Other spaces for young women's identity work in physics: Resources accessed through university-adjacent informal physics learning contexts in Sweden

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For young women, inbound identity trajectories into physics are generally regarded as exceptional. In this study, we investigated the experiences that young women have which may support their sustained interest and achievement in physics, and their ongoing inbound trajectories into post-secondary physics education. To understand these experiences, we look to the role of informal physics learning (IPL) environments as spaces which can offer resources that support women's trajectories into physics. In this paper, we highlight the important role of what we call "university-adjacent" IPL experiences—internships, summer schools, and associations that connect secondary students with the research lives of physicists. Focusing on case studies of six women enrolled in post-secondary physics programs across Sweden, we identify the various forms of resources made available through IPL environments, and how these create possibilities for young women to engage in forms of identity work that contribute to the construction of new possible selves in physics. Findings suggest that young women can access important relational and ideational resources through university-adjacent IPL programs. Relational resources included (a) supportive social networks, (b) enduring relationships, and (c) relatability. Importantly, our research finds that IPL opportunities that emphasize relationship building can create immersive experiences which go beyond representation and rather emphasize opportunities to develop *practice-linked identities.* Ideational resources emerged as (a) sources of information which possibilized physics for participants, and (b) types of information that provided possibilities to learn about the life of a physicist. Finally, while we claim that IPL experiences provide important possibilities for young women to immerse themselves in the practices of physics, we also discuss that these kinds of experiences remain inaccessible to most students, and thus reproduce a certain elitism in the field.

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I. INTRODUCTION

In this work, we are interested in characterizing experiences that facilitate young women's identity trajectories into physics, and the exceptional experiences that many students seek out to maintain their inbound trajectories to physics. Our focus on identity trajectories responds to a call by Traxler and colleagues [1] to orient gender research in physics education away from questions that investigate the learning experiences of women in comparison to men as a normative standard. They, along with others [2,3], argue that until recently research into the participation of women and other minoritized groups in physics has often taken the form of "gap gazing," identifying performance gaps between men and women. Thus, over the past decade, physics education research has experienced an identity turn to understand the participation of minoritized groups like women and racialized students in the field [3–7]. The identity turn in physics education research has helped researchers to understand with nuance not only why physics can engage in "pedagogic work" that keeps women and girls out [8] but also the cultural practices of the discipline that reproduce masculinity and keep dominant groups in [9,10]. This paper explores some of the spaces that help young women to push back against this pedagogic work of physics, and to engage in the ongoing work of becoming an insider to physics.

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Identity work in physics is cultivated early on in educational trajectories. However, for students from backgrounds that are usually minoritized in physics—especially white and racialized women and students from working class backgrounds—inbound identity trajectories into physics are regarded as exceptional [11]. Research investigating school experiences suggests that children's positive attitudes toward science by age 10 will significantly decline by age 14 [12]. For girls, positive physics attitudes and identities continue to decline as they move through secondary school, and that at the time of secondary school girls will decide whether or not physics is "for them" [8,13]. Studies suggest that girls lose interest in formal science classes throughout secondary schooling [14]. This is critical as interest is thought to be an important identity-determining factor [4,15], but interest often wanes for girls in secondary school [4]. Thus, we investigated what opportunities young women have to possibilize identity trajectories into physics to counterbalance this waning, and how these trajectories can be supported by exceptional experiences, especially those found in informal learning contexts.

Recent research has focused on disciplinary contexts that influence *physics identities*, and the intersecting roles that gender, race, and class play in the development of these (e.g., Refs. [3,7,8,15]. Of note, Hazari and colleagues [15] argue for an interrogation into disciplinary identity construction, and the contexts that facilitate this. They ask, "what happens when the students are surrounded by others with similar science intentions and who have less diverse intentions?" (p. 1589). In this case, Hazari and colleagues argue that as students progress in their degree programs, they are increasingly surrounded by others who may share their interests and ambitions in ways that can impact their sense of belonging [15]. Importantly, they posit that students will have had many opportunities to share experiences with others (e.g., courses, lab work), and will be able to form identifiable communities through those shared experiences, but that a sense of belonging may be tenuous for minoritized students in a dominant culture. While much research into identity relies on the importance of recognition, drawing on the framework first posited by Carlone and Johnson [16], Hazari and colleagues [15] argue that sense of belonging is distinguishable from recognition "since individuals may feel recognized as a "physics person" (by educators, classmates, etc.) while still feeling like they do not fit in with peers and others in their disciplinary community, possibly because they hold other identities that are exceptional and unique from others in the community (e.g., gender, race, or ethnicity)." (p. 1589)

In the Swedish post-secondary context, where students commonly apply for a program in a given subject already for their first year at university, students will begin to share those experiences from day one, when they take a number of focused compulsory courses in math, physics, and computer science. Thus, the opportunities to develop a sense of belonging (or a sense of exclusion) as they engage with students in their program begins early in Sweden. The addition of "sense of belonging" to the construct of physics identity presents an opportunity to consider how students engage with physics communities in meaningful ways, and to conceptualize growth in identity as students experience more of a physics community. In Hazari and colleagues' study [15], sense of belonging entailed the perception of fitting in (or not feeling excluded from) the disciplinary community of physics, and appeared significant for senior physics students, who have had time to develop membership in their physics community. As students are streamed into physics programs by the time they reach university in Sweden, in this study we are interested in opportunities young women have had to develop this sense of belonging *before* they enter undergraduate physics programs. We regard this as a fruitful time to examine, as this is the moment when students are most likely exposed to the pedagogic work that physics does to discourage women and other minoritized people from the field [8]. Archer and colleagues describe pedagogic work as that involving socializing young people to "know their place" in the social order of physics, and to inculcate students to believe that their place in the social order is legitimate. This is relevant to Swedish secondary school physics contexts where social ideas about gender and competence are perpetuated in physics classroom discourse [17], and where ideas about natural talent and effortless achievement in physics are perpetuated in physics classrooms [18,19], and post-secondary programs [20]. Thus, to get a sense of what opportunities are available for young women to develop sense of belonging as part of their physics identities, we look outside of the classroom and to the role of learning in informal physics educational (IPL) contexts.

