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"Some explanation here": a case study of learning opportunities and tensions in an informal science learning environment

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Abstract Recent scholarship highlights the wealth of varied and interconnected opportunities for learning science that informal environments can provide; yet, participants with different experiences, knowledge, and backgrounds do not all learn in the same ways. Thus, studies are needed that examine how particular participants take up learning opportunities (LOs) in informal contexts. In this ethnographic case study, we focus on the learning experiences of one fifth-grade girl, Nina, who reported that she was not able to learn as much as she had hoped from her participation in an afterschool robotics engineering club. Through analysis of video-recordings, interviews, and field notes, we investigated how instructors and peers shaped LOs for Nina and the environmental tensions that affected how LOs were shaped and how Nina took them up. Comparison of examples in which instructor and peer-afforded LOs were realized and unrealized (i.e., presented in ways that Nina could take them up or not) illuminates multiple tensions. Club members faced tensions related to differing goals and abilities to teach each other, while the instructors faced tensions related to their roles in informal learning environments and their propensity to direct participants to other resources. As a result, many potential LOs for Nina in this rich inquiry learning environment where unrealized because instructors and peers did not shape them in ways that were explicit, elaborated upon, or connected to Nina's prior knowledge, and because Nina was not necessarily attuned to potential LOs in the informal context. We conclude with implications for instructors in informal learning environments.

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Recent scholarship highlights the wealth of varied and interconnected opportunities for learning science that informal environments can provide for participants (e.g., Bricker and Bell 2014; Rahm and Moore 2016; Zimmerman 2012). Scholars promote informal science learning environments as able to attract and sustain broader participation in STEM (Bell et al. 2009; Feinstein and Meshoulam 2014), particularly those traditionally underrepresented in STEM fields (Calabrese Barton et al. 2013; Tan et al. 2013). Yet, informal learning environments vary widely, offering affordances and constraints for diverse learners based on their material and socio-interactional properties. Furthermore, participants with varied experiences, knowledge, and backgrounds learn differently from different informal experiences (Dierking 1991). Therefore, detailed systematic studies are needed that closely examine particular individuals' learning experiences in specific informal environments in order to understand the learning opportunities they afford (See Bricker and Bell 2014; Rahm and Moore 2016; Levine Rose and Calabrese-Barton 2012). We are specifically interested in how learning opportunities are realized in environments where science inquiry, engineering design practices, and technological literacy are integrated to engage participants in addressing complex interdisciplinary problems (NRC 2012).

In this ethnographic case study, we explore the learning experiences of one fifth-grade girl, Nina, over the course of her nine-month participation in a robotics afterschool club where engineering processes, science knowledge, and computer programming were integrated in collaborative design challenges. We became interested in Nina based on our reading of interview transcripts in which Nina revealed that she was unhappy with her learning opportunities in the club. Because Nina initially exhibited high interest in club activities, consistently engaged in substantive interactions with club leaders and fellow members, and had nearly perfect attendance during the first half of the club's lifespan, her admissions of dissatisfaction were noteworthy. Nina's dissatisfaction was troubling because this engineering club was inquiry-based, interest-driven, and featured choice, challenge, collaboration, and authentic audience, all elements that support learning opportunities for diverse participants (e.g., Coffield 2000; Falk and Dierking 2002). Yet, Nina still felt that she was unable to learn what she wanted.

Two research questions guided analysis:

- How were learning opportunities shaped for Nina in this informal science learning environment?
- How did environmental tensions affect how learning opportunities were shaped for Nina and how she took them up?

To address these questions, we systematically analyzed data related to Nina's participation and learning, comparing interactional episodes in which learning opportunities were fully realized for Nina with episodes in which they were unrealized (i.e., when learning opportunities were initiated but not expanded upon or pursued beyond initial exchanges). Analysis was grounded in socio-constructivist learning theory and the literature on learning opportunities; findings were interpreted in light of current understandings of learning in informal science environments.

Theoretical framework

Socio-constructivism

We take a socio-constructivists stance on learning, based in part on Nina's own description of learning (see Findings for Nina's description). Through a socio-constructivist lens, learning occurs by adding, distinguishing, re-contextualizing, or otherwise re-conceptualizing beliefs, knowledge, processes, or practices. Learners transform existing ideas while juxtaposing new information against expectations acquired through past experience (Anderson et al. 2003; Palincsar 1998). This transformation also influences action, as learners become capably knowledgeable (Lave and Wenger 1991), improving their ability to employ tools and materials in the service of generating solutions to meaningful problems.

