being laid off, she returned to her alma mater to pursue a teaching degree. During this time, she worked again at Traveling Physics. Based on her past experiences in the tech industry, Amber came into Traveling Physics with some additional motivations, specifically with her *Values* of inspiring women. "For me personally, because I am a woman in science and something I didn't come to until I was in the tech industry, and I saw how few women there were that I worked with, my personal goal was to go out and inspire young women. So showing them and enabling them that they can do science." After a semester of education courses, she decided that she did not want a formal educational career; however, she had built *Social* relationships with the other volunteers. One of these relationships led to her and another volunteer opening up a business together. Amber eventually left that business and went back to work in the tech industry.

Amber says that when she was back in the tech industry, "I was continually really trying to get back into [Traveling Physics] because I realized that was the thing I loved in life. I mean, even my coworkers would say, 'You go do this thing on some weekends where you drop in, and you do [Traveling Physics], and all you do is talk about [it]. Why don't you go get a job [there]?"' Her love for Traveling Physics would be an *Enhancement* motivation, but it was one that developed over time and played a role in her wanting to return and stay involved. Not only was her love of Traveling Physics apparent to her, but her tech colleagues noticed and commented on her enjoyment of the program, even to the point of encouraging her to pursue the program professionally. She applied for multiple positions at Traveling Physics and ultimately was hired as an assistant director.

In our interview, Amber reflected on how her past volunteering experiences impacted her after graduating. While she learned some physics knowledge and skills by building experiments, she also says that volunteering "enabled me to be okay to continue to fail. It was okay to come in here and work on a project for an entire semester, and the project doesn't work, and that's okay...Gosh, when [my business] imploded, and we weren't making any money and that was it, I was like, 'I don't know what to do,' And I'm like, 'Gosh, what would [Traveling Physics director] do?' It's like, 'Oh, you learn.' You pick up the pieces. You see what's the thing you enjoy, and you use that as your guiding light to go forward." Volunteering helped Amber to gain life skills in overcoming failure, and she used that *Understanding* later on in her career.

Amber's career path was not a straight forward one. She changed jobs multiple times and worked in multiple different fields. However, throughout her career, she was regularly involved in Traveling Physics, which helped influence the career choices that she made. Figure 5.1 is a visual representation of her career path.

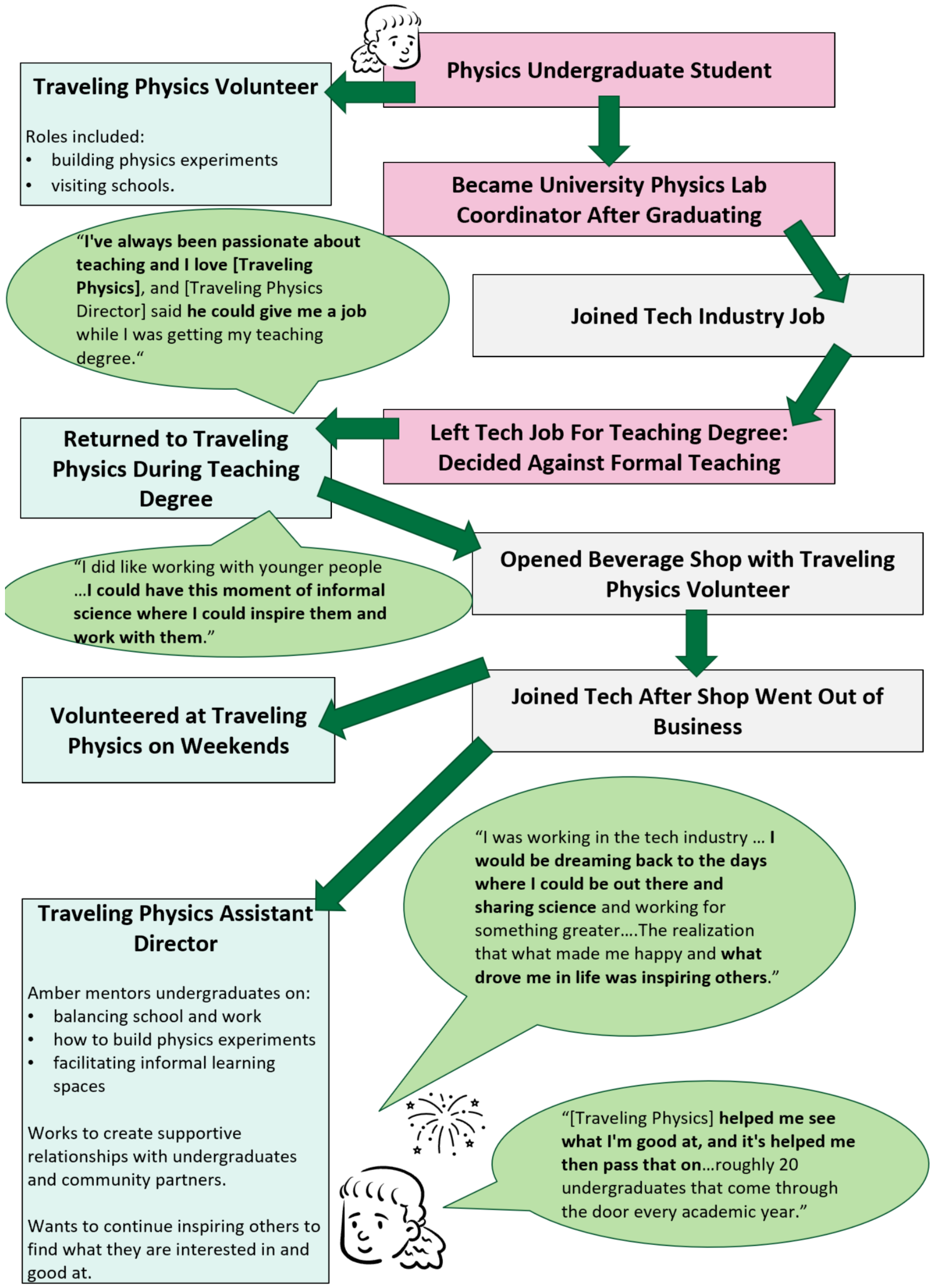

Figure 5.1: This is a visual representation of Amber's career path. She first joined Traveling Physics as a physics undergraduate. After graduating, she worked as a lab coordinator before transitioning to the tech industry. Later, she pursued a teaching degree, where she also returned to Traveling Physics because she *Valued* inspiring younger people. After some *Social* connections with another volunteer, she co-started a business. She later returned to the tech industry, where she dreamt of returning to Traveling Physics in a full-time role. Ultimately, she got a leadership position at Traveling Physics. A variation of this figure was originally presented as a poster [138].

5.4.2 Mark

As an undergraduate, Mark was asked by the physics department to teach some of the introductory physics labs as a teaching assistant. This was one of the early moments where Mark learned that he enjoyed teaching. When he attended graduate school, the *Enhancement* from his undergraduate teaching motivated him to get involved in the introductory labs and working with the Traveling Physics coordinator. "[In undergrad], I knew how the lab ran, so I helped tell the teaching assistants the next time what we were doing and I would help set up the labs for everybody, started editing the manuals and realized, hey, I like this. So that's why when I saw that when I got to [graduate school] with [Traveling Physics director], I was very willing to jump in and help and stay in that aspect of it." In the introductory physics labs, his responsibilities included managing the lab spaces, teaching some of the labs, and leading the teaching assistants.

Mark's motivations for volunteering were more than just feeling good. "I love physics, I love the doing of it, but if I couldn't share it with somebody in some fashion, I don't think I'd still be in it. That's what I realized I liked, and I felt like I could do that if I was with teaching assistants, the lab students, and, and then ultimately outreach...I feel like I'm sharing it, not dispensing information." A couple motivations overlap here. He *Values* the sharing of physics versus the dispensing of knowledge. He also determined that in order for him to stay in a physics *Career*, sharing physics with others was a necessary aspect for him. Volunteering helped him to *Understand* how to learn and share physics. "It changed the way I approach physics when I'm learning it. Because ...when I'm learning it, I'm trying to make connections now...and help [others] see how it works. The concepts and the principles rather than just here's some problem solving skills to get you through and graduate. Because that was more the drive of my undergraduate career. [Traveling Physics] was the flip. It was the reverse."