A. Literature review

1. Learning in informal physics education contexts

Informal science has been the focus of efforts to improve participation in science for several decades [21]. Early research identified informal science learning (ISL) experiences as impacting students' attitudes towards science and belief in their abilities to do science [22]. ISL is often accessed in out-of-school contexts, and is thought to facilitate sustained interest in science and to support identity trajectories into science [23–25]. The National Research Council in its report on ISL [23] describe these environments as constituting a broad array of settings including designed settings like museums and science centers [26]; or in contexts like summer programs and camps [27], and everyday settings like science encounters in the home, supported by caregivers engaging youth in science talk [28–30].

Falk and Dierking [30] argue that ISL settings can create entry points for youth who have not previously been engaged by science in school. They argue further that participation in ISL programs can have more positive

impacts on science trajectories than school science, because long-term participation in ISL activities may expose young people to more science than they have the opportunity to learn in school [25,31]. This may be associated with long-term positive outcomes in science learning such as associating positive memories with science [32] and sustained interest in science [33]. Others have shown that participation in ISL programs can support students' science, technology, engineering, and mathematics (STEM) career interests [22,23]. Habig and colleagues [26] suggested that ISL programs can positively impact STEM career outcomes by offering meaningful opportunities for youth to be practitioners of science; building social networks with meaningful others [16]; opportunities to develop shared science identities with like minded others (other youth, but also facilitators and scientists); and exposure to STEM in ways that permit youth to discover possible selves.

Bell and colleagues [24] argued that outcomes of ISL experiences are complex and difficult to capture. Outcomes that concern us in this study are those focussed on opportunities for young people to "think about themselves as science learners, and develop an identity as someone who knows about, uses and sometimes contributes to science" [16, p. 46]. Rahm, for example, has argued that ISL experiences provide opportunities for youth to think of themselves as "insiders to science" (e.g., Refs. [34,35]). Other researchers have demonstrated that ISL can disrupt normative fields of science, resulting in youths' legitimate membership in a learning community, or, rightful presence [36]. Recent research also shows that ISL experiences can bolster and support the inbound identity trajectories of those already interested in science, by providing resources that lead to the accumulation of forms of science capital which have high use and exchange value in post-secondary contexts [37]. Research with university students acting as facilitators of "physics outreach" has also discussed how ISL experiences can have impacts for the students' identity work outside of the constraints that are usually found in academic physics settings [38]. This work examined how participating in an ISL community of practice allowed students to be recognized as members in the physics community in new ways, and expanding their participation beyond the normative practices of university physics [39]. Furthermore, research investigating women's involvement in facilitating informal physics programs found that they experienced increased opportunities for internal and external recognition, thus reinforcing their identities as physics people [40], and gave them an opportunity to "curate their own sense of expertise" (p. 363) which improved their confidence in choice of major. These are significant findings for this study, as we focus our attention primarily on informal settings that support physics identity work which we consider to be *university adjacent*. These are experiences that are offered either through universities, or in connection with universities (e.g., internships in laboratories, summer schools offered through universities, university lecture series, associations connecting scholars working in universities, and associations connecting university-bound students or university students with each other).

From an equity perspective, ISL programs have been shown to engage and have positive impacts for women and students historically marginalized from science. A seminal longitudinal study by Fadigan and Hammrich [24] retrospectively analyzed data from women participating in the Women in the Natural Science program, a year-long program designed to offer science enrichment to young women from single parent households, attending public schools. They reported that successful women in science attributed their long-term and career-oriented interest in STEM to participation in the WINS program. This study highlighted the importance of having STEM-related staff to talk to, approachable role models, and opportunities to learn about STEM-related careers and develop relevant skills in young women's trajectories into STEM fields. McCreedy and Dierking [32] argued that informal STEM programs can leave girls with memorable experiences that "cascade over time" by building on one another and connecting to other experiences both at the time of the program and in their futures. They argued that these cascading influences make long-term impacts on women's careers in STEM, their informal engagement in STEM practices, and their "ways of thinking about what science is and who does it" (p. 38).

These findings inspired us to consider the career-oriented but also identity and community-building gains that ISL opportunities provide for young women in physics contexts. For this paper, we focused specifically on informal learning experiences that young women access through environments that we consider to be university adjacent. These can be internships (in university labs), participation in physics associations, and summer schools (often offered through universities). We will refer to all these opportunities as informal physics learning programs, contexts or learning situations.

B. Theoretical framework

1. Physics identity

As we have investigated the impacts of IPL experiences on young women's identity work in physics, we have framed our research around the possibilities that participation in IPL environments can offer to develop their physics identities (e.g., Refs. [3,15]). Our approach to physics identity draws from research that focuses on understandings of the self, including self-report data, and narratives of actions and interactions with others within social contexts related to physics [4,16]. Thus, we draw on a model for identity that foregrounds the importance of stories of recognition alongside competence and performance as interrelated features that individuals narrate as part of their science identities [16]. This model was

expanded [4] to include interest as a salient feature of physics identity.

Our interviews with young women in physics were dominated by stories of experiences in IPL contexts which seemed to have a profound impact on their trajectories into studying physics at university. To understand what these programs offer to young women as they develop their identities as physics people, we draw on theories of learning in practice [41]. The students who embark on these IPL experiences are on inbound learning trajectories and as newcomers they are "joining the community with the prospect of becoming full participants in its practice" [29] (p. 154). However, opportunities to experience practices which can support full participation in physics are limited in secondary school contexts. Berge and colleagues suggest that common classroom practices limit the possibilities for participation in physics, as there physics is positioned as a subject that one might not be able to master [18]. Thus, full participation in physics, they argue, carries a "risk" that one might answer a question incorrectly, rendering the classroom a less safe place to learn. The epistemic practice of framing physics knowledge as right or wrong reinforces this view [42]. To unpack this phenomenon using the language of our framework: the risk inherent in common school physics practices is that one will not be *recognized* by peers or the teacher as a physics learner, which will threaten students' *sense of belonging* in the classroom. This characterization of Swedish physics classrooms further motivated us to investigate the role of IPL experiences which, unlike classroom environments, may offer opportunities for young women to learn and immerse themselves in practices that are critical to becoming physics people, and go beyond the learning of concepts or skills:

> *Because learning transforms who we are and what we can do, it is an experience of identity. It is not just an accumulation of skills and information, but a process of becoming—to become a certain person or, conversely, to avoid becoming a certain person [41]* (p. 215).