Learning is often enacted through sustained, engaged participation in consequential experiences (Gresalfi et al. 2009), but although learning is always situated in participation, participation is not learning itself. While participation provides the grounding for learning, "learning goes beyond the moment of participation to constitute a history and to shape a future act of participating" (Moje and Lewis 2007, p.16). Further, what is learned through participation carries forward into new environments to also shape future acts of learning.

Socio-constructivist frameworks befit informal environments because they define learning as an intentional meaning-making process mediated by learners' interactions with people and artifacts (Jonassen and Land 2012). Knowledge is co-constructed through the juxtaposition of diverse understandings as experts and novices interact around joint problems of interest. Thus, rather than a completely learner-centered orientation, socio-constructivist perspectives posit an interdependency between learner and teacher. Learners need chances to actively explore resources and engage problems on their own, but they also need more knowledgeable persons to provide timely information (Schwartz and Bransford 1998), helping them notice and attune to the affordances of environments (Gibson 1977). Peers can also support co-construction of meaning. As peers socially negotiate their understandings of a joint situation, they activate, differentiate, and elaborate on their prior knowledge; through generating and explaining new ideas, they transform their understanding of concepts (Kapur and Bielaczyc 2012). Concurrently, peer interaction can present barriers to learning, as it requires negotiating diverse response quality and sources of authority, as well as access to ideas, materials, and positioning (Engle et al. 2014).

Learning opportunities

Interested in the potentials for learning that Nina felt she was not afforded, we focused on learning opportunities of the robotics engineering club. A *learning opportunity* (LO) is "an interactional phenomenon, which extends beyond a unidirectional presentation of information" (Tuyay et al. 1995, p.76), which includes statements, questions, visuals, modeling, gestures, and feelings. LOs occur when learners receive help articulating their thinking in order to make sense of activities, experiences, and information, and exist when participants have the chance to interact with new information, connecting it to their prior knowledge.

Further, LOs position participants relative to information in ways that help them realize options for understanding and designing solutions to a meaningful problem (Gresalfi et al. 2009). Such opportunities draw on learners' personal resources and communicative processes (Bloome et al. 2009). However, LOs do not equate to learning, nor do all participants equally share thinking practices (e.g., programming robots, measuring precision) associated with LOs (Gresalfi 2009; Rex 2006).

Science inquiry and engineering design contexts create particular kinds of challenges for presenting and evaluating LOs because of the need to connect disciplinary content and core ideas with the practices that spawn them (NRC 2012). Resonant with our socio-constructivist stance on learning, science learners ideally shift between empirical-inductive thought (understanding concrete objects and events) and hypothetical-deductive thought (testing and comprehending hypothetical phenomena). Because this is a complex shift, learners often struggle with concepts needed to comprehend new material and with developing accurate theories to explain evidence (Schauble 1990). Therefore, simple exposure is rarely sufficient to facilitate learning; learners may need scaffolded LOs to make sense of scientific principles and build on them (Herrenkohl et al. 1999).

Informal learning environments

Informal learning environments are voluntary spaces where participants engage in activities not developed for school curriculum (Hofstein and Rosenfeld 1996). Such settings range from community and family activities (e.g., Bricker and Bell 2014; Zimmerman 2012) to more intentionally-designed spaces where trained instructors guide participants in hands-on experiences; e.g. museums and science centers, summer camps, and *community-based science youth program*s (Hofstein and Rosenfeld 1996) such as the afterschool engineering club in this study.

Sharp distinctions between informal and formal learning environments are too simplistic to capture the rich complexity of environments in which science learning can occur; some scholars suggest environments exist along a continuum (Austin and Pinkard 2008; Crowley et al. 2014). Nonetheless, the distinction is useful in identifying features, purposes, and affordances for learning in differing contexts, as well as the tensions that may exists for learners trying to navigate them. For instance, curricular goals tend to be highly structured/standardized in formal learning environments, whereas informal environments are intentionally open-ended to promote accidental learning (Sefton-Green 2013). Furthermore, informal environments tend to engage learners in ill-structured problems, solving for unknowns that are complex and ambiguous rather than algorithmic and pre-determined (see Jonassen 2000). Social interaction patterns tend to differ between formal and informal environments as well (e.g., Bricker and Bell 2014; cf., Tal and Morag 2007). For example, informal instructors are traditionally more concerned with engaged participation, affective outcomes, and developing personal interests than necessarily ensuring/monitoring learning (Rockman et al. 2007). Perhaps because of this, they tend to act as mentors responding to participants' interests and goals rather than as teachers imparting knowledge and direction (Austin and Pinkard 2008).