Mark also had *Protective* motivations from not feeling trusted to do work in research labs. "In two research labs...they hardly gave me any responsibility or significant responsibility or asked me to do any. I didn't feel like I was helpful, part of a team or useful. Joining [Traveling Physics], all of that switched. They were like, 'hey, would you like to work on this or what would you like to work on? OK, pursue it.' And then they gave guidance, but you got to explore with it and learn and try and maybe you came back and it was wrong and they give you advice and you go work on it some more." Even when he was taking other coursework and labs as a student, Mark found the manuals and activities to be "cookbook" and that his role was more about "going through the motions. You were just another cog in a wheel...I'd never felt that in [Traveling Physics]. [I] always felt useful, appreciated, helpful." Traveling Physics provided Mark a place where he felt trusted, able to contribute, and able to learn and apply his skills.

As a lecture demonstration specialist, he currently does demonstrations for physics courses and sometimes teaches courses. He also facilitates teaching workshops with K-12 teachers and does public engagement with K-12 schools. Mark reflects on how Traveling Physics impacted the *Career* path that he took. "I just want to emphasize again it did steer me [and] had a huge influence on where I'm at now. The outreach, the teaching, the trying to relate more to the public and the students rather than just going into research...I'm about teaching first and foremost. Everything I do is about that now." As a form of *Enhancement*, Mark says "[Traveling Physics] made me who I am and I'm grateful for it."

5.4.3 Claire

She was a neuroscience major who also studied sociology and science education. Since early college, she had been interested in pursuing an education career. This motivation stemmed from her *Values* of impacting kids and getting them interested in science. "I wanted to have more of a significant like role in in kids lives. And I also wanted to incorporate my like love of science and so science education really kind of just put all of those together." She saw an advertisement for After School Physics and joined because of her *Career* goals. "I've had that interest in education for a while. Especially trying to combine education, like with my own passion of science, I think I saw a poster for it and then I saw some people I already knew, like TA's and LA's also attending, and I wanted to check it out and I made a lot of cool friends with the group and some cool connections as well." Here, *Social* was another motivation for Claire. She already knew people in that particular program and then she continued to make friends and connections through volunteering.

Claire describes her overall experience volunteering in After School Physics as "overwhelmingly positive" and that "it was really heartwarming to play with the kids." These positive experiences are a form of *Enhancement*. Some of these positive feelings came from her *Social* relationships with the other volunteers, noting that "It was really cool to connect with other people that were interested in science education." With a combination of student volunteers of varying academic ranks, many of whom were physics majors, Claire mentioned that "there was another girl that attended with me. Another undergrad. She was in like astrophysics, I think, but we really connected over being the younger ladies in [After School Physics]. I think we became really good friends." Even though Claire was a neuroscience major, she says that in her carpool rides to schools with the other volunteers that they would have a mix of science-related conversations. “It was really cool to just have, like, science discussions with people that can, like, keep up even if they’re not necessarily in the same discipline. But I felt like it was a lot of support.”

As a current middle school science teacher, Claire notes that education was already the *Career* path that she was going down. “[After School Physics] was one of the first moves I made to solidify myself in sort of a science education pathway. And so as I was exposed to pedagogy there, I was just starting to be exposed to it within my own courses. But it solidified the age group I wanted to work with. The subject matter I wanted to work with. And I think in some ways the demographic I wanted to work with as well.”

5.5 Discussion

Amber, Mark, and Claire represent three different types of educational career pathways. Within the three interviews, we find all six categories to be present; however, for each person, some motivational categories were more prominent than others and manifest in different ways. For example, Amber and Claire had some form of *Career* motivation but in different forms. Amber’s *Career* motivations began more with physics knowledge and skills which then evolved into pursuing education, while Claire’s *Career* motivations in education were solidified and narrowed down. Mark had prior teaching experiences that he found positive, but it was those in combination with his *Protective* motivations from his physics research lab experience that contributed to his pursut of a career in education. Table 5.2 serves as a brief summary of how each category was present across the three interviews and which categories were most prominent for each person. The boldface highlights how that motivation connects to their current work.

Table 5.2: Some of the most notable motivational categories for each interview. The bolding connects that motivation to their current work.

Amber Traveling Physics	**Mark** Traveling Physics	**Claire** After School Physics
Career: She initially saw the program as a place to gain and apply physics knowledge to prepare for a career in the tech industry. **She transitioned into a career of informal physics.**	*Protective*: Program gave him a feeling of trust and agency, unlike other research and physics experiences he had.	*Career*: She joined because the program already aligned to her goals of becoming a teacher. **This ultimately solidified the career that she wanted.**
Values: She wanted to inspire young people. After her experience in the tech industry, **she was more motivated to inspire young women through Traveling Physics.**	*Understanding*: He learned presentation skills and how to connect with the people he is sharing physics with. **Applies these skills in his current job.**	*Social*: She already knew some other volunteers and then built new relationships throughout her time in the program.
Enhancement: Her tech industry colleagues were commenting on her love of being involved with the Traveling Physics program. **She applied for Traveling Physics job.**	*Enhancement*: Past positive teaching experiences helped motivate him to volunteer in the program. **He then becomes grateful for how it made him who he is today.**	*Values*: Wanted to play a role in kids' lives and to get them interested in science. **Current job is a middle school science teacher.**

There are several limitations with this study. In addition to the participants self-reporting their experiences, most of them are years removed from their time volunteering as students, so recollection of memories should be taken into consideration. In addition, while the alumni we discussed here ended up in education-related jobs, that is not the case for all alumni. We are encouraged by how well the framework illustrated the nuances in people's motivations, and how those motivations evolved throughout their time in the program and into their careers. Similar to other studies that adapted the volunteerism framework to their own contexts [80, 81, 82, 83], we find that this framework appears to appropriate for the informal physics context.

5.6 Future Work

Understanding people's motivations for volunteering in informal physics programs can provide further contextual information that can be used to further support volunteers. Next steps include applying this volunteerism framework to our larger dataset, which includes a variety of job trajectories, some of which are non-education focused. One particular note of interest I have, which came from me conducting each interview, is the involvement public engagement work after graduating. Some research participants continued to volunteer in some type of informal space, but others did not. Some cited other commitments such as work, spending time with family, etc. Others mentioned having a difficult time finding ways to get involved in informal spaces, especially if they did not work at, or lived farther away from, a university.

Most of the participants that I interviewed for this study also talked about how much fun they had volunteering in their programs. It would be interesting to do a more specific analysis on what “fun” is. For example, do volunteers think building experiments is fun? Is it socializing with other volunteers? Engaging with kids? All of the above?

As a part of my data collection for this project, I did site visits to Traveling Physics and After School Physics. I observed that having moments of downtime and group social opportunities seemed to contribute to the sense of community among the volunteers. For example, Traveling Physics hosted a group meeting at the beginning of their work day to discuss their experiences with the previous event. After that meeting, volunteers went to work on building activities for their next events. Throughout this build time, the personnel would converse with each other about topics related and unrelated to the program. Traveling Physics also had a designated time to have lunch together for each of their work days. At lunch time, the personnel shared stories and jokes with each other, appearing to be really close to each other. For After School Physics, I rode in the car with the group of volunteers to one of the schools that they work with. In the car was me, a postdoc, a senior graduate student, and first-year graduate student, and an undergraduate student. There were some conversations about the activities that the program was about to do, but there were also conversations between the postdoc and senior graduate student about job searches, conversations between the two graduate students about graduate courses, and conversations with the undergraduate about what life as a graduate student was like. On the car ride after the event, there were conversations about what went well and poorly with the activities they just led. There were also conversations about each of the volunteers’ hobbies, which included hiking and board games. In that car ride, volunteers exchanged numbers and made plans for having a future game night. There appeared to be strong social bonds being formed among the personnel members in aspects of programs outside of their main events. I think this is an area of informal physics programming that should be studied more closely.

