Motivation and needs of informal physics practitioners

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Physicists engage with the public to varying degrees at different stages of their careers. However, their public engagement covers many activities, events, and audiences, making their motivations and professional development needs not well understood. As part of ongoing efforts to build and support a community in the informal physics space, we conducted interviews with physicists with a range of different experiences in public engagement. We use personas methodology and self-determination theory to articulate their public engagement motivation, challenges, and needs. We present our set of three personas: the physicist who engages in informal physics for self-reflection, the physicist who wants to spark interest and understanding in physics, and the physicist who wants to provide diverse role models to younger students and inspire them to pursue a science, technology, engineering, and mathematics career. Needs covered a range of resources including science communication training, community building among informal physics practitioners, and mechanisms to recognize, elevate, and value informal physics. By bringing user-centered design methodology to a new topical area of physics education research, we expand our understanding of motivations and needs of practitioners in physics public engagement. Therefore, departments, organizations, and institutions could draw upon the personas developed to consider the ways to better support physicists in their respective environments.

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I. INTRODUCTION

Informal physics education refers to activities and events centered on engagement with physics outside the formal classroom. Public engagement has been defined as encompassing "the myriad of ways in which the activity and benefits of higher education and research can be shared with the public. Engagement is by definition a two-way process, involving interaction and listening, with the goal of generating mutual benefit" [1]. We refer to informal physics and public engagement interchangeably as informal physics activities play an important role in the public's general understanding of physics and science.

Many types of activities, platforms, and programs fall under informal physics education such as after-school programs, public talks, demonstration presentations, open houses, science festivals, planetariums, social media, websites, popularized books, movies, and games [2]. While many of these activities can be specific to physics and astronomy, some of them include a broader sense of education across science fields or all of science, technology, engineering, and mathematics (STEM). Despite the wide variety of possible activities, a common characteristic they share is that participation is voluntary and activities are meant to provide participants the freedom to explore and be curious about how the world works.

Research in informal physics, often referred to as informal physics education and research (IPER), has focused on physics identity development, development of informal education programs, skill development for facilitators, impact of engagement in informal physics on audiences, and the landscape of practices undertaken in this space [3]. Research shows that participation in informal physics programs significantly enhances facilitators' communication skills, teamwork capacity, and confidence [4–6]. Moreover, participation in these programs has the added benefit of increasing the sense of belonging to the field of physics for both facilitators and audience. In particular, for individuals from underrepresented populations, engagement with physics in these informal spaces allows them to develop their physics identity as they bring their whole selves to these spaces [6–11]. In turn, informal physics increases the interest and relevance of physics and science as a potential career path [12].

Furthermore, informal education programs provide opportunities for significant numbers of individuals in various geographic locations and diverse demographics to hear and engage with physics and physicists [13]. The dimensions at play in informal physics programs are varied, rich, and nuanced. In a study about the landscape of informal physics, Izadi *et al.* provide an overview of all possible components of informal programs: personnel (volunteers and paid staff), resources (funding and community partners), program (goals, interactive activities, and physics content), audience (geographic location and attendee demographics), assessment (educational research, tools, and instruments for evaluation), and institution (role of institution administration and type of host institution) [13]. These various dimensions show the different avenues and challenges to engage with audiences about physics.

Efforts have also been made to survey programs to characterize some of the challenges faced in this space [14,15]. Factors such as personnel [16] and funding were among the biggest barriers to the functionality and sustainability of programs long term [14,15]. Additionally, there is a common sense of isolation for facilitators and researchers in informal physics education who struggle to sustain and grow their efforts in informal spaces [17,18]. Nevertheless, research remains scarce on the needs of facilitators of informal physics activities. Given that there is little research on what type of training and support these practitioners and researchers need in order to sustain, grow, and feel connected to a community of informal science educators, it is necessary to better understand the experiences of the physicists who facilitate these informal activities.