Differences across types of environments may create tensions for participants and instructors as they navigate informal science learning. For instance, there may be tensions surrounding the extent to which learning should be structured and directed and expectations about the degree to which in- and out-of-school curricula should be connected (Bell et al. 2009). Furthermore, across our reading of the literature, instructors' roles vary widely across informal contexts, possibly resulting in role-ambiguity for instructors. Finally, LOs in informal environments often facilitate occasions for social interaction through flexible participation structures (Crowley et al. 2014), which may be in tension with the need to provide just-in-time support for multiple pathways. Instructors must protect participants' autonomy while responding to wide-ranging ages, experiences, prior knowledge, and divergent participant goals (Bevan and Dillon 2010).

Methods

Study context

Nina's afterschool robotics engineering club met in a suburban school in the southwestern United States. The two club leaders (volunteers from a local electronics company), Chris and Mica, led club meetings in a volunteer teacher's classroom. They selected 11 of 22 fourth- and fifth-grade teacher/parent recommended applicants based on two try-out sessions during which mini-teams solved basic robotics missions. Club leaders and two teachers discussed each applicant's building, programming, and collaboration performance. Nina was perceived as a highly-desired member and unanimously voted in. Mica noted that Nina asked "forward-looking questions… she's aware that this [tryout] is only a small sample of what's in store." Participants' admittance was also based on academic performance, and Nina self-reported A/B averages for all subjects, further showing her competence.

Club leaders divided the selected fourth/fifth-graders into two teams; two-sixth-graders with previous robotics experience joined each team as team-captains. Thus, Nina's team was composed of seven members: six boys, of whom four were white, one was Hispanic, and one was of East Indian background, and Nina, an African American girl. The club leaders and sixth-grade captains had been involved the previous year. Despite their novice status, the fourth/fifth-graders brought a range of relevant experience as evidenced in their written applications and confirmed in initial interviews. All participants had building experience; two of the boys were avid LEGO builders while Nina enjoyed constructing pre-designed LEGO vehicles. Some participants had no robotics or programming experience (like Nina) and others had experience ranging from a one-day excursion to a summer robotics camp.

The club met weekly for two hours from September to May. In the first half of club's lifespan, the primary objective of club meetings was to prepare for a First LEGO League (FLL) competition. FLL is a worldwide organization open to children 9 to 14 years old. FLL promotes interest in STEM fields through "having fun and getting excited about science and technology" (FLL Coaches' Handbook 2008, p. iii), in keeping with informal environments' emphasis on engaged participation. Club members used LEGO Mindstorms kits to design, construct, program, and test robots to meet pre-specified missions performed on a themed playing field. Each team decided which missions to undertake and how to accomplish them.

Most pre-competition club meetings were filled with students eagerly running around, trying to quickly complete missions; excited yelling and group high-fives were commonplace. Nina built positive relationships with her teammates and took an active part in this excitement. Following the competition, club meetings were based around leader-designed engineering challenges to be accomplished in one or two sessions wherein club leaders occasionally provided instruction. The intent of these challenges was to increase club members' knowledge and skills to prepare them for next year's FLL competition.

Data collection and analyses

Both authors are former teachers with research interests in STEM and project-based learning. The second author observed all but two club meetings and in other contexts in the school. She video-recorded meetings and wrote expansive field notes. Following club meetings, she conducted semi-structured interviews to elicit participants' perspectives on their experiences during club activities (Bogdan and Biklen 2007). The first author meticulously watched each video and read all club materials and interviews.

The second author's position as a researcher-observer in the club and regular classrooms at the school gave both researchers an advantageous perspective for understanding complexities of the club context. It situates our method as ethnographic approach because of our deep understanding of the learning environment (Lillis 2008) and use of educational ethnographic perspectives and tools to guide our interpretations (Green and Bloome 1997). Conducting a qualitative case study (Ragin and Becker 1992) focused on one engineering club participant, we completed an in-depth analysis that offered key insights into how LOs were shaped for Nina over the course of the club and tensions that influenced those LOs, thereby highlighting complexities associated with informal science learning.

Our data include video-recordings of ten club meetings Nina attended (approximately ten hours), expanded field notes, ten transcribed interviews with Nina, and five transcribed club leader meetings. Analysis began with creating video logs of recorded club meetings, focusing on Nina's actions within the ongoing collaborative interaction. We looked specifically at Nina's positioning to tools (e.g., the robot, computer, field), and her interactions with instructors and peers (Jordan and Henderson 1995). We then added synthesizing memos after viewing each video.