Chapter 6. Discussion

In Chapter 3, I identified the important structures of informal physics programs, finding that the personnel play a central role in the functionality of these programs. This laid the foundation for Chapter 4, where I developed a framework of key components designed to help informal physics practitioners reflect upon the critical aspects of their programs. Given the importance of personnel, multiple of these components were directly related to the personnel. While Chapters 3 and 4 looked at how personnel are important to informal physics programs, Chapter 5 analyzed how informal physics programs are important to personnel, specifically in motivating students' career pursuits. Understanding the motivations of their student volunteers can help program leaders consider how to better support their personnel.

My hope is that this work contributes to supporting informal physics program leaders, and in turn, that also helps leaders to support their program personnel. I am both a researcher and a practitioner. In this chapter, I reflect on my research in the context of my personal role as an informal physics practitioner, specifically through the lens of my key components framework. I then include some recommendations for researchers, practitioners, and physics departments.

6.1 My Positionality as an Informal Physics Researcher and Practitioner

Similar to the other program leaders reported on in Chapter 3, my work as an informal physics practitioner was done in addition to my main job responsibilities as a graduate student. My experience as an informal physics practitioner helped me to ask pointed questions and follow-up questions in interviews, as well as have some contextual insights during data analysis. While I consider my practitioner experience to be an asset during the research process, there are also opportunities for potential bias to occur when collecting and interpreting data. For example, I can often relate to other program leaders when they discuss challenges that I may have also experienced as a practitioner, and that might make me sympathetic to their perspective.

Prior to being a physics education researcher, I was actively involved in public engagement. As an undergraduate, I was an intern at a traveling science program where I was a part of a team of staff and undergraduate students who built hands-on science experiments and brought them to K-12 schools and public events. While I had already enjoyed education, I was not seriously considering it as a potential career path until I became involved in public engagement. The years I had spent in this traveling science program helped me gain an understanding of how to design activities, engage with audiences of varying ages and backgrounds, and some of the logistical decisions that a program has to make. As a part of my undergraduate experience in informal physics, I felt a strong sense of community with other personnel as well as with our audiences. The excitement and joy that I got from exploring the wonders of science with others helped me to view informal education as a potential career option, which is one of the motivations for my work in Chapter 5.

Throughout my graduate student career, I continued doing public engagement work, but this time as a program leader. Since 2020, I have been the public engagement coordinator for a graduate student organization housed in the physics department. The organization's main goal is to promote and support diversity within the physical sciences. To do so, it hosts a variety of events for university students in physical science programs as well as host mentoring programs for graduate and undergraduate students. While most of the work in the program focuses on supporting university students, my role was doing work with the community beyond the university. My public engagement work included visiting primarily elementary and middle schools as well as participating in open-house style events. Graduate school is stressful. I treasure the opportunities I had in public engagement. Having kids tell me that they thought the experiments I built were cool and that they wanted to make their own has been really heartwarming. Getting others excited about physics has helped me to also stay excited about physics.

6.2 Using the Key Components Framework to Reflect on my Experiences as an Informal Physics Program Leader

In Chapter 4, I developed a framework of key components that describes important aspects of informal physics programs that program leaders have influence over. Future work includes using this framework to develop tools that program leaders can use to evaluate their own programs. The framework was originally presented in Figure 4.2 as a circle of all 12 key components. The circle is meant to show that all 12 components are connected to each other. However, all 12 components may not be of equal importance for each program. For example, the personnel components may be more heavily weighted for a program that prioritizes undergraduate involvement in community engagement. A different program may prioritize supporting youth in pursuing studies in STEM, so the program may put more weight on the audience and program design related components. While it is important to focus on all 12 components, it is also important for tools and resources to be flexible and malleable to each program's unique situations and needs. At the moment, we are testing out potential tool formats, such as reflection questions about each component. In this section, I tested out this approach by reflecting upon my own experiences leading an informal physics program.

As described in 4.9.2, I envisioned two ways that a program leader could use these reflective questions. When I started writing this section, I had planned on going through each component individually. After writing my reflections for the first couple of components, I found myself reflecting on experiences that spanned multiple components. I found that since I already had years of experience in this position, it was easier to reflect on experiences that I found went well and those that were challenging first. From there, I identified the present components and reflected on areas of improvement, which I present below.

6.2.1 What Went Great: Goals, Program Content and Design, Physical and Digital Resources, Funding and Budget, Assessment

I am listing *Goals*, *Program Content and Design*, *Physical and Digital Resources*, *Funding and Budget*, and *Assessment* together here because I find them to be highly related in my particular case. When I started in this position, the program only owned a few demonstrations. Past public engagement activities usually borrowed supplies from the physics department. One of my goals within the program was to show that science can be done anywhere by anyone. My approach for doing so was building hands-on demonstrations that are made out of common household items with the intention that students are inspired to make their own science experiments at home cheaply.

The public engagement funding that I got was provided by the department. Every year, I submitted a budget proposal for public engagement and I always got what I asked for financially. I used these funds to buy supplies to build hands-on demonstrations that the program can claim as its own. One example of an activity is a set of cartesian divers made out of water bottles and ketchup packets (see Figure 6.1). Another example is exploring forces with hairdryers and ping pong balls.

When I visited schools, I typically brought a set of demonstrations that I set up around the classroom. These demonstrations typically covered general physics topics, though sometimes teachers may request a topic theme (for example, forces) that would influence the activities I brought. Students self-explore with the activities themselves. My volunteers and I would move around the classroom conversing with students, ask probing questions, and explore alongside the students. We would then wrap up the session by having students share out what they learned and ask any questions they might have.

I used a combination of formal and informal assessment techniques in my program. After a school visit, I ask the teachers to fill out a feedback form about the experience, which is a more formal form of assessment. I have had some teachers tell me that they had students say that they want to go home and make their own experiments, which was one of my goals. I also rely on informal forms of assessment like observations and casual conversations with students. While students were exploring with activities or building their own demonstrations, I would casually talk with individual students and learn what they found interesting. I found that especially with younger students, they had no problem saying if something was cool, and especially if something was not cool. These types of observations and interactions helped me to adapt and alter the activities that I used in following events. For example, I have an activity where students explore how Slinky springs can be used to make interesting sounds.

I have witnessed students get excited and spend a lot of time exploring with the Slinkys, therefore I make a point to bring that activity to most of my events. A demonstration that I thought was really cool centered on exploring polarization and digital screens, shown in Figure 6.2. I found this activity interesting, however, I found it to be one of the activities that students interacted with the least, so I stopped running it.