IPL environments provide students opportunities to learn the cultural practices of physics that carry with them the norms, expectations, and ideas that enable or constrain participation in these worlds [43]. This is of particular concern as we regard IPL opportunities as contexts in which young women can learn about the norms and cultural practices of physics *in situ*, which may provide possibilities to see themselves as doing physics in context. Following recent theoretical work by Hazari and colleagues [15], we also suggest that these opportunities can provide early possibilities to develop a sense of belonging [44] in ways that contribute to their physics identities. Hazari and colleagues argue that sense of belonging is influenced by the community that surrounds students. At university, "sense of belonging refers to students' perceived social support on campus, a feeling or sensation of connectedness, and the experience of mattering or feeling cared about, accepted, respected, valued by, and important to the campus community or others on campus such as faculty, staff, and peers." [44] (p. 4). But if young women and other minoritized students had opportunities to develop this sense of belonging to a broader physics community even before entering university, would it impact possibilities for them to see themselves as members of this community at a time when young women especially are generally thought to leave the "physics pipeline"? Hazari and colleagues [15] argue that early physics learning opportunities (particularly IPL experiences) contribute to physics interest in ways that are significant for physics identity development, but that opportunities to develop a sense of belonging come later when one develops "disciplinary community-based social elements of physics identity development (e.g., how one fits into a physics community and is recognized given other identity expressions)" (p. 1601). Importantly, Hazari and colleagues argue that being seen as "normative" rather than "exceptional" is important.

This is the focal point for our study, as we consider the possibilities that opportunities to engage in IPL communities can develop one's physics identity in ways that contribute to one's sense of belonging. In Swedish physics classrooms, learning physics is dominated by practices focused on gains in conceptual knowledge, dealing with physics as empirical enquiry, and preparing for exams [18]. At the same time, nonconceptual gains like "mastering" physics and having a "feel for" physics render participation in classroom physics risky, as the inverse (not mastering physics, or not having a feel for it) may position students incompetently. Conversely, IPL spaces may provide opportunities to develop "practice-linked identities" [45] which are unavailable to secondary aged youth through physics engagement in regular secondary school classrooms [25]. Nasir and Hand argue that practice-linked identities are "the identities that people come to take on, construct, and embrace that are linked to participation in particular social and cultural practices" [45] (p. 146).

2. Resources and practice-linked identities

To understand how practice-linked identities are made available to young women in IPL contexts, we drew on the concept of *resources* [46,47]. We regard resources as unequally distributed, and their availability is often under the control of institutions and social norms. Access to resources comes from experiences and opportunities, and the accumulation of these can lead to various forms of capital that individuals accrue along their identity trajectories [37]. To characterize the forms of resources that participants accessed in IPL settings, we constructed our analytic framework following the work of Nasir and Cooks [46] who describe practice-linked resources that actors use as they construct practice-linked identities. They argue that access to resources and the use of resources can support

inquiry into how the social world makes identities available to individuals in learning settings.

Nasir [48] distinguishes three kinds of resources located in social learning environments: material, relational, and ideational. In this case, material resources are the artifacts that one learns to master as a part of physics. This could be access to instruments or virtual worlds that connect one to the practice of physics in material ways. These can also be spaces in which physics is practiced and experienced. Relational resources are the social networks and encounters with meaningful others [16] that may represent attainable role models, or sources of recognition. Relational resources can facilitate a sense of belonging in the community of practice as newcomers interact, socialize, and find support from meaningful others. Finally, ideational resources offer possibilities for students to develop shared identities with other students but also with mentors and meaningful others. Nasir and Cooks suggest ideational resources are "ideas about oneself and one's relationship to and place in the practice and the world, as well as ideas about what is valued and what is good" [46] (p. 46). Thus, these resources are accessed through practice and opportunities to experience physics in ways that support possibilities to actually see oneself doing and being in physics. Access to these resources may be restricted in classroom contexts where interactions with the physics community is limited to peers and a teacher, and when authentic practice is limited to laboratory exercises.

Hyater-Adams and colleagues [49] mobilized Nasir's [48] concept of resources in their "critical physics identity" framework which interrogates the interactions of six dimensions of physics identity and racialized identity: recognition, performance or competence, interest, material resources, ideational resources, and relational resources. The authors proposed that Nasir's framework provides possibilities to consider racialized identities alongside physics identities which can allow researchers to tease apart common experiences that racialized physicists narrate, and the impacts that aspects of systems within physics culture have on these experiences. Rather than comparing the relative resources of individuals (and the attendant systemic and structural factors that contribute to the experiences of women in physics), we investigated the availability of resources in experiences outside of formal schooling, which are often only accessed by students who already have considerable privilege [50]. We acknowledge that Nasir's framework was intended to center racialized identities in the context of the U.S., and that we are using this framing in an entirely different context. However, we have found this framework helpful to unpick the resources and practices that construct insiderness to physics in a context where there is still a considerable gender disparity in physics. Thus, when considering the physics experiences of women in Sweden, it is helpful to consider the resources that enable identity work and how these operate in a context where the broader discourses around gender signal that equity prevails.

The framework described here permitted us to investigate the kinds of resources made available through IPL experiences, and the impacts these have on participants' identity work. The research questions we are interested in exploring via this framework are

How do young women describe the kinds of resources they have accessed through university-adjacent IPL experiences?
How do the resources accessed through IPL contexts contribute to young women's practice-linked identities as physics people?

We describe the operationalization of our framework further in the analysis portion of the Methodology section.

II. METHODOLOGY

A. Context and methods

Despite being highly ranked on the Global gender gap rankings by the World Economic Forum (4th in 2017), Sweden still has a highly uneven recruitment in terms of gender to higher education in the physical sciences [20]. Swedish higher education is also still very much divided by social class, despite many structural obstacles (such as tuition fees) not being in place [51]. In Sweden, university physics programs are characterized by a narrow student demographic: 24% women among the beginner students 2017 (UHR—Antagningsstatistik); Master of Engineering[1] programs: 16% students with "foreign background" (i.e., born outside of Sweden or two parents born outside of Sweden), 20% students with parents without higher education [52].