This underlying gap in the physics education literature about understanding more holistically the motivations and needs of informal physics practitioners is echoed in the broader science education literature. Research with science communication professionals shows that it is necessary, yet challenging, for scientists to articulate their motivations for doing public engagement [19]. The science communication literature argues that elucidating why scientists share their excitement for science can enable the creation and sustainability of more productive training and resources to support scientists' public engagement [20–22]. The work of finding a holistic and systematic understanding of what brings and sustains scientists to public engagement is important as it can help empower the science community to promote access, understanding, and widespread participation in science in spaces outside the formal classroom. Research-based and user-centered approaches to informing professional development resources are a strategic way to address this need.

Given that both the science education and physics education literature advocate for a deeper and more robust ways to understand the pathways and engagement of scientists in informal spaces, we developed a research project within our subfield to better understand physicists' needs around public engagement. We sought to answer: *What are the motivations and professional development needs of physicists who engage in informal physics?* To answer this question, we conducted interviews with physics practitioners and researchers with a range of different experiences.

Note on terminology: Typically, "facilitator" refers to a physicist who either individually or with collaborators engages directly with the audience in informal physics spaces. "Practitioner" refers to a physicist who is involved in designing and managing an informal physics space; they may or may not also act as facilitators in the space. For simplicity, we will use the terms facilitator and practitioner interchangeably.

A. Positionality

As researchers, our affiliations and experiences in informal physics and physics education research influence the way we conduct this work. We include positionality statements to contextualize our findings because our backgrounds inevitably contain inherent biases, affordances, and limitations.

El-Adawy is a physics education researcher with expertise in STEM researchers' professional development. She has conducted research on informal physics as part of her Ph.D. Lau is a physics education researcher with expertise in faculty professional development around teaching. She has been a facilitator of informal physics activities and currently manages a number of public engagement professional development programs. Sayre is a physics education researcher with expertise in persona generation in physics education spaces and STEM faculty professional development for teaching and research. She rarely engages in IPER directly, though she manages an award portfolio that includes informal physics. Fracchiolla is an IPER expert, researcher, and facilitator, with more than 10 years of experience in designing, coordinating, and facilitating informal physics programs.

II. METHODOLOGY: PERSONAS

Because we were trying to understand what are interests, needs, and challenges of physicists who do public engagement, we used a user-centered design methodology: personas. We use personas methodology because of its usefulness showcased in education research for instructional design and professional development. For example, the research team at PhysPort [23], a professional development website for physics faculty, used personas to improve the design and development of resources and activities for faculty by understanding their needs when making changes to their teaching [24]. Personas have also been used to support the design of research programs with student-centered approaches based on undergraduate researchers' various motivations and experiences [25]. Additionally, personas have been applied to design instructional resources around learners' needs in the workplace [26].

Personas are personlike constructs created from the data of a group of potential users, which are synthesized into archetypes [25]. Each persona is created around a common goal for users that stems from the data and informs the design process. Data from multiple individuals are abstracted into one persona. Personas are typically created in sets that collectively represent the most important or frequent goals of users. Users can identify with multiple personas depending on their motivations, needs, and context. Personas allow us to create targeted professional development resources based on motivations, needs, and experiences of potential users because they highlight the diversity of potential users while centering their needs.

By creating archetypes that are very humanlike without representing the peculiarities of one person, several benefits emerge. First, researchers preserve the confidentiality of interview participants because the synthesized patterns are a combination of features from multiple interview participants [24], a benefit for both researchers and research participants. Second, personas represent real users for which resources are meant to be created instead of the assumptions of designers who may envision a variety of resources that are not useful for the actual target population [27], a benefit for users. Third, personas are personlike, and it is easier for designers to keep their needs in mind than it is to remember and relate to abstracted statistics about user segments, a benefit for designers. Finally, researchers focus on the goals and needs of users across the entire design process of resources, which creates rich descriptions of a variety of experiences and needs of the target users, a benefit for all. These benefits to researchers, designers, users, and participants align with the goal of this project, which is to understand the needs of informal physics facilitators and develop user-centric resources to support them in order to lower barriers to informal physics education implementation and participation.

III. FRAMEWORK: SELF-DETERMINATION THEORY

To identify the goals by which we can create personas, we draw on self-determination theory (SDT). SDT is a theory about motivation that centers on a learner's agency when making choices to reach desired goals [28]. SDT and personas methodology have been used together to identify research participants' various goals and motivations in previous physics education research work [29]. In particular, SDT allows personas to be developed by honing in on individual motivation and describing nuanced variations of users' experience [29]. For example, Huynh [29] showed that building personas of undergraduate researchers grounded in the SDT framework provided faculty with a coherent understanding of students' experiences in research in the department and provided the groundwork for the design of student-centered research programs.