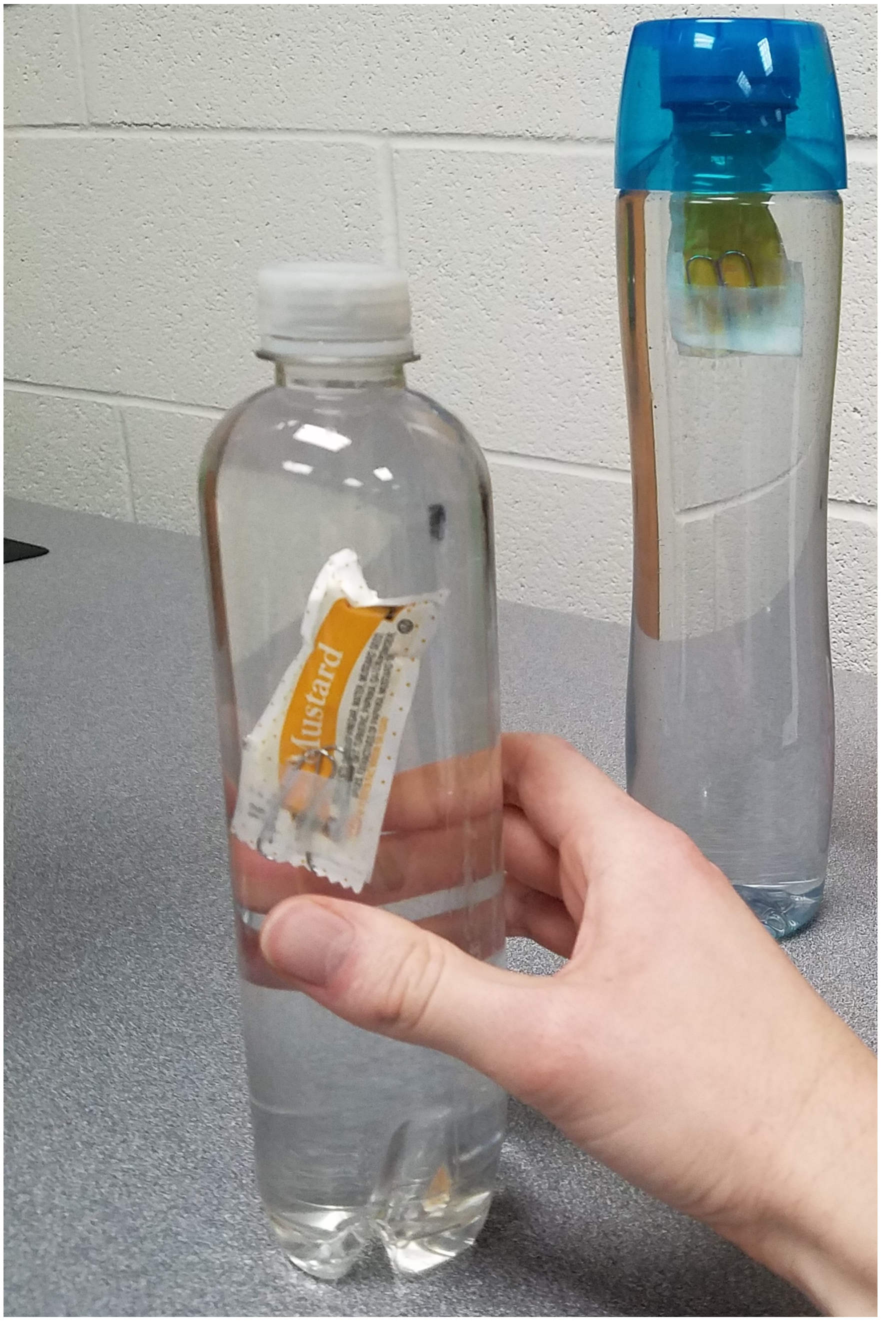

Figure 6.1: These are two Cartesian divers made out of water bottles and packets of mustard (can work with other condiment packets). The water bottles are filled with water with a packet floating inside. The packets float to the top of the bottle (as seen in the bottle on the right) because there are air bubbles inside the packet. As someone squeezes the bottle (as shown on the bottle on the left), the packet begins to sink. This is because the air bubble is getting compressed, taking up less volume, and thus becoming more dense. I have found this to be a popular activity among students. They seem to enjoy seeing how hard they can squeeze the bottle. They also often take the bottle around the room and show their friends, teachers, and/or parents.

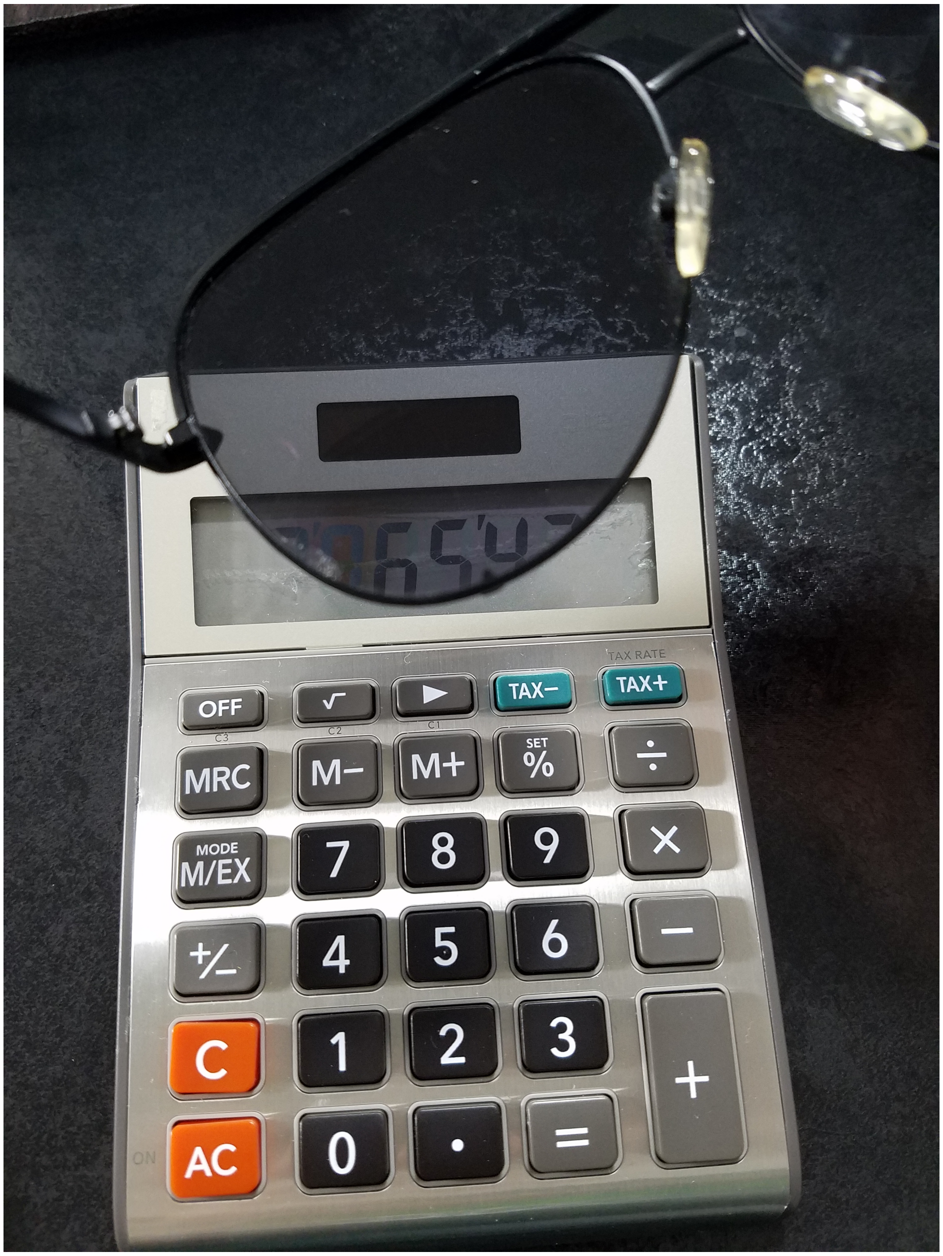

Figure 6.2: LCD screens, like the screen on this calculator, has a polarizing film on top that blocks out some of the light on the screen, which is how we are able to read the display. For this demonstration, I peeled off the polarizing film. This means that when the calculator is on, no light from the screen is being blocked, making it difficult to read the screen, appearing as if it is turned off. But if the person looking at the calculator is wearing polarized sunglasses, the sunglasses block out the light in the same manner as the polarizing film, allowing the wearer to be able to read the screen. I like this experiment, however, when I took it to schools, students engaged with it considerably less than the other activities. As a result, I stopped bringing it on school visits as often and built additional activities that were similar to other demonstrations that students enjoyed.

Reflecting on these components, I find that I maximize my available budget to purchase the necessary physical resources I need to build hands-on physics demos and activities. These activities are the centerpiece of the public engagement events that I run. I designed these activities with the goal of getting students interested in science and to explore science outside of the classroom on their own accord. Based on my informal and formal assessments, it appears that I am meeting this goal. That said, I use these forms of assessment to better the activities and program design, such as upgrading or removing less engaging demonstrations.

6.2.2 What Went Well: Understanding Audience Motivations and Needs, Support of Audience Engagement and Learning, Relationship with Partners and Community

When I became the public engagement leader, I had been living in Michigan for less than a year. I did not have much familiarity with schools in the area and had minimal direct personal connections with community partners. To get in contact with schools, I relied on mutual connections. I knew some professors in the College of Education and some other program leaders who led teacher workshops. I asked them to share information about my public engagement work with their teacher connections. This led to some connections with local teachers. In addition, the university has a science festival program that creates a contact list of university scientists and programs that teachers can contact about visiting their schools. I have registered my public engagement work to be on that list, and each year, I get about 4-5 teachers that contact me about visiting their classrooms. After I had worked with a particular school or teacher, there were often times where I was invited back the following year.