This study used a collective case study approach [53] to understand the resources young women encounter and draw on as they engage in IPL contexts. We treated each participant as a case during data collection and analysis, and then considered all the cases collectively as we established themes related to resources. Thus, we regard the collection of narratives of university-adjacent IPL (U-A IPL) experiences as the unit of analysis for our collective case in this study, rather than the individual participants. Data were collected using an interview approach inspired by life history interviews [54] to explore what has allowed individual participants to "go against the grain." Interviews were conducted by the second and third authors, on the university campuses, and occasionally via an online platform when pandemic conditions did not permit in-person meetings.

[1]These statistics are for all Master of Engineering programs which include Engineering Physics, a program that is considered a "physics" program of study and in which a proportion of total physics students would be enrolled.

TABLE I. Participant profiles.

Name	Background	Parent occupations (M-mother; F-father)	IPL experience [pseudonym in square brackets]	Resources accessed from IPL experiences
Sigrid	Swedish, 2nd gen university student	F-Engineer	Internship at [large European physics institute]	Relational resource (enduring relationships)
		M-Engineer	Cofounder of ["Science Girls"]	Relational resource (supportive social networks)
Hanna	Transnational (Global South), 1st gen university student	F-Various unskilled work	Internship at [large European physics institute]	Relational resource (enduring relationships)
		M-Cleaner	Summer research school at [Canadian Physics Institute]	Ideational resource (possibilizing physics)
			Summer research school in Sweden	Ideational resource (possibilizing physics)
Rebecka	Transnational (European country), 1st gen university student	F-Musician	Several physics internships at different Swedish universities	Relational resource (enduring relationships)
		M-Child minder		Ideational resource (learning about the life of a physicist)
Lydia	Swedish, 3rd gen university student	F-Engineer M-Nurse	[Swedish University] physics conference	Ideational resource (possibilizing physics)
Stella	Swedish, 3rd gen university student	F-Engineer	[Astronomy] summer school	Ideational (possibilizing physics)
		M-Social worker	[Astronomy] youth camps	Ideational (possibilizing physics)
			Visits to [large European physics institute]	Ideational (possibilizing physics)
Alva	Swedish, 3rd gen university student	F-Engineer M-Secondary teacher	Tech girls event with female engineers	Ideational (possibilizing physics)

In total 21 students participating in university physics education programs were interviewed. Participants were recruited from Bachelor of Physics programs and Engineering Physics programs at several different Swedish universities, with convenience sampling to ensure that participants represented (one or more of) the underrepresented social categories in university physics education: women, students from nonacademic backgrounds, and/or students with migration background. Fifteen of the interviewed students were in the first year of their studies, the other six in their second year. The data reported on in this paper focus on six young women who articulated IPL experiences in physics as contributing to their inbound experiences. Four of these participants were 2nd or 3rd generation university students, whose Swedish parents both attended universities in Sweden. The occupations of their parents are described in Table I (pseudonyms are used for all participants and names of internship locations are anonymized for confidentiality). Two of these participants were first generation university students who also came from families with migration backgrounds. One of the participants, Rebecka, has parents who migrated to Sweden from another European country. Another participant, Hanna, moved to Sweden with her family from a country in the Global South. Sigrid had Swedish parents who attended university, and Lydia, Stella, and Alva described having Swedish parents and grandparents with university degrees.

Interviews with participants were conducted using Adriensen's timeline interviewing method [55]. Participants were asked to construct a timeline with paper, sticky notes, and markers indicating important physics-related events across their educational trajectories. The timeline interviews allowed participants to select moments in their educational trajectories that they felt were important to highlight. In timeline interviewing, the interviewee can define the course of the interview and has agency over how the timeline is constructed and discussed. When introduced to the participant, the interviewer indicates that the timeline is meant to help interviewees think about important events, moments when they made one choice over another, and important people alongside important events. In these interviews, participants were asked "if you were to tell the story of how you ended up here, where would you begin?". In that way, they define the moment that begins their trajectory into physics, and the course that trajectory takes. Notes are written on the timeline either by the interviewee or the interviewer, but they are available to both, and not hidden from the interviewee. In this sense, the interview is truly a co-construction [56] wherein the interviewee can take ownership of the process and the way

in which their life story is told. The timeline interview has benefits for the research questions asked here, as it highlights particular important events, that we were then able to spot easily in the analysis and collate. Interviewers took care to ensure that participants elaborated on incidents that revealed their identification in terms of a range of social categories, e.g., gender, age, social class, ethnicity, and (dis)ability. The interviews also focused on participants' identification with and aspiration in science and aim to elicit their experiences of informal and formal science education practices (as teaching approaches have been found to be associated with students' science aspirations, cf. Refs. [57,58]). Participants were asked questions about their experiences at home with their families, their experiences in school physics, their teachers and classmates, and whether they consumed media that was related to physics. They were also asked to describe moments on their timeline where they felt physics was more or less "for me," which is what prompted descriptions of IPL experiences. Generally, formal learning experiences were found to be less pronounced in participants' narratives than their experiences in informal learning contexts. All the IPL experiences described by the six women in this study emerged organically in their talk about important experiences on their timeline. They were not asked about these experiences directly, as not all participants engaged in such events. Thus, our analysis focused on the importance that participants placed on IPL experiences, and what kinds of resources they accessed via these opportunities. The interviews were conducted in Swedish, and interview transcripts translated to English.

B. Analysis

Interviews ranged from 60 to 120 min each and were transcribed verbatim resulting in approximately 30–60 pages of transcript per participant. Coding of the transcripts were iterative and done with all four members of the research team. The first author coded interview data in English, and the remaining co-authors provided nuance to transcript excerpts in Swedish. Participant data were chunked into background information, and profiles were produced for each participant that detailed demographic data and family histories, important life experiences (e.g., immigration, relationships with parents or siblings, national or transnational movement), in-school and out-of-school episodes of importance, and descriptions of physics experiences and encounters with meaningful others. Background summaries were read by all of the research team, and initial areas of focus (e.g., IPL learning experiences, school choice, affective experiences) emerging from these were discussed in several meetings. The first round of coding entailed open coding [59], and we focused on *in vivo* codes to preserve participants' words. These were sorted thematically [60] to identify aspects of IPL-related experiences and discussed among research team members. We then returned to the coded data with a more theoretically focused round of coding that characterized the IPL experiences in terms of resources. We sorted our coded data into categories using Nasir and Cooks' [46] constructs of material, ideational, and relational resources. This yielded two strong themes of relational and ideational resources but did not yield a theme of material resources. We then characterized various experiences as opportunities to access relational and ideational resources. For example, as Nasir and Cooks [46] described relational resources as interpersonal connections to members in a setting, we thus looked for various opportunities that the IPL setting provided for networking, relationship building with mentors, or supportive relationships with peers. As Nasir and Cooks describe ideational resources as ideas about the self in relation to the practice, we thus looked for opportunities that IPL practices had to possibilize physics as a career, or to learn more about what it might be like to be a physicist in ways not usually accessed through formal learning environments. We then considered whether these contributed to participants' sense of belonging in the discipline or whether these offered opportunities for recognition in ways that contributed to their practice-linked identities [46]. This round of deductive coding then yielded three subthemes under relational resources (supportive networks; enduring relationships; and relatability), and two subthemes under ideational resources (possibilizing physics; and imagining one's life as a physicist). In what follows, we describe in detail the two forms of resources, drawing from participants' stories and interview excepts. At times, we summarize and paraphrase participants' words and experiences, to detail the various forms of resources we wish to depict here. We focus on how the resources provide possibilities for identity work as insiders to physics in our description, and thus try to focus on what benefits the participants derive from access to these resources.