In parallel, honing on the individual motivation of individuals through SDT is a valuable perspective in the context of informal physics. Literature in informal physics education highlights that intrinsic motivation is a driving factor for engagement in informal physics for both facilitators and participants [7]. Thus, not only has SDT been used in previous education-focused personas development but it is also appropriate to use in our context as the theory is in alignment with participation in informal physics.

SDT's prior use with personas and our aim to fill in the gap in the literature about gaining a deeper understanding of informal physics practitioners' experiences made us deliberately choose SDT to investigate the motivation of physicists engaged in informal physics. SDT suggests that three psychological needs, competence, relatedness, and autonomy, have to be satisfied to have the most self-determined form of motivation [30]. We contextualized the definitions of the components to be applicable to the informal physics context as follows:

- Autonomy: Desire to have sense of choice in their public engagement work;
- Relatedness: Desire to be connected and recognized with others in public engagement;
- Competence: Desire to experience mastery in public engagement work.

IV. METHODS

A. Context: Recruitment of research participants

To identify individuals and networks engaged in informal physics to participate in our study, we used a mixture of convenience sampling [31] and a snowball approach [32]. Given our affiliations, we started by soliciting participants from the central professional organization in the field of physics, the American Physical Society (APS), which is believed to be representative of the physics field. In particular, we had easy access to APS members who engage with the APS Public Engagement unit.

These members tend to be physicists interested in physics learning outside the traditional formal classroom. Thus, we gathered an initial list of names and networks to tap into from researchers and practitioners in informal physics who engage with a relatively new APS Public Engagement initiative, The Joint Network for Informal Physics Education and Research (JNIPER) [33], pronounced: "Juniper." JNIPER brings together physicists who facilitate informal physics learning activities, along with researchers who investigate the impact of these activities, to align and centralize the informal learning efforts of the physics community at large [33]. Once we gathered a list of about 30 individuals, we sent out a screening questionnaire to ask if they were willing to participate in the research study and/or if they had suggestions for other individuals to seek out to broaden the network of practitioners and researchers we would interview. For those who responded positively to the screening survey, we then reached out to conduct one-on-one semistructured interviews for our research study.

Our dataset contained 23 participants from various backgrounds and experiences in informal physics. Interviews were conducted with practitioners and/or researchers who are engaged in informal physics activities, events, and programs. Interviewees covered a large span of career stages: graduate students, postdoctoral researchers, physics teachers, physics faculty, physicists at national or international labs, and science communication professionals. There is a large diversity in the type of activities and audiences they engage in. Some of the activities included working with groups at universities, local schools, and a variety of public forums. Though personas do not require data saturation [34], we note that many themes saturated across participants' characteristics and informal physics activities. We expand in detail on theme saturation in the personas development process in Sec. V.

B. Data collection

With the aim of understanding why physicists want to do public engagement and what can be done to support them, we developed a semistructured interview protocol covering four main topics: (a) the interviewee's current role and experience with informal physics; (b) their conception of and motivation for informal physics work; (c) needs with informal physics work; and (d) professional identity. Our protocol included questions such as

- Could you give us a broad overview of your current professional obligations and involvement in public engagement?
- What is your current informal physics education/research community?
- What are some challenges/barriers you are encountering with engaging in public engagement activities?
- What would you need to overcome those challenges? What kind of support would be most helpful to you?

Interviews were conducted by the first author over video conference (Zoom), recorded, and transcribed (Zoom automatic transcription service) for analysis. The length of the interviews varied between 30 and 60 min depending on the availability of the interviewee and how much detail the interviewee gave in their answers. There was no significant difference in the number of codes depending on the length of the interview.

V. PERSONAS DEVELOPMENT

The big picture overview of our personas development process that connects our methods, theoretical framework, and analysis is illustrated in Fig. 1.