We then began characterizing the nature of LOs, concentrating solely on those that were afforded to Nina (i.e., LOs for which Nina was present and obviously attending to them). Because there were not clear learning objectives for the club, we utilized our definition of LOs (i.e., more than a unidirectional presentation of information where learners receive help articulating thinking, connecting new information to prior knowledge, or realizing options for generating solutions) in conjunction with Rex's (2006) questions for describing LOs: who, what, with whom, when (on what occasions, how frequently), where (interactionally, physically), how, under what conditions, for what purposes, and with what outcomes (p. 7).

We discovered that many potential LOs were not fully realized (i.e., when LOs were initiated but not expanded upon or pursued beyond initial exchanges). For example, "You got lucky, but that's not [a] reliable [solution]." Though potentially helpful, this claim was left with no follow up information, connection to prior knowledge, or encouragement for participants to articulate their thinking. In contrast, a fully realized LO meets the previously outlined criteria to become a LO. For example, "Sometimes [the robot] gets a little confused if [the program blocks] aren't connected properly, so if you've got a block in here that you don't want, either delete it or….now try it and see if it works." Here, the instructor models how to fix an inoperative program, connecting it to participants' prior knowledge of linking program commands, modeling and describing ways to correct the problem, and encouraging participants to try for themselves. By contrasting realized LOs for Nina with unrealized LOs, we identified socio-interactional patterns that inhibited/facilitated Nina's learning.

To characterize *what* Nina did/not learn, we applied Bell et al. (2009) six strands of learning objectives in informal science environments to the LOs we identified: (1)

developing an interest in science where the participant is excited and motivated to learn, (2) understanding science concepts where the participant is able to comprehend and apply key science principles, (3) engaging in scientific logic where the participant employs scientific reasoning, (4) scientific reflecting where the participant metacognitively considers their learning process, (5) collaborative scientific participation where the participant works with others while using appropriate vocabulary and tools, (6) contributing to science where the participant develops a science identity (p. 43–47). We used the strands as a tool to help characterize the extent to which Nina successfully took up LOs afforded over the course of the club.

Because the discursive nature of the data limits access to Nina’s thinking processes, we relied on socio-constructivist beliefs that learning can be observed, for example, when learners make connections to disciplinary knowledge, elaborate on critical features of new concepts, or increase flexibility as they generate solutions (Kapur and Bielaczyc 2012). We also drew on the second authors’ knowledge of robotics engineering ideas and practices (Jordan 2010, 2014; Jordan and McDaniel 2014). As analysis continued, responses to Nina’s requests for assistance and the tensions experienced not only by Nina, but also by her instructors and peers became issues of interest, as well as indications that Nina was not learning the concepts that she desired. Thus, we debated each LO, its take up and surrounding tensions, revisiting them numerous times in concert with substantiating and disconfirming evidence from field notes, video logs, interviews, and club-leader meetings (Cobb and Whitenack 1996).

Finally, we re-examined video logs for possible “rich points” (Erickson 1992) where Nina was a key participant, new concepts were introduced, and/or we felt Nina had a realized LO. Managing the amount of data, we chose four sessions that met this criteria (two pre-competition, two after) for further microanalysis to ensure a holistic, dialogic interpretation of the data (Smagorinsky 2008). We re-watched each of these videos, discussing and comparing all potential LOs (realized and unrealized) in depth, adding lengthy memos to those made by the first author. We compared within and across episodes, trying to understand how LOs unfolded across sessions and across the year. This process allowed us to examine the interplay among the presentation of LOs, requests for LOs, and how Nina did/did not take up LOs.

Because there were rich data points outside of these four videos that explicated challenges for Nina in her LOs, we also re-analyzed and included these in the findings. Our findings are representative of key examples that illustrate the rich points of the data that help to elucidate our findings, triangulated with field notes and interview data.

Findings

We report the findings in three parts. We first describe the general nature of LOs for Nina in the robotics engineering afterschool club, broadly outlining Nina’s learning through her participation. Consistent with socio-constructivist theories, socio-interactional encounters shaped the great majority of LOs (although we identified some LOs resulting from Nina’s individual interaction with materials and tools). Therefore, in part two we explain how club leaders attempted to create LOs for Nina in this informal science learning environment. Comparing representative examples, we show how these LOs were/not realized because of tensions in this informal science learning environment, and to what effect for Nina. Part three parallels these issues for peer-afforded LOs.