III. RESULTS

Our analysis suggests that IPL programs make available resources that support participants' identities as "insiders" to physics. Nasir [48] argues that individuals use resources as they construct identities in social settings, and that these resources are not properties of individuals, but are located in the environment. As we have stories from physics students which describe several learning environments, we suggest that identity work in physics happens not only in high school or university classrooms, but importantly, in out-of-classroom learning experiences. We argue from the stories we have collected that especially U-A IPL experiences offer richer and more varied resources for identity work than what students access in classrooms alone. We begin by describing the relational resources participants encountered and accrued through their participation in summer schools, internships, and associations. We then describe ideational resources accessed through these same opportunities. Throughout our descriptions of

the kinds of resources participants have accessed through their IPL experiences, we ensure to discuss the kinds of identity work these resources afford. We describe these as opportunities to see themselves as insiders to physics, possibilities that these give for a sense of belonging, and moments of recognition that are important to their on-going identity trajectories. In this way, we see resources as constantly contributing to the identity work participants are describing along their timelines.

A. Relational resources

Depending on the nature of the IPL program they engage in, relational resources may take on different forms. Here we describe three important forms of relational resources: supportive social networks, enduring relationships, and relatability.

1. Supportive social networks

Some participants reported that participating in associations related to equity-deserving groups in physics was important to their persistence in the field, or to youth associations in which they could interact with other science-oriented youth in informal learning settings. Here we provide an example from Sigrid's dataset. Sigrid described considerable participation in one of these groups, which she herself co-founded while she was in secondary school, and that she continues to participate in today. Her descriptions of participating in the *Science Girls* (pseudonym) virtual association likens it to a counterspace [61,62] to support identity work in physics. Counterspaces are known to be social safe spaces that allow underrepresented students to validate their own experiences, share stories of isolation or microaggressions, and promote their own learning [61]. Counterspaces in peer-to-peer relationships are thought to inspire persistence (by allowing one to see others' successes) but also to support a sense of belonging by connecting to others who are similar to oneself in ways that young women do not often find in the field. Thus, we regard this form of networking as a relational resource that can support identity work in physics by providing support to promote a sense of belonging.

One way that participation in this association supported Sigrid's identity work was by supporting her confidence in physics, and her feelings of membership in the community. She suggests that: "*I notice that the more I keep on with that association, I notice that I gain more confidence in myself and in my interest, and I think it's fun. I feel so much better in that community.*" Sigrid described dealing with imposter syndrome in her university experience, especially in physics classes where she was a minority among a group of men. She described struggling to raise her hand in class, and even though her grades are high and she demonstrates competence in most measurable ways, she doubts her abilities in physics. Starting a *Science Girls* association, gave her an opportunity to access a virtual support network which she feels membership in: "*I have never felt that I do not fit in, or that I have nothing important to say, or that I can not participate in a discussion when it comes to [Science Girls'] chat server, or in that community at all. It feels like my opinion is very valid, and that I have enough knowledge to be able to talk about this.*" This suggests that interactions which provide validation can act as resources for recognition as emergent physicists in ways that Sigrid, for example, did not experience in her university physics experiences. This can counter the usual, individualistic, and competitive experiences students often have in physics classes and can promote a form of resilience in these contexts.

2. Enduring relationships

Several participants described opportunities to connect with physicists in ways that yielded lasting impressions and often enduring connections. These kinds of resources were typically accessed during internship opportunities which brought participants in close contact with meaningful physicists in their field of interest. Nasir and Hand [45] suggest identity entails viewing participation in a practice as an integral part of who one is, thus practice-linked identities. Nasir and Cooks [46] suggest that relational resources that contribute to practice-linked identities are specifically interpersonal and accumulate over time. The first kind of relational resource we discuss here is accessed by participants via repeated interactions with meaningful physics people (who are not their teachers) and endure over time. Participants in this study described connections with mentors or new friends in physics research contexts that strengthened their sense of connection to the practice of physics. For example, Rebecka describes the relationships she built with Ph.D. students in a lab internship helped her develop a sense of the social practices of physicists:

> *Everyone is so involved in their projects, and people ask about other people's projects, and that's what I thought was fun. And then you have your own thing, and then you sit and work on one thing, and immerse yourself in it. I think so… I like that way of working.*

Rebecka described her relationship with Ph.D. students as enduring as she spent time in an internship in the lab with them, and now they are teaching assistants in her courses at the university. Similarly, Sigrid discussed meeting with researchers during a laboratory internship who she has maintained contact with beyond the internship opportunity. Her description of the laboratory environment also presented a view of laboratory life beyond experiments and the lab itself:

> *It's the coziest environment I've ever been in. It's a bit, I think, like the academy, kind of a feeling. But it was really, really, wonderful. Everyone was so nerdy, so nice. It felt like what country you came from does not*

matter, politics … Everyone was just interested in science and was so nice and fun. So, I always smile when I think about it because it was such a wonderful atmosphere.

This description counters isolating classroom experiences Sigrid described in which she often feels nervous to even raise her hand. It also suggests that the relational resources she encountered in her laboratory internship may work to refigure her previous physics experiences and contribute to her practice-linked identity as a physics student.