Step 1: We conducted a thematic analysis of the interview transcripts [35]. The process consisted of iteratively reading the transcripts and paying particular attention to the participants' answers about goals, needs, and resources for engaging in informal physics. For each transcript, key ideas of participants were identified within emergent themes such as *interest in informal physics: recruiting underrepresented populations to physics*, *resource used: discussions with practitioners*, *challenge: isolated from community*, *need: science communication: meeting your audience where they are at*. All transcripts were read and an initial list of themes was generated. From this initial list of topics, we grouped and refined those emergent themes. For example, some of the initial themes were *getting started in informal physics*, *community building in informal physics,* and *discussion around value of informal physics*. These themes characterized often a few sentences in the transcripts to reflect a complete idea participants were sharing. We returned to the

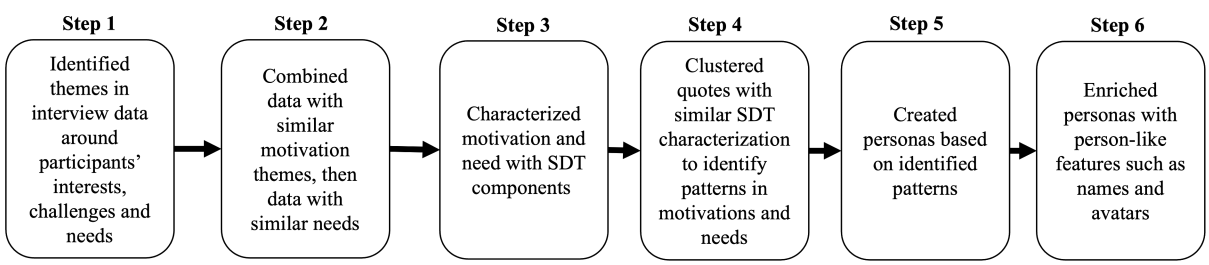


FIG. 1. An overview of the different steps of the personas development process from thematic analysis to generation of personlike features of our personas.

interviews with the emergent themes in mind to specifically seek evidence for them across the interview corpus and to develop and examine the breadth of human experience within each theme. This process allowed us to refine the preliminary list of themes into broadly relevant and refined themes that emerged from our interview set. Our thematic analysis generated emergent themes centered on participants' interests, resources used, challenges, and needs.

For each interview, we additionally summarized biographical and demographic information about participants, including their career stage (physics graduate student, postdoc, faculty, informal physics professional, physicist at national laboratory, high school physics teacher). We connected this information to the themes present in each interview. Quotes illustrative of motivation to engage in informal physics were also included with this summary information for use in persona generation after thematic analysis.

Step 2: We combined users by motivation to identify patterns in terms of challenges and resources needed, which led to an initial list of potential archetypes. We attempted a first iteration of personas development at this stage, which led to the creation of four initial personas. Details of this first iteration are characterized and described in our earlier work [36,37]. In our first iteration, we were able to create personas distinct in their goals. However, there was overlap across personas in terms of challenges and needs. We presented our work to different PER groups and at national conferences to get feedback. It became apparent that it was difficult to truly discern between two of the personas created. Because we were still interested in understanding motivation, this is when we decided to continue our personas development by grounding our analysis at this step in the SDT framework as it allows us to hone in on individual motivation [29]. This deliberate choice of using SDT as an analytical tool to characterize and develop personas provided us with a more robust way to distinguish among patterns in both goals and needs for our participants.

Step 3: From the themes identified for each interview, we coded chunks of the data associated with each theme with the self-determination theory (SDT) components (*competence*, *autonomy*, and *relatedness*) defined in the informal physics context in Sec. III. In other words, we characterized participants' motivations and needs for engaging in informal physics using SDT components. Table I shows examples of this characterization. For example, some participants are motivated by the opportunity to self-reflect on their journey and relate their growth to the public (motivated by *relatedness*). They often expressed the need for resources around increasing their competence and mastery of their public engagement work, through skill development of varying degrees (resources to increase their *competence*). Another example is some participants are motivated by the opportunity to connect on an identity level with their audience (motivated by *relatedness*). They often expressed the need for resources around increasing ways to recognize the value of this work by building infrastructures that support informal physics work (resources to increase their *autonomy*). Having the infrastructure in places such as administrative support and funding for informal physics would allow the work participants do in informal physics to be viewed as an integral part of their job responsibilities.