When a teacher emailed me about visiting their school, I typically scheduled a phone or video meeting with them to discuss what made sense in terms of scheduling, format, topics, number of students, etc. Average visits were about 45-minutes, but some teachers requested that I visit multiple classes at the school. Some teachers did not have a preference on content, so I brought whatever I wanted. Other teachers were more specific. For example, I had a teacher request activities that were related to weather, chemical reactions, and matter since those were the units that her students were studying at the time. I had another teacher who was a long-term substitute teacher for elementary music who asked me to visit for the entire school day to do science of sound demonstrations for all of their students. By meeting with teachers ahead of time, we were able to set clear expectations of what the visit would look like, what students would find interesting, and other logistics.

There were, however, some challenges, especially in the beginning of the COVID-19 pandemic, where I was doing virtual visits to schools. This varied in structure based on health department recommendations and the policies of each school. For virtual visits, I would join a class via a video conference call. Based on each particular situation, students were each individually on the video call from their own residence, or students were socially distanced in their classroom while my video was projected on a screen in a room. For the virtual events, I led demonstrations and was able to have engaging back and forth conversations with K-8 students. In the meetings I had with teachers prior to the visit, I relied on teachers to understand what worked well in the virtual space. For example, the approaches for getting students to unmute themselves on Zoom were different for middle school students than they were for 2nd graders. Teachers were able to provide wonderful insight on what kept the attention and interest of their particular students, which helped me to develop activities that met the students' needs and kept them engaged.

I found that I was particularly successful with engaging K-8 students. An age group that I had more challenges with engaging was with high schoolers. I did a virtual visit to a set of high school classes, and I had a more difficult time getting students excited and engaged. I did not quite meet my goal with that student population, I think partially due to the activities and partially due to the awkwardness of the virtual visit structure. Generally, I found in-person visits to be more engaging than virtual visits because students could explore with the demonstrations and activities themselves rather than watching me on a computer screen. When working with high school students, it was especially difficult to get much engagement. For example, in trying to ask questions to the students, I was often met with silence. Mid-visit with the high school class, I decided to shift away from doing the demonstrations as I was observing that students were not that interested in it. I started talking a bit more about what a career in physics looks like, thinking that may be of more interest and relevance to high school students. I got a little more engagement, but by that point, I had lost some confidence in myself and overall engagement was low.

After this event, I decided to advertise events with physics demonstrations to K-8 classes rather than K-12. I did some advertising to high school classes about doing visits that were more focused on careers in physics, with the idea that I could recruit some physics graduate students to join me in high school classrooms and discuss the different types of physics fields and careers. I promoted this through the university science festival like my other events, but I was never contacted about this style of event. For more engaging events for high schoolers, I would definitely need to rely more on high school teachers. In order to make connections with high school teachers, I would have to be more deliberate in contacting them directly to see if they would be interested in collaborating. Building those relationships takes time and effort to do it right. Given my limited time and the success I was having with K-8 graders, I decided to shift my focus away from working with high school students.

6.2.3 What Went Okay: Recruitment and Onboarding of Personnel, Connection to the Institution

Since my public engagement work was through a student organization, I primarily recruited university students to volunteer for events. My main method of recruitment was through email. For each event, I would send an email to all the graduate students in the physics department. The email would include event details like time, age group, and general information about what volunteering responsibilities would include. For any one event, I usually got about 1-2 people interested in volunteering out of a department of 200+ graduate students. Sometimes I did not get any physics student volunteers.

Surprisingly, most of my volunteers ended up being from outside of the department. That is primary because in addition to the public engagement work that I have discussed thus far, I also created and hosted a podcast where I interviewed 90 graduate students about their research, interests, hobbies, and how they ended up where they are today. The podcast started off with me interviewing other MSU physics graduate students about their life stories and how that connected to their research and graduate student experiences. Over time, I began interviewing MSU students in other disciplines. I did not know most of these students in other disciplines prior to interviewing them. After the interview, I would ask them if they were interested in receiving emails about volunteering opportunities. Everytime I sent an email to the department looking for volunteers, I also sent an identical email to students I met through my podcast.

I found that having volunteers from other disciplines lead to some exciting collaborations.

I encouraged my volunteers to lean on their own interests and knowledge when facilitating these informal learning spaces. For example, I got a request from a teacher about doing some activities that dealt with chemical reactions. I asked my volunteers if they had any activities that they wanted to create for this visit. I had a volunteer who wanted to lead an activity on elephant toothpaste. It is a chemical reaction with dish soap, hydrogen peroxide, and yeast. She chose it because she was a chemical engineering graduate student at the time, so talking about chemical reactions was something that she was comfortable and knowledgeable with.

I have also had volunteers who want to engage and be role models for kids, but expressed concerns because they did not have a physics or STEM background. Conversely, I also have had volunteers who had the content background but were nervous about how to engage with children. I communicated with my team collectively and individually so that we could support each other as well as the students we were working with. For example, a local elementary school requested activities that were about forces. As a physicist, I had some ideas for activities, but many of my volunteers were experts in other fields. I encouraged them to design something related to their interests or areas of study. One volunteer was a medical student who, after meeting and discussing with me, was able to design a series of water bottles of food coloring connected with straws such that when a bottle was compressed, it pumped the fluid into the other chambers, much like a heart. The students loved this and asked so many questions, to which she was able to answer the biology related questions and I could help answer the physics related questions.

After a few years in my position as a program leader, I ran into a common issue that other program leaders have: student volunteers graduate or become busy with other responsibilities. I decided to stop hosting my podcast, which I was doing by myself, which partially made it difficult for me to build connections with students in other disciplines, which were most of my volunteers. The few physics volunteers that have worked with me have told me that they enjoyed their volunteer experience, but getting people to volunteer in the first place has been challenging. I tried other methods of recruitment besides email such as talking to people directly or promoting public engagement efforts at orientation events for first-year graduate students, but I did not notice vast improvements in recruitment.

The department has been supportive of my work in many ways. One year, I was awarded the departmental outreach award. Faculty members have repeatedly reached out to me saying that they appreciate my podcasting work, even going as far as encouraging prospective graduate students to listen to it. I have enjoyed the kind words from the department; however, most of the verbal support has been for my podcasting and using it for recruiting prospective graduate students, and there has been less promotion or acknowledgement of the other public engagement work that I do. As a graduate student, I also did not ask department faculty to volunteer in activities or ask faculty to encourage other students to volunteer, primarily due to the awkwardness of that power dynamic.

The main challenge I had was that people were supportive of me being the one who did public engagement work, but there was less support in helping me do that work. As I reflect on this experience, I think I needed to do more on demonstrating the benefits of volunteering, possibly sharing the testimonials of previous volunteers who stated that they enjoyed their experience. I also think I should have had more direct conversations with the department about promoting my other forms of public engagement.

6.2.4 What Was Challenging: Distribution of Roles and Tasks, Continued Support of Personnel

Much like some of the program leaders mentioned in Chapter 3, I felt that much of the tasks related to the public engagement work fell directly onto me. Tasks included writing proposals to participate in larger public engagement events like the university science festival, communicating with teachers and other community partners, purchasing supplies, planning and building activities and demonstrations, recruiting volunteers, and event facilitation.

As discussed in 6.2.3, on occasion, I was able to get some assistance from volunteers in creating their own activities and demonstrations, however, this primarily happened for the virtual events, which were more presentation-focused, and typically took place when there were stricter COVID-19 restrictions that made it difficult to meet in person and exchange supplies.

For some events, I had about 3-4 volunteers, which was helpful because we were able to all engage with the audience individually at the same time. In addition, while some volunteers were working with some audience members, I could also focus on other tasks, like preparing for the next audience group that we were going to see, fixing demonstrations that broke, or talking with teachers and parents. There were some events where I was the only facilitator. That meant that if a demonstration broke, I had to pull it off to the side and could not fix it until I returned home. It also meant that there were fewer opportunities to have individual interactions with every audience member. There were some events, such as visiting the music class described in 6.2.2, that I was facilitating by myself all day, which meant that I could not take a break and there was no one to split tasks with. It also meant that there was not anyone that I could reflect with about how the event was going and some changes that could be made.