Hanna also described encountering meaningful relationships via an astronomy association. In this encounter, meaningful and enduring relationships were built via discussions with physicists, students, and technicians who came together at unofficial events which promoted astronomy. She described "*click[ing] very well with these guys*" although they tended to be older than she was, some even retired. Hanna regarded these events as community building, and an opportunity for her to gain a sense of belonging in informal ways with meaningful others in physics. We suggest that these informal and often unplanned encounters with meaningful others in physics can contribute to practice-linked physics identities in unexpected ways. They permit opportunities for students to observe the life of physicists outside of the lab (often a surprising finding for students) which also offer students a sense of belonging to the physics community.

3. Relatability

Finally, participants reported that opportunities to encounter physicists in extra-classroom or laboratory settings could offer the possibilities to see themselves in the field. Sigrid, for example, discussed how prominent women in physics like Marie Curie are often heralded as role models for young girls, but they lack relatability:

When you talk about, like this, women scientists, or whatever it is, you think like this, Marie Curie, but I do not see myself as Marie Curie. I do not know anyone who thinks they are as exceptional as Nobel laureates it is not so… I could not compare myself with it.

Rather, Sigrid referred to a woman she met during her internship, and suggested that her down-to-earth character acted as a resource for Sigrid to imagine herself as a physics student:

But [Ph.D. student], she had danced, as I did, and she was… she was joking and she was an ordinary person. And that doesn't downgrade her in any way. She did such cool stuff in physics, but she was so ordinary. And I felt "okay, if she can, then I should be able to. This feels very achievable."

These interactions were important to Sigrid, who struggled to find the confidence of insiderness in many formal physics learning contexts, and who often lacked relatable role models in these contexts. These experiences and learning about the importance of a relatable social network for insider identity work in physics, played a role in prompting Sigrid to form the *Science Girls* network described earlier.

B. Ideational resources

Ideational resources in out-of-classroom physics learning contexts were often made available through social interactions, but also occasionally became available through attending physics events. Ideational resources emerged as sources of information which possibilized physics for participants. They also emerged as a certain type of information: imagining one's life as a physicist. Whereas relational resources exposed participants to people in the field, and gave them opportunities to build meaningful relationships, ideational resources emerged as opportunities to "try out" physics identities, and to imagine oneself being in that career. Nasir and Cooks [46] suggested that ideational resources can help actors develop a sense of themselves as a certain kind of person. Sometimes these resources do the work of positioning an actor as an insider, and other times they simply provide opportunities to see what insiderness looks like.

1. Possibilizing physics

Programs as sources of information which possibilized physics were the simplest of these ideational resources, where participants described encounters with physicists or other physics students as opportunities to learn about the field, and to figure the field into their own career trajectories. For instance, Hanna describes the role of the summer schools in her academic trajectory, stating: "*what definitely helped me choose physics were these summer research schools.*" Hanna is a participant with a background of transnational migration, having moved to Sweden via a country in the Global South. She has as strong desire to connect back to her home country in her career and only became aware that she might be able to do this through physics by attending a summer school at a prominent research institute. Their outreach programs were influential to her thinking about connecting research back to her home country, and she has already contacted her embassy to start planning a summer research school in physics there. Participating in an institute helped her clarify what she wants to do with physics: "*I do not just want to do just one thing. It feels like people either promote physics learning as a science communicator in some way, or they do science themselves. And I do not want to do one or the other, I want to do both."* Others, like Sigrid, used internship opportunities to connect with other physicists and ask questions about career options: "*Everyone I met, I asked 'what should I choose?' And the majority said it does not matter what I*

choose." An internship opportunity helped her clarify that she wanted "*to stay in the academy.*"

We highlight these examples to suggest that deciding what one wants to do with physics can be an opaque process, and opportunities to immerse oneself in the work of research or outreach, can crystallize for students what they enjoy about the subject, and can contextualize that in the actual day to day work of physicists. For example, Lydia described a conference she attended while still in high school, and how that one experience gave her a sharper understanding of what doing physics might entail. She suggests that she started thinking about a career in physics through her exposure to it on YouTube videos about quantum physics or TED talks "*and then I started to feel that yes, but this was actually really, really fascinating. But then it still felt very far away that I would study it or even work with it, I would say.*" But attending the conference and hearing actual physicists talk about building a quantum computer or other practices made physics "*suddenly [feel] much closer, because they had just happened to stumble onto that path, and then they happened to get a Ph.D. in something and then now they are researching it and… yes, it felt like anything can happen*." For Hanna, the opportunity to work in a research context possibilized physics for her. She described her experience as making a career in physics more "*obvious*" to her. Working in a summer research school context helped her to see "*that it can be done, that it is a possibility,*" but also the actual work she did, and the presentation of that work to physics colleagues gave her a sense of accomplishment: "*so you have done something yourself and you show what you have accomplished during this time*."

A final example of how physics is possibilized through U-A IPL experiences, is the confidence that participants derive from participating in IPL, which supports their sense of belonging in the field. Stella describes numerous experiences of site visits to universities, membership in astronomy associations, and participation in physics summer schools while she was still a secondary school student. She particularly relates the significance of being a girl attending astronomy summer camps, and how that positioned her as an exceptional student. She says "*when applying, you have … it's important that I'm girl*". It should be noted that Stella's participation in physics associations, internships and camps is extensive, and she comes by these through her father, who is an aerospace engineer. This is significant because her participation is supported by these connections, but she also describes visiting her father's colleagues and being recognized by them and subsequently welcomed into their workspaces, which supports her own feelings of insiderness. Stella's experiences with IPL activities are so extensive, she does not speak of any other formative experiences in her life leading up to her post-secondary education. Almost all her involvement in IPL contexts was facilitated in some way by her father, or by the capital she gained from attending previous summer schools, or internships. These experiences possibilize physics for Stella in an ideational way and have led to numerous opportunities to further career possibilities in physics for her, including a research publication at a very young age.