Step 4: After going through the process of step 3 on all the interview data collected, we clustered the quotes with similar SDT characterization to identify patterns in motivations and needs. We found the SDT framework was a

TABLE I. Examples of how interview data was characterized using the SDT components.

	Interview data	SDT component	Interview data	SDT component
Participant 1	*I engage in informal physics because it affords me the opportunity to connect with groups that I might not otherwise ever connect with.*	Relatedness	*I've had these conversations with people before: How do I interact with the kids so some sort of handout or something could be great or a video on how to best communicate with this audience.*	Competence
Participant 2	*I just think it's really important, especially for women and from people from other groups that are underrepresented in physics to kind of get out there and show the public that not all physicists look like Sheldon from the big bang theory.*	Relatedness	*If universities recognize that public engagement is actually helping to justify their existence, then I think resource would be given to supporting us and promoting people who do this work. I don't just mean like career promotion, I mean saying we want people who are good at this and systems would be put in place to support us if the recognition exists.*	Autonomy

good way to conceptualize resource needs. We found that quotes with particular types of motivations were often coupled with similar characteristics of needs.

Step 5: At this step, we generated personas descriptions. Connecting motivations to needs via SDT allowed us to create a set of personas distinct in their goals and needs thanks to the framing offered by the theoretical components. As a design methodology, personas allow us to attend to these nuances of needs, which helps us to brainstorm ways to best support our goal of designing user-centered resources. In turn, this allows us to fill the knowledge gap in the existing literature around understanding motivations, needs, and challenges with the aim of building professional development resources and opportunities needed to support the community of informal physics educators.

Step 6: The final step in generating personas is to enrich their motivations and resource needs with personlike features, such as names and avatars. This step provides more context to the reader about our interview participants and assists designers in using the personas to develop resources. Each persona's characteristics were drawn from the interview participants and their descriptions of their activities and engagement, blending features, and activities across multiple participants. Each persona therefore does not represent a single person but a creative amalgam of participants. This feature of personas, as a research methodology, allows us to preserve the confidentiality of the participants.

We went through multiple iterations of personas development. The first author examined the data following this process that we just described and illustrated in Fig. 1. However, at each step of the process, members of the team discussed emerging patterns, which often led to the first author going back to data for clarification or providing more details about identified themes. We also sought feedback and suggestions from physics education researchers at national conferences during the development process. Continued discussions occurred among members of the research team on the patterns and ideas identified throughout and the personas created, refining their development until consensus among the project's researchers was achieved.

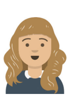
VI. FINDINGS

We present our set of three personas: Kyle, the self-reflective facilitator; Rory, the sparking interest and understanding facilitator; and Tracy, the representation matters facilitator. We summarize Kyle, Rory, and Tracy's key needs and implications for the development of resources in Table II.

A. Kyle, the self-reflective facilitator

Kyle, the self-reflective facilitator, engages in informal physics because they enjoy how energized they get when interacting with an audience to convey knowledge. The relatedness features of Kyle are their desire to connect their own journey in physics with others in public engagement. Informal physics education activities are an opportunity to self-reflect on their experience in physics, especially their belonging and own understanding of content knowledge in physics, which allows them to relay their journey to their audience. A representative quote of Kyle's goal is

TABLE II. Personas representing variation of physicists around needs in informal physics and potential implications for research team designing resources.

Persona	Key needs	Implication for designing resources
 Kyle: the self-reflective facilitator	• A centralized resource hub to get started • Science communication training • Skill development on how to organize to sustain engagement in informal physics	• Designing a searchable list of activities that are easy to implement • Designing training on skill development: storytelling with confidence and logistical programmatic factors
 Rory: the sparking interest and understanding facilitator	• Community building among physicists who do this work in isolation • Community building between physicists and science communication professionals	• Designing opportunities to share ideas and findings with other practitioners, professionals, researchers at conferences • Designing a network that allows practitioners to identify opportunities to partner with other practitioners or with researchers
 Tracy: the representation matters facilitator	• Funding for informal physics • More buy-in from institutions • Investment in infrastructure to support informal physics	• Designing spaces for discussions to occur to get the community to recognize and elevate the value of informal physics • Designing opportunities to share benefits of public engagement and advocate for funding

> *I personally get a little bit of a high from doing it. I love to be in front of a crowd and talking about things that I know. I love answering people's questions.*

Although engaging with the public energizes Kyle about their science and enables self-reflection, they find it challenging to figure out how to best interact with different types of audiences. Kyle also faces organizational challenges. They are not sure how to best organize their engagement in informal physics to sustain their engagement for long periods of time while managing their many responsibilities.