The *Continued Support of Personnel* component was also challenging for me. The public engagement events were not on a consistent basis, for example, weekly like some other programs are. That is because for any one school visit, there may be about a day's worth of commitment from me with teacher communication, travel, purchasing supplies, building activities, and the visit itself. As a graduate student, I have limited time and resources to commit to that voluntarily on a frequent basis. As a result, the most events I facilitated in a year was nine. It was difficult enough to recruit volunteers for a single event, let alone the planning process. Therefore, it was also difficult to build much of a community among the volunteers in this informal space. I had volunteers who said they enjoyed volunteering, but graduate student schedules are so busy that even the ones who enjoyed their time were only available to volunteer for a couple of events.

I had a graduate student tell me once that they were interested in volunteering, but were nervous because they did not have a lot of experience working with kids. They ended up volunteering for an event and they did great. Before each event starts, I like to do a short prep meeting with volunteers about what to expect and some tips on working with the audiences, but this volunteer's comment got me thinking about how maybe I could host some form of workshop session in the department about public engagement work to help train, and potentially recruit, volunteers. By the time that I thought about this, I was part way through my final year in this position and had very little time to commit to hosting such a workshop.

Reflecting back on my time as a program leader, if I were to do it all over again, I would host a public engagement workshop, at least once to see how it went. It could be a way to recruit some volunteers and build some confidence among some students. Given that university students already cite time constraints for volunteering for events, I am hesitant on asking them to participate in an additional workshop. On the other hand, it may pique their interest and make them more willing to dedicate their time.

6.3 Considering Different Framework Representations

The Key Components framework is a complex framework due to the detail and interconnectedness of the components. To assist researchers and practitioners in understanding the complex nature of these components, it can be helpful to provide multiple representations as each representation may resonate differently for each person. For example, an alternative representation is the use of metaphors, as I discuss here.

Metaphors can be a useful tool to describe complex systems in a more relatable fashion [139]. Education studies have found metaphors to serve as tools in understanding student's perceptions and conceptual understanding of a situation [140, 141]. The physics community has a history of using metaphors to describe abstract physics concepts in a more relatable form. Some examples include comparing the flow of electricity to water flowing through pipes, describing the history of the universe through clocks and calendars, and Maxwell's demon [142, 143, 144]. No metaphor is perfect, but they can still be useful by representing frameworks in different ways that may resonate with different people. Below, I provide two metaphor examples to illustrate our key components framework.

6.3.1 Plant Metaphor

Informal physics programs are gardens of opportunity, cared for by the program leaders. A small, local garden differs from a large botanical garden in the amount of foot traffic, number of plants, types of plants, and layout. The gardener has to decide if they are going to include plants that are okay to touch, like in a children's garden, or if they are going to include only plants that one just observes. Perhaps the gardener includes both. This is similar to a program leader deciding if physics activities are going to be hands-on or structured as presentations.

Plants need water. Water can come from rainfall, but it can also come from irrigation. Can the garden as it currently functions thrive from just one of those water sources, or does it need multiple sources of water? Does it need a lot or a little water? If the gardener has a desert botanical garden of cacti and succulent plants, the garden can perhaps thrive even if some water sources have dried up. Other gardeners may need to seek out other water sources to keep their garden thriving. These are similar decisions that program leaders have to consider with funding. Program leaders have to consider how much funding they need and what they will do if they lose a funding source.

What does the community want to see out of a garden? Are there particular plants they want to see? Are there opportunities for community members to plant their own plants in this garden? In this garden, is there one gardener, or are there multiple gardeners who manage the space. Are the gardeners paid to manage the garden, or is it all volunteer work? Program leaders also have to consider if their activities are even of interest to the community and if the community has opportunities to guide the direction of the program. In addition, program leaders need to consider their personnel, their responsibilities, and support systems.

6.3.2 Car Metaphor

All cars have the same general mechanics: they have wheels, a steering wheel, seats, and require some form of fuel like gasoline or electricity to run. However, different types of programs are used for different purposes. Perhaps the goal is to engage more with nature, so the car is designed with off-roading in mind. That requires special attention to aspects like tires and suspension. Tires are still important to an average street car, but not in the same capacity. Some vehicles are designed to handle a lot of people while other cars are much smaller. The bigger the car, the more fuel that it consumes. The driver of the vehicle can decide where the car goes, but drivers may take varying levels in input and feedback from passengers and mechanics to decide their next step.

Informal physics program leaders are the drivers of their program. They make decisions on the direction of the program and which aspects of the program may need upgrades or maintenance. Some programs have smaller numbers of personnel, audiences, and partners while other programs have large numbers of those. The larger the program, usually the more funding it needs in order to operate. Personnel, audiences, and partners can contribute to maintaining the program and provide feedback on where it is moving to.

6.4 Recommendations

The takeaways of this dissertation are that personnel are crucial to the functionality of informal physics programs, and that these programs also have positive impacts on their personnel. However, a common challenge for program leaders is that they are overwhelmed with responsibilities and tasks, often lacking the support and tools needed to improve and meet their goals. Chapter 4 is a step in the direction of creating those supports and tools with the key components framework, but there is still more that needs to be done.

As discussed throughout this dissertation, there are many types of people involved in the informal physics space, directly and indirectly. There are program leaders, volunteers, audiences, institutional administrators, community partners, education researchers, and more. Each of these groups have varying levels of impact on programs, and programs can have some level of impact on each group. Programs can benefit institutions with recruitment of students and help faculty to reach broader impact goals. Programs can partner with local businesses in hosting events that then ultimately bring audiences to those businesses. Program leaders want to do more assessment and evaluation with their programs, but often lack the time, tools, and experience to do so, which means that there are potential partnership opportunities for education researchers to carry out research.

With any sort of working relationship or partnership, it is important for everyone to have clear expectations of what they are wanting and what they are able to provide. This takes communication and an awareness of the voice and responsibility that each person has. I have found the Degree of Collaboration Abacus Tool [145] to be helpful in thinking about the distribution of responsibilities of each person in my public engagement, research, and other collaborative efforts. In their paper about this tool, Doberneck and Dann describe it as "a visual or metaphorical tool used to account for the valence of the relationship between two collaborating entitiescommunity and university partners. In other words, the abacus tool can visually represent whether, during each step of a shared project, the community or university partner has more voice in project decision-making or whether both partners share the work equally" [145].

Imagine an abacus, a ladder-like frame with horizontal rungs that beads are able to move left and right on. In this metaphor, one side of the abacus represents the voice and responsibility of one partner, and the other side represents the other partner. Each rung represents the steps, tasks, or decisions that need to be made on the project that the partners are working together on. The placement of the beads on each rung represent where the level of voice and power exists. Figure 6.3 provides an example of the abacus tool being used for outlining the responsibilities for when I partner with school teachers in organizing school visits [145].