2. Imagining one's life as a physicist

As Nasir and Cooks [46] argued, relational resources can operate as gateways to ideational resources. We found this to be the case in participant narratives about relationships that gave insight into what it was like to be a physicist, both in practice, but also how female physicists were viewed by society. Ideational resources also emerged as opportunities for participants to envision themselves engaged in the practices of physics and to imagine themselves living the life of a physicist. For example, Alva described opportunities to attend events that exposed her to careers in engineering, particularly from women's perspectives. She described the importance of getting to hear from women who were engineers in Sweden and seemed to have positive workplace experiences. She said after attending the talk of a woman engineer, she had the feeling of "*I can definitely imagine doing this."*

Rebecka engaged in numerous extracurricular programs throughout high school, each of them providing different experiences. One internship she set up for herself involved working in x-ray crystallography in a lab at a university. She worked in the lab for six months and learned, as she said: "*how it worked*." Through this, Rebecka gained insight into laboratory life:

> *It was great fun, really super fun, because we always had lunch with all these postdocs and Ph.D. students and professors. They always had such funny conversations. […] Yes, it was great fun. Or talked about their projects, and then I had to go to other Ph.D. students' offices and see what they were doing. It was fun.*

Rebecka also claimed that these opportunities to do physics were important to helping her determine her trajectory, suggesting "*the more I did physics, the more I thought I wanted to be an engineer."* After trying out an engineering program and a company internship, she was convinced that physics was her thing and started on the bachelor's program. However, actually adjusting to university life was fairly smooth for Rebecka as she had "*hung around a lot in university*" prior to arriving for her degree program, thus she claimed not to be surprised by the pace of life in the physics program.

Sigrid described a different kind of ideational resource she gained from attending a summer school abroad. In this case, learning about how women in physics are viewed in different cultures gave her a window into the experience of the life of a female physicist. At the summer school, she was asked: "*is it common in Sweden that girls study*

math and physics?" According to Sigrid she was very "*shocked by that comment*" and as she was the only girl in those courses at the summer school she began to realize that her experience excelling in math and physics in Sweden was considered uncommon. For Sigrid, this initiated the formation of her own *Science Girls* association in which young women in physical science can discuss their experiences of minoritization, and find support for experiences of imposter syndrome, and feelings of inadequacy or discomfort. Alva shared a similar experience from attending a tech girls meeting, where she and other young women had the expectation that "*there are many guys in engineering so you may not have a lot of girlfriends,*" and that they would "*not feel comfortable in workplaces with only men.*" What Alva took from discussing these expectations with women working in the field was that things are "*getting better*" for women in physics-related workplaces, and it seemed that the goal of the conversations was "*not so oh, come and work here,*" but rather to get a sense of what work life was like, so young women would have their eyes wide open when making career decisions. These encounters provided a view of physics in practice and gave the young women a sense of what it might be like to work in a field where women are minoritized. Hazari and colleagues [63] argued that these kinds of encounters can buffer women's own stereotypic perceptions, often by affirming their own values. They recommend explicit conversations about stereotypes and issues related to the minoritization of women in the physical sciences, suggesting that these may "lead to greater self-realization for female students, [and] may also have an effect on their choice of a physical science career" (p. 3).

IV. DISCUSSION

In this paper we provide insight into the resources participants accessed in university-adjacent informal physics learning environments, which support practice-linked identities in physics. We have focused our analysis on those IPL experiences we consider to be university adjacent, because this was the dominant form of IPL described among this group of participants, even if many of them have participated in other forms of IPL as well. We also find these experiences to be unique and challenging to access for most secondary students. Considerable efforts have been made in physics to understand issues that keep students out of the discipline, and to find ways to attract more students, especially those traditionally underrepresented in the field (e.g., Refs. [64,65]). The learning experiences we have presented in this study highlight the important resources that young women in physics may access to support their ongoing trajectories into physics. We identified the importance of relational resources participants accessed through internships, associations and summer schools, and importantly, we suggest that these relational resources can lead to ideational resources which can support identity work in physics. In the following discussion, we emphasize that these U-A IPL programs provide immersive experiences that are important for young women to begin to imagine possible selves in physics [66]. We also suggest that these possibilities come from more than just exposure to role models, but also opportunities to practice physics identities. Finally, we discuss how these university-adjacent programs are still in the realm of the elite and are extremely inaccessible to most students.

A. Possible selves in physics

Initiatives to encourage girls to enter into physics tend to focus on making physics fun, or informing students about the kinds of jobs and careers they can access with physics degrees [67]. However, these measures do nothing to critique or change physics cultures, or even to raise awareness about the potentially hostile cultures young women might face in these cultures [63,68,69]. By leaving physics culture unexamined, efforts to recruit and retain minoritized students that rely on making physics seem "more fun" or to inform youth about physics careers may contribute to the persistence of discourses that continue to marginalize young women [70,71]. Additionally, these efforts put the onus on young women to adopt more positive attitudes towards physics, or to simply learn more about the field, without providing opportunities to engage meaningfully with others in the field or to learn about physics culture. In focusing on changing individuals to fit the culture, these kinds of initiatives tacitly assume that social inequalities will be fixed, as long as individuals continue to be interested and engaged. Our research suggests that opportunities that emphasize relationship building may be effective means of encouraging young women to engage in physics. Importantly, we noticed in our data that participants rarely talked about the physics concepts, disciplinary areas or learning outcomes these experiences focused on, and did not discuss valuing the experiences for the physics content knowledge they gained. Rather, most participants emphasized the relationships they built and the value that immersive experiences had for their sense of self in physics. Additionally, our data suggest that as participants connected to others in physics outside of their school or classroom environment, it strengthened their own connection to physics practices in ways that supported their disciplinary sense of belonging [15,72]. Archer and colleagues [8] described the pedagogic work that physics does to reproduce dominant relations of privilege and inequality in ways that lead young women to think that "physics is not for me." We suggest that experiences outside of classroom contexts can create opportunities to disrupt this narrative. The experiences participants described in this study create opportunities to access resources that may thicken their inbound trajectories by providing opportunities for young women to imagine "possible selves" in physics [66]. Access to programs that provide the possibility to practice physicist identities (in more than just "hands-on activities") can

support their imagined futures—and at times even refigure those futures.