Kyle's challenges convey needs around competence, particularly the desire to be better at informal physics. For example, participant 1 quotes in Table I are illustrative of this need. They would like to have access to centralized resources on how to get started when engaging with a specific type of audience or event in informal physics. They also would like to get training in science communication to best engage with different types of audiences and develop their skills in designing, managing, and organizing activities and events with multiple stakeholders (volunteers, audience, and institutions).

An example of Kyle would be a physics graduate student who is part of a student-led program that works with K-12 students during an after-school program. They work to provide activities and illustrate physics concepts sometimes at the school or sometimes on university campus locations. Kyle works with other graduate students in this program, which may have started before they joined it, and Kyle's responsibilities in the program may vary from developing or implementing activities to coordinating with other facilitators.

Based on the Kyle's persona, we identified two approaches to support Kyle's resource and skill development needs, which directly address the competence needs they expressed (see Table II). First, we need to design a searchable list of activities that are easy to implement when getting started with new content and new audiences, which addresses the need for a centralized hub of resources. Second, we need to support skill development which focuses on storytelling while considering logistical programmatic factors, which address the skill development needs they expressed. There is a one-to-one correspondence between these resources and Kyle's competence needs. Providing this specific training for individuals who identify with Kyle's persona can support their continued engagement in informal physics.

B. Rory, the sparking interest and understanding facilitator

Rory, the sparking interest and understanding facilitator, engages in informal physics because they enjoy conveying their excitement about science to others and seeing the "light bulb" moments when participants understand a new physics concept. This motivation, grounded in relatedness, is driven by their desire to connect scientists and the public to form better relations and understanding of the scientific process. A representative quote of Rory's goal is

> *I love when students figure something out and they get super excited and start explaining it to all their friends. So the possibility that when I am doing one of these events that I could inspire someone to go to work in the sciences, to possibly work in physics areas that I am really passionate about. As a by-product, my work in outreach and engagement is also about getting the audience to appreciate science so the scientific process has become much more of what I try to teach.*

As a result of sharing their excitement with their audience, Rory is not only hoping some participants may consider a STEM career path but also appreciate the scientific process. Rory develops their skill as a facilitator through trial and error practice.

Rory's needs are centered on relatedness and connecting with the community, particularly being supported and engaged with a community of practitioners. They see two big gaps between groups of physicists around informal physics education, and they think it is important to bridge these gaps personally. The first gap is between physicists (e.g., faculty) who engage in informal physics and physicists who do not. The second gap is between full-time informal physics professionals (e.g., full-time science communication professionals) and physicists who engage in informal physics part time (e.g., physics faculty). To bridge both of these gaps, Rory wants help to expand their engagement with the broader physics community towards a larger goal of elevating the perceived value of public engagement among physicists.

An example of Rory would be a science communicator professional who works closely with the public engagement units in national or international labs. Rory talks with the public during guided tours of the lab and plans demos for specific events for students at the lab. They also engage with the public on news outlets and radio shows about physics discoveries, history, or the latest newsworthy research developments. Rory might have a personal podcast or other social media that centers on science topics or they might contribute to one as part of their job.

Based on the Rory's persona, we identified two community-building approaches to support their needs (see Table II). First, we need to create opportunities and spaces for various members of the informal physics community to interact with each other and support each other. Second, we need to design avenues for networking and building partnerships and collaborations among practitioners and researchers. These approaches would address Rory's relatedness needs since previous research shows that creating spaces for professional development community around shared interest can help participants support each other and sustain their professional development growth [38,39].