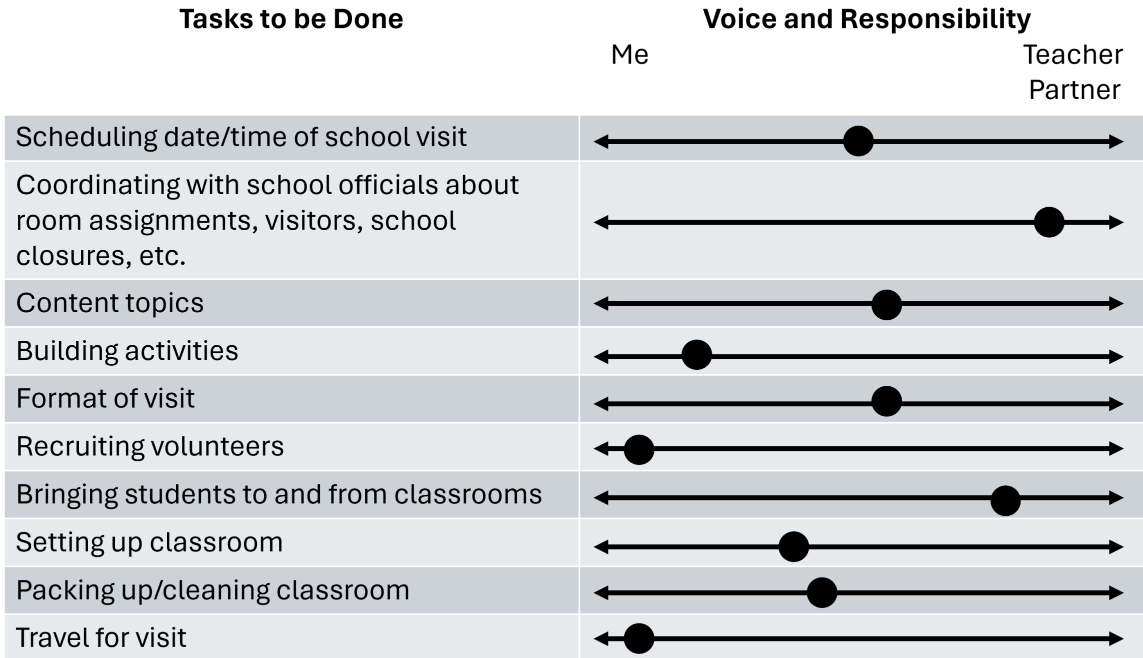

Figure 6.3: This is an example of the abacus tool being used for when I work with a teacher for coordinating a school visit. For steps like scheduling a date and time, both of us have about an equal voice as we both have our own time restrictions and availability. When visiting a school, the teacher I am partnering with is typically the one who coordinates with locating a physical space, coordinating schedules with other teachers, and gets approval from school administrators for hosting the visit. I, on the other hand, am responsible for recruiting other graduate student volunteers and transporting them to the school. This figure models just some of the task distributions among me and my teacher partner. A similar model can be used for task distribution among me and program volunteers. This figure was modeled after the figures published in Doberneck and Dann [145].

A healthy partnership does not necessarily mean that every rung has beads in the middle. This tool also does not have to be limited to just two partners. Variations of this concept can be used when multiple groups are involved. There are some steps where it is more appropriate for a particular partner to have more of a voice. I encourage program leaders to use an abacus-like tool when reflecting on their programs for a couple of reasons. Listing out and documenting all the decisions and necessary responsibilities helps put into perspective the volume of considerations that exist in running a program. Using the key components framework can help to identify the important tasks that are, or should be, done. The placement of beads can then also put into perspective just how many of these decisions and responsibilities fall onto the program leaders. Reflecting on this exercise may help program leaders and other individuals like volunteers, administrators, researchers, and community members identify areas of the program where responsibility can be adjusted in a more equitable manner.

Informal physics programs have many positive impacts on physicists, physics students, and local communities. My work here has identified many of the key structures of these programs, one of which is the importance of the personnel. Program leaders often experience challenges with running their programs and wish there was a tool or resource that they could use to assess their program. The key components framework lays the foundation for developing such tools. Further collaboration between practitioners, researchers, and community partners can build off of this work to further support and improve these programs.

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APPENDIX A. CHAPTER 3 INTERVIEW PROTOCOL

This appendix was originally published as supplemental material for Stanley et al. [106].

Prior to being interviewed, participants in this study filled out a survey, providing logistical information about their program. Some of these questions follow-up on their survey responses for clarification and more details. These were semi-structured interviews and the interviewer would ask follow up questions based on the participant's responses. Below is the full list of questions, broken up into themes. Questions were asked from all themes in all interviews, but based on the content of the response and follow-up questions, not every single specific question from this list was asked of each interview participant.

Development, history, and goals of the program

- When did you join the [program name]? How did that get started? What was your motivation for joining?
- Have you seen any drastic changes over time in any aspects of the program?
- What is the history of the program? How did it get started? What was the motivation to start the program? Who started it?
- In the survey, you described your role in the program as [their survey response]. Could you explain more on the day-to-day operation? How do you define your relationship with the rest of the personnel? Are there any other details in that regard you would like to share with us here?
- In the survey, you described the objective of your program to be [their survey response]. Has that changed over time? In which way and why?

Connection to institution and resources

- How is the program connected to the physics department and/or university?
- What other resources are available to the program, provided by the institution, physics department, physics community at your institution, such as educational, structural (space, transportation) or personnel?
- Where is the program held? What space do you use for your different activities?
- Has the program always been hosted at the mentioned institution? Why or why not?
- How does the placement within the host institution impact the program?
- What are the most important overall impacts the program has had on the institution? Has there been any major structural impacts? Has there been any major cultural impacts?
- Tell me about the culture of your (department/center/national lab). How collaborative is your institution?
- How do people work together?
- How receptive are members of your institution to the program?
- What is the role of the administration of the institution in the informal program? Have these roles changed over time? Why?
- What are the characteristics of the institutions culture that has a larger impact on the program? In which way? Why?
- How do you think your research affects your role in the program?

Leadership, volunteers, recruitment and training

- How did you count the number of personnel? Anyone that you did not count? Any changes over time?
- How is the program structured in terms of the personnel? Do you have staff, volunteers, etc? Staff? What are their roles in the program?
- Do the personnel receive training for the role they play in the program? What kind of training? For how long?
- Has leadership changed over time? What is their relationship with the rest of the personnel, partners, and sponsors?
- How do you recruit facilitators and volunteers? How do you advertise for your program? How do you normally attract volunteers?
- What are the facilitators and volunteers backgrounds? (are they undergraduate, graduate students, STEM, Education, etc)?
- What are the roles of individual physicists (faculty, staff) and university physics students in the program?

Connections to community partners and funding

- What is the role of community partners with your program? What is their connection to your program/event? Has this changed over time? In which way and why?
- How would you describe your relationship with your partners?
- What is the role of sponsors with your program? What is their connection to your program/event? Has this changed over time? In which way and why?

- If there could be a community or organization that could provide support to programs like yours, what kind of support would you like to see?
- How is the program funded? How has this changed over time?
- In your opinion, what factors affect or have affected the sustainability of the program?

Physics content, activity format, and assessments

- Could you give us more information on the physics contents/concepts that your program aims to cover? Has the content changed over time?
- Is the program based on a particular educational model?
- What are the logistics of the program? (For example, preparation before the activity, emailing, setting up events...)
- Are there any particular pedagogical techniques emphasized and employed for the design and implementation of the activities?
- What educational and discipline-specific resources are used to inform the design/development of the activities?
- Do you think that having some assessment/evaluation involved with your program could have positive effects on the program in the future in any way? Do you have any assessment ideas in mind that can be used to evaluate the program's performance or measure some aspects?
- You mentioned in the survey that your assessment is based on [their survey response], could you tell us more? What are the expected outcomes? Do you use that information to make changes in the model/design of the program?

- What assessment resources do you draw from? How do you measure outcomes? How do you measure if the program's goals have been achieved?

Impact on audiences and volunteers, challenges, and looking forward

- What is the impact of your program on volunteers? On audiences?
- What makes the program successful? What are the characteristics of the program that makes it successful? Why?
- Are program volunteers achieving their own goals? How is that determined?
- Has the programs audience demographics changed over time?
- Are audiences achieving their goals? How is that determined?
- Are there any current challenges the program is experiencing?
- Where do you see the program going in the next 5 years?

APPENDIX B. CHAPTER 3 OVERLAP TABLE

This appendix was originally published as supplemental material for Stanley et al. [106].

Table B.1: The below table shows the percentage of code overlaps present for each framework category pair across all three case study programs. The sum of the columns may not add up to 100% due to rounding.

	Pub Physics N= 258 overlaps	Camp Physics N = 202 overlaps	Physics Club N = 56 overlaps
Assessment-Audience	3.1%	2.5%	1.8%
Assessment-Institution	0.0%	1.0%	1.8%
Assessment-Personnel	2.7%	2.5%	3.6%
Assessment-Program	2.3%	1.0%	5.4%
Assessment-Resources	0.0%	1.0%	0.0%
Audience-Institution	0.8%	0.5%	0.0%
Audience-Personnel	5.4%	8.9%	5.4%
Audience-Program	12.4%	19.3%	12.5%
Audience-Resources	1.9%	7.9%	0.0%
Institution-Personnel	7.0%	11.4%	21.4%
Institution-Program	8.1%	3.0%	0.0%
Institution-Resources	2.3%	5.0%	3.6%
Personnel-Program	29.8%	15.3%	25.0%
Personnel-Resources	11.6%	10.9%	14.3%
Program-Resources	12.4%	9.9%	5.4%

APPENDIX C. CHAPTER 4 PROGRAM DESCRIPTIONS

Table C.1: We selected 15 programs from our dataset to build our key components framework. These programs differ in format, content, audience demographics, and institution type.