B. Centering relationality

Research investigating the value of encounters with physics outside of school can move us beyond solutions to underrepresentation like providing role models and towards an understanding of what is useful to young people in terms of envisioning a future self in physics. While much effort has been placed on creating opportunities for minoritized youth to access role models in physics, there is little evidence that this approach impacts participation rates in physics. Gilbert and Calvert found that "participants said that good female 'role models' were important to young women in science education. However, when asked, none of the women could produce any convincing stories illustrating the significance of role models in their lives (either in the form of actual people or in stories in books)" ([73] p. 874). In contrast, participants in our study identified numerous relational resources that supported their identity trajectories in physics. Important among these are relationships with physicists who could provide a realistic image of what life in physics looks like, and supported participants' sense of belonging in physics. Rather than looking up to role models, the resources participants described were relational and ideational, indicating that developing (sometimes lasting) relationships with meaningful others was significant. This suggests that interventions that go beyond representation and rather emphasize opportunities to develop "practice-linked identities" [45] should be prioritized. We suggest that approaches which center relationality (rather than just representation) can contribute to young women's resilience in physics. Here, we do not refer to resilience as an individual construct, but rather a relational and political construct. Discourses of resilience tend to place emphasis on individual preparedness, informed decision making, and adaptability [74], wherein role models might demonstrate how to adapt to physics contexts in ways that promote compliance and complicity. Rather, we suggest that the relational approach to learning about being in physics culture can emphasize developing "ecologies of resilience" [75], to support participation in physics. Ungar [75] suggests that in ecologies of resilience, relationships with people and things are mutually influencing, and function in a continuous exchange. These relationships can contribute to negotiation of meaning, and navigation of resources which then foster forms of resilience that are grounded in relations and belonging. We see this in the community Sigrid has built around her *Science Girls* association. The relationships she has built through engagement in that mostly online community have supported her navigation of the first year of university physics. She described finding support from this community in times when she feels imposter syndrome in her class, in ways that give her the strength to "raise her hand" and participate in a context where she would usually feel intimidation. However, this still leaves the concern that physics cultures remain hostile to young women, despite the possibilities to find a place for oneself through relationship building.

C. Preservation of dominant relations in physics

While this study highlights the importance of U-A IPL experiences to support students' sense of belonging to physics, we also wish to emphasize the scarcity of these opportunities for most secondary students. The experiences we described in this paper are not readily available to all students. Many of the participants we interviewed described going to great lengths to secure internships, often traveling around the country to identify possible opportunities, or being selected by teachers to attend research visits or summer schools overseas. While these highly select opportunities that immerse young people in the lives of physicists may provide openings for some young women to gain a sense of belonging in the field, they also preserve dominant relations of elitism in physics. This elitism is related in part to the position of physics in the so-called scientific hierarchy [76], to the sense that natural talent or ability is required to succeed in physics [6], and also with the persistent underrepresentation of women and other minoritized groups in the field [77]. We see this elitism perpetuated in the inaccessibility of these informal experiences, which we know to be critical for supporting students' sense of belonging in the field. Not all students have the means to attend summer schools abroad, or to travel abroad for internships. Stella articulated this, suggesting that some of the camps she was interested in attending would have been "quite a lot of money" and was out of the question because of that. Furthermore, that students need to do extensive research to find them, or be hand selected to attend them, suggest that even learning about these programs requires resources that most students do not typically access. Accessing these opportunities requires a great deal of resourcefulness on the part of young women, many of whom may not even know that these kinds of opportunities exist. Relying on these opportunities to support students' engagement in physics reproduces a meritocracy wherein those who seem to work hard to find resources will succeed, where those who seem to lack resourcefulness will not. The reality is that many may simply not have the opportunity. However, we do see some promising counter examples from our data which suggests that young people are engaged in work to shift these relations. For example, Sigrid and Hanna are involved in creating opportunities and providing resources for other young women to engage in physics learning environments that support and promote insider identity work in physics. Sigrid's *Science Girls* initiative is an example of a learning space that prioritizes inclusion and challenges our finding that informal physics learning opportunities reproduce dominant relations of elitism in physics.

While we have framed these opportunities as possibilities to create "ways in" for young women in physics, we do not wish to endorse an inaccessible and competitive system of social mobility in physics that may do more to obscure social inequalities than it does to repair them. Littler [78] has argued that this form of neoliberal meritocracy actually curtails social mobility, and creates the idea of a level playing field that does not exist. Indeed, we find that young women may find their place in physics through resourcefulness and resilience, but their individual successes do nothing to shift the dominant relations that exist in physics, which require students to seek out these additional opportunities in the first place.

D. Limitations

We acknowledge that this study is not representative of all or even a broad range of young people's experiences in physics in Sweden. In fact, the kinds of U-A IPL programs accessed by these young women are so unusual as to render them quite exceptional, which is why we wished to cast a spotlight on these experiences. As such, the stories we presented here should be read as a slice of the kinds of experiences that can propel young women into careers in physics, rather than a regular occurrence in the lives of students. In highlighting these stories, we exclude the regular and important home-based experiences that may contribute to young women's identity in physics. For example, we do not include the unstructured activities or forms of science talk participants may engage in at home, with their caregivers or extended family members. These types of informal experiences are rich, but often mundane and may go unnoticed in the lives of young women, especially as they narrate important events contributing to their trajectories into physics. In timeline interviewing, these possibly unremarkable experiences may not be discussed as "stand out" experiences in the context of the interview. This is a limitation of the timelining methodology where the extraordinary may be highlighted in lieu of the ordinary.

We also wish to address the limitations we faced in reporting these stories. The terms of our informed consent require us to anonymize the identities of the participants considerably, and thus we cannot reveal many identifying details of their backgrounds. As the experiences these young women described were so exceptional, we struggled to share enough information about their experiences, while still maintaining their confidentiality. There are so few women studying physics in Sweden, and still fewer who have accessed, to this extent, U-A IPL programs, that we were cautious not to divulge too much information about the participants or the programs. In most cases, this rendered our descriptions significantly less rich than we would have wished to share. For example, to not compromise the identities of the we have not given too much information about parents' occupations which would render them identifiable. We have also not provided details of migration status (like country of origin) to preserve participants' anonymity. Thus, we have largely talked about "young women" in this context without discussing national identity or ethnicity in depth, which has compromised some of the richness we otherwise see in the data.

E. Implications

Our findings suggest that U-A IPL programs, such as summer schools, internships, university lectures, and participation in associations, can open important spaces for young women's identity work in physics. In these spaces, young women can access important identity-forming resources that can contribute to their ongoing identity work in physics. However, these spaces are often inaccessible to most students and require a great deal of social capital to identify, apply, and even to attend. Although IPL programs might provide opportunities to work against the dominant relations of physics where students, especially girls, learn that physics is "not for me" [8], the inaccessibility of these programs reproduce elitism in physics, as they require enormous social resources to seek out.

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