C. Tracy, the representation matters facilitator

Tracy, the representation matters facilitator, engages in informal physics because of their identity connection with the audience. This motivation, grounded in relatedness, is driven by the value they see in inspiring diverse people to pursue STEM career paths. A representative quote of Tracy's goal is

> *I'm trying to get more girls, women, and people of color into physics.*

Tracy discusses their informal physics efforts with other practitioners but is frustrated by the pushback they receive from the physics community, which does not always see public engagement as an integral part of a physicist's job. To support their work in this space, they need resources to foster their autonomy:

- Funding to allow them to recruit and retain more individuals in informal physics programs as both participants and facilitators; and to expand assessment of programs and informal physics events;
- More buy-in from institutions on the value of their informal physics work, which would foster their sense of agency in what they can do in this space;
- Logistical and managerial support for their public engagement activities. They need more infrastructure to be built in order to foster their sense of autonomy. This will allow them to dedicate their time and effort to the content and design of the engagement activities.

Tracy's motivation and needs are congruent with findings from the literature, which has shown the critical role that recognition and relational resources play in linking programmatic efforts to support students from underrepresented groups and physics identity development [40]. Specifically, Hyater-Adams *et al.*'s work demonstrates how positive relationships in informal physics events can increase one's identification with the practice of physics.

An example of Tracy would be a physics faculty who engages with the general public during public talks about their science. They might work with K-12 schools to provide information and illustrate how some physics concepts work through a series of demonstrations. Alternatively, Tracy might participate in events with youth organizations around science topics (e.g., STEM badges for Girl Scouts).

Based on the Tracy persona, we identified two resources to support them in advocating for their work in this space (see Table II). First, we need to design space for discussions to occur to get the physics professional community to recognize and elevate the value of informal physics activities. Second, we need to design opportunities to share the benefits of public engagement and advocate for funding for informal physics programs. Building systems of recognition and rewards for facilitators of informal physics aligns with the literature discussing the many critical layers needed to support informal physics facilitators, including funding and institutional support [13,41]. These resources would not only directly address Tracy's key needs, they would support Tracy's continued motivation to facilitate informal physics activities to inspire diverse people to engage in physics.

VII. DISCUSSION

The focus of this study was to better understand facilitators' motivations and professional needs in informal physics. From our dataset, we generated three personas: the physicist who engages in informal physics for self-reflection, the physicist who wants to spark interest and understanding of physics, and the physicist who wants to provide diverse role models to younger students and inspire them to pursue a STEM career. Using personas highlighted features of physicists' needs, we may not have captured otherwise or may not have centered on developing materials. For example, we might have thought that materials should be aimed at different career stages for physicists: materials for graduate students, for faculty, for full-time science communicators, etc. However, in constructing these personas, we noticed that career stage and motivation are not in a one-to-one correspondence. There were multiple career stages represented in each persona, and the needs of facilitators mapped better to their motivations than their career stages. Foregrounding facilitators' motivations allows us to design materials that are better at meeting the needs of diverse informal physics educators. Personas, as a research methodology, coupled to SDT, as a theoretical framework, allowed us to take this user-centered approach.

A. Implications

Our findings underline an important feature of public engagement, which is that the facilitation of public engagement is driven by intrinsic motivation. This theme that previous research had articulated as a significant contributor to participation in informal physics programs [7] emerged in our personas as well. It is important to highlight this self-driven underlying motivation. Participation in any capacity in informal physics is often voluntary and internally motivated. Prior IPER work has highlighted this characteristic of informal physics about freedom to explore and engage with physics. Our personas showcase participants' intrinsic fulfillment in connecting with one's journey and with others when engaging in informal physics. This finding also ties in with previous research that showcases how the facilitation of informal physics fosters physics identity development [10] and emphasizes how critical informal physics can be in developing a belonging in physics. These important motivational aspects of engaging in informal physics emerge directly from our analysis and persona development. This implies that some physicists view public engagement as an intrinsic part of their role as physicists. As such, it is valuable for organizations and departments to support informal physics engagement and the professional development of physicists in this space.