Program	Format	Topics	Interviewee	Location	Audience Type	Institution Type
1	Public Lecture	Astronomy	Faculty	Midwest	Adults	R1 University
2	Summer Camp	Topics in Current Physics Research	Paid Staff	Midwest	K-12	Large Research Facility
3	Public Lecture, Demonstration Shows	Topics in Current Physics Research	Paid Staff	Midwest	Adults	R1 University
4	Observatory	Astronomy	Paid Staff	Midwest	General	R1 University
5	Open House, Planetarium Shows	General physics, astronomy	Undergraduate Student	Midwest	K-12	R1 University
6	Demonstration Shows	General physics	Faculty	West	General	R1 University
7	Summer Camp	General physics	Faculty	East	K-12	Private Liberal Arts
8	Public Lecture	Topics in Current Physics Research	Paid Staff	West	Adults	Large Research Facility
9	Planetarium	Astronomy, planetarium shows	Paid Staff	West	General	R1 University
10	Summer Camp	Topics in Current Physics Research	Paid Staff	Midwest	K-12	Large Research Facility
11	Demonstration Shows, Open House	General physics	Graduate Student	Midwest	K-12	R1 University
12	Museum Program	General physics	Faculty	West	K-12	R1 University, Museum
13	Demonstration Shows	General physics	Paid Staff	Midwest	K-12	R1 University
14	Planetarium	Astronomy	Paid Staff	Midwest	General	R1 University
15	Science Festival	General physics	Faculty	Midwest	General	R1 University

APPENDIX D. CHAPTER 4 REFLECTION QUESTIONS

Below is a list of questions for each key component that program leaders can use to reflect upon their program. Not every question may necessarily be relevant to every program leader. In addition, some questions may be relevant for multiple components.

Goals

- What are the goals of my program?
- Who developed the goals? Are they shared by all program personnel?
- How are the goals of my program being met, and in what ways are they not met?
- What are the contributing factors to the success of my program goals?
- What are the challenges to meeting the program goals?

Program Content & Design

- What physics topics do my audiences find interesting?
- What physics topics do my personnel and I have expertise on?
- Am I able to travel to audiences? Are audiences able to travel to my program?
- Where am I able to host my program?
- How does the physical space where I host my program impact the types of activities I host?

Strategies for Assessment

- What forms of assessment are utilized in my program?
- What is my program focused on assessing?

- What is the purpose or motivation of assessment within my program?
- Are the types of assessments used by my program effective for meeting the goals of assessment?
- How can my program use results from assessments to make changes or improvements?

Recruitment and Onboarding of Personnel

- What type of volunteer (student, faculty, etc) would be the best fit for the tasks I need done?
- Are my advertisement methods appropriate and relevant for the type of volunteer I am trying to recruit?
- What do my volunteers need to be trained on?
- Who is conducting the training? Leadership? More experienced volunteers? Combination of both?
- What incentives can I offer?
- What are the benefits I can tell potential volunteers to convince them to volunteer?
- How do the schedules of my volunteers align with when I host my events?

Distribution of Roles and Tasks

- What are the tasks that need to be completed for my program to run?
- Of the volunteers I have, who is able to complete each task?
- Are some of my volunteers able to carry out multiple tasks?
- What is the time commitment for each task?

- Do my volunteers have the time available to complete these tasks?
- What is the order of importance of each task?
- Do tasks have to be completed in a particular order or can they be completed in parallel?
- How many tasks or responsibilities does each personnel member have?

Continued Support of Personnel

- Am I able to give financial support or course credit to my volunteers?
- Do volunteers have autonomy in creating activities?
- What does volunteer mentorship look like? Are volunteers being mentored by program leadership? Are they mentored by more senior volunteers?
- Do volunteers get leadership opportunities?

Understanding Audience Motivations and Needs

- Who is the audience I am aiming to connect with?
- Who are the audiences nearby?
- What lived experiences and cultural resources does the audience have?
- What are my audiences interested in?
- What do my audiences want to learn about / need to learn about?
- What other activities or events are available or popular with audiences in the area?
- What are the limitations on the audience's ability to attend events? Is my program affordable?

- What ways does our program content connect to local and national STEM curriculum or standards?

Support of Audience Engagement and Learning

- What are the spaces where audience members can ask questions in my program? Is it set-up so that there can be a back and forth conversation?
- How do audiences interact with the personnel? With other audience members?
- What are the ways that audience members can give me feedback?
- What background knowledge does the audience have on the physics topics?
- Are my program materials accessible to audiences with differing needs? Are my program materials translated into languages that serve my audiences?

Connection to Community and Partners

- Who are my partners? How many partners do I have?
- What are my goals with this partnership? What are my partners' goals?
- What do I need/want from this partnership? What do my partners need/want?
- What expertise do I bring to this partnership? What expertise do my partners bring to this partnership?
- How often do I communicate with my partners? What does this communication look like?
- How long do I anticipate this partnership lasting?
- How have my partnership relationships evolved over time?

Relationship with Institution

- How does my institution benefit my program?
- How does my program benefit my institution?
- What are the supports that I would like to see from my institution?
- Am I able to request for support from the institution? (ask for funding, physical space, volunteers, etc.)
- What does the institution see as the benefits of my program?
- Can my program partner with other institutional events? Ex. Participating in recruitment events

Physical and Digital Resources

- What are the physical spaces that I need to host an event?
- What are the physical spaces that I need outside of events (lab space, offices, storage space)?
- What are the limitations of my physical space?
- What type of supplies do I need?
- Do I have an inventory list of the supplies and activities that I have?
- What does my online presence look like (website, social media)? What information about my program is available?
- How often are my online materials updated?

Funding and Budget

- What do I need funding for? Purchasing supplies? Paying personnel? Travel? Food?
- How much funding do I need to carry out my goals?
- What are my sources of funding?
- Do I have one source of funding or multiple sources of funding?
- Does my institution have funding opportunities for my program?
- How long will my funding source last?
- If a funding source ends, what adjustments would I need to make to my program?

APPENDIX E. CHAPTER 5 INTERVIEW PROTOCOL

These were semi-structured interviews and the interviewer would ask follow up questions based on the participant's responses. Below is the full list of questions, broken up into themes. Questions were asked from all themes in all interviews, but based on the content of the response and follow-up questions, not every single specific question from this list was asked of each interview participant.

Background and Current Work

- Where did you attend for your post-secondary education?
- What was your field of study?
  - What led you to this area of study?
- What have you been doing since leaving [post-secondary institution]?
  - Can you describe some of your current work responsibilities?
- What are some skills that you find important in your current work?
  - Can you provide some examples of how these skills are important to your current work?
- For program leaders
  - Why did you pick this job? Where there any positions that you had that led you here?
  - Tell me about your current position. What are your roles and responsibilities?

Informal Physics Experience

- When you were at [post-secondary institution], you were involved in an informal physics program(s). Can you describe the program?
  - What was your involvement in the program?
- What was your motivation for joining [program]?
- What do you feel were the goals of the program?
- What were your goals in the program?
- As a child, do you have any memorable experiences with informal spaces? Examples: after school programs, summer camps, science museums
  - What effect did these experiences have on your educational/career pursuits?
  - What effect did these experiences have on your involvement in [program]?
- How would you describe your overall experience in [program]?
  - Can you describe a particularly memorable experience you had with [program]?
  - Can you describe a particular experience you had engaging with the audience/community member/public member with [program]?
  - Can you describe a particular experience you had interacting with your fellow members of [program]?
- How are those experiences different from other experiences you had (research, classes, etc)?
- How have your experiences in [program] influenced, if at all, your current career?

- Is there a specific experience you can describe that influenced your career pursuits?

- What did you value most from your experience in [program]?
  - Do you ever use anything from those experiences today?
  - Did you learn anything that impacted you?

- Are you still involved in informal physics/physics public engagement activities?
  - Can you describe them?
  - How about non-physics related service/engagement?
  - Do you feel that there are opportunities for you to get involved in such engagements?

- Where do you see your career going?

- Is there anything else you would like to share about your experience in [program] or your career?