By developing this set of personas, we expand on the informal physics community's understanding of the needs of practitioners in this space and contribute to filling the gap in the informal physics literature as well as science education literature. By investigating the experiences of physicists who facilitate these types of activities, we have a better understanding of the subtle nuances of their experiences and the type of programmatic efforts and resources that could potentially support their growth. In particular, the development of these three personas informs the design of resources listed in the third column of Table II, which includes skill development, resource development, community building, and advocacy for the value of informal physics. These resources in Table II can support the enhancement of programmatic efforts in organizations and physics departments. As such, our research results contribute to professional development in informal education and support research-practice partnerships.

As an example, the creation of personas and associated resource needs informed the first set of initiatives the APS JNIPER program launched in Fall 2022, which includes monthly coffee hours and a JNIPER slack channel where members share resources. The coffee hours address Rory's need around community building, specifically the need to connect several types of professionals in the informal physics space. The coffee hours also address Tracy's need to have discussion spaces to advocate for the needs of informal physics facilitators' autonomy. Furthermore, the active online community is a first step in addressing Kyle's need to have a resource hub on how to get started and share best practices and materials. As expected with personas methodology, a few activities can serve multiple user-types, even if the reason why the activity is helpful differs between each user. This gathering of data on members' needs not only informed the development of resources for JNIPER but also the development of a survey of APS members' involvement, interests, challenges, and perceived value regarding public engagement in physics [42]. Hence, bringing this methodological approach to professional development in informal education enriches the development of user-centric resources to support informal physics facilitators.

Furthermore, departments, organizations, and institutions could use our findings as a starting point to consider ways to better support physicists in their respective environments. For example, physics departments can use our findings to encourage undergraduate and graduate students to participate in informal activities. This would help build mechanisms for community building, which can increase student well-being, retention, and sense of belonging. In parallel, our findings can support other facilitators in informal physics programs in physics departments because our personas could help them better articulate their needs and identify mechanisms to address them. The literature has emphasized the need to articulate physicists' motivations for doing public engagement to better tailor professional development resources to their goals [19]. While this research study provided a baseline for programmatic design for an APS Public Engagement program, the population interviewed represents many types of physicists who engage in public engagement. We interviewed a range of folks involved in APS Public Engagement, and snowball sampling ensured we reached beyond our immediate network. Thus, motivations and needs identified are representatives of individuals who engage in a variety of informal physics activities. Therefore, various physicists can draw upon our personas as a baseline to consider ways to better support physicists' professional development in their respective environments.

B. Limitations

Although APS membership is a representative sample of physicists, active members within the APS Public Engagement unit do not capture all physicists who may engage in informal physics. Future studies should consider surveying a broader scope of physicists to capture all reasons physicists may engage with the public and the type of support they need. Getting a better understanding of what are the different motivations of all physicists when they engage with informal physics can help align the training and resources of facilitators with the diversity of potential objectives physicists may have. The survey of APS members' involvement, interests, challenges, and perceived value regarding public engagement in physics [42] is a first step in that direction.

An additional limitation is that we designed our study to focus on facilitators' experiences and resource needs due to the minimal research on informal physics facilitators. However, at its core, public engagement is a two-way interaction that requires professional development resources that support both parties. As the science education literature identifies, it is important to align training for facilitators with a diversity of audience goals that may bring them to participate in public engagement activities [43]. Consequently, in the future, we should consider how facilitators' professional development resources interact with the motivations and resource needs of participants in informal physics. This holistic approach could allow us to form professional development opportunities that are culturally responsive and inclusive of all stakeholders in the informal physics space.

VIII. CONCLUSION

Physicists engage with the public to varying degrees at different stages of their careers, but their public engagement covers many activities, events, and audiences, making their motivations and professional development needs not well understood. As part of ongoing efforts to build and support a community in the informal physics space, this paper discussed the findings from our interviews with physics practitioners and researchers with a range of different experiences in informal education. These findings fill a gap in both the physics and science education literature by providing an understanding of the nuanced motivations of physicists who do public engagement. We broadened our understanding of motivations and needs of physicists engaged in science education outside the formal classroom. Our personas approach enabled us to determine the existing interest and professional development needs of practitioners and researchers in this space. In addition, the development of the three personas brings user-centered design to informal physics professional development research, which enables the design of useful and targeted resources for physicists.

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