Nina's learning

Analyses indicate that various potential LOs were presented to Nina across the timespan of the club, but many of these LOs were unrealized. Most successfully, Nina took up LOs for understanding the specifications associated with FLL competition missions: objectives, rules, tools, points awarded for completion, and how to set up the playing field. However, LOs related to deeper science and engineering concepts, disciplinary core ideas, and practices (e.g., developing and communicating design ideas, applying programming logic, systematically testing a design) were often unrealized. As a result, analyses signify that Nina did not completely or consistently meet all of Bell et al. (2009) learning strands.

Although Nina was excited and motivated to learn initially (Strand 1), indicated by her continued enthusiastic participation during club meetings, interview showed that this enthusiasm masked her eventual dissatisfaction with the club. Additionally, Nina never came to fully understand many basic principles and scientific concepts needed for testing or logically reasoning the tasks (Strands 2 and 3). While she exhibited a propensity to reflect on her learning process, voicing aloud things she felt she learned ("Oh, so *that's* how you do it") or needed to learn, rarely in our observation was she invited to expand on this metacognitive thinking (Strand 4), a key factor in LOs. Although Nina grew in her knowledge of the vocabulary and tools associated with robotics, she struggled to use and discuss them appropriately (e.g., trailing off when attempting to explain complicated processes, Strand 5). Finally, Nina did not see herself as a contributing scientist (Strand 6); throughout the club, she described herself as a novice (discussed further below).

Evidence almost without exception shows Nina on-task, participating, trying to help her team in whatever way possible (e.g., resetting the field, initiating programs on the smart brick). However, Nina made little progress in learning to program robots (as she self-reported and we saw in work-sessions where we never observed her successfully program alone or add more than two steps to a program). This was despite her expression across the lifespan of the club that learning to program was one of her chief goals. The following excerpt from an interview conducted near the culmination of the club signals Nina's unhappiness with her LOs and lack of learning. Here, Nina described her experience during a club meeting in which she attempted to learn how to program her robot:

Nina:	Chris and Mica …were doing these complicated programs and things and I was like, okay, some explanation here. But, I didn't understand pretty much a lot
Researcher:	What did you do when you didn't understand?
Nina:	Well, [Chris] told me the basic concept, which was just to copy what he did and—he said it was good practice, but basically I thought of it as just copying. I wasn't learning anything.
Researcher:	…how did you feel about that?
Nina:	I didn't feel too confident or good about that, because I mean, I wasn't learning anything; what's the point? We could have just used what Chris did… And I thought that was real boring, just sitting there copying. I wasn't learning anything.

The negative affective consequences that participation without learning ("I didn't feel confident or good"; "it was just boring") struck us because it indicated a lack of interest (Strand 1), which Bell et al. (2009) argue is an essential and unique element of informal learning environments. It also indicated that Nina did not understand how to program her robot, one of her main goals throughout the club; thus, Strand 2 was also not met.

The excerpt above is noteworthy because of what it indicates about both Nina’s perspective on her LOs and her definition of learning. Reinforcing our socio-constructivist stance, Nina’s definition helped us further understand how LOs might have been re-shaped for Nina to take them up more successfully. Nina conveyed that she saw learning as a change in what she was able to do with materials (program). Learning happens in her mind, changes what she can understand (“I didn’t understand pretty much a lot”), occurs through explicit instruction by experts (“some explanation here”), goes beyond replication and involves acts of decision making and solution generation (she rejected “just…copying”), and makes a meaningful contribution to ongoing situated activities (“…what’s the point? We could have just used what Chris did”). Furthermore, Nina aptly distinguished between participating and learning (copying is participation, not learning), which is an *essential* distinction.

Other club-members may not have made this distinction or felt inhibited in their learning. For example, Nina’s peer, Billy, seemed to show equal enthusiasm throughout the club, came in with similar experience level of science and programming, and worked closely with Nina for at least two-thirds of the time for 9/10 meetings. Despite his similar experiences, Billy did not express displeasure with his learning. Because learning is diverse in varying environments, Billy responded differently to the LOs that instructors and peers shaped, LOs that we describe in the next two sections.

Instructor-afforded LOs

In this section, we discuss how the club leaders’ perceived roles in this informal inquiry setting constrained how they shaped LOs even when Nina asked for direct help. As a result of role-related tensions (i.e., the rules of the FLL club and the club leaders’ propensity to re-direct members to other resources), Chris and Mica did not often provide fully realized LOs for Nina, as our examples show. First, to contrast, we present an illustrative episode in which a club leader afforded fully-realized LOs to show the ways in which Nina was best able to attune to LOs.

On January 9, Nina worked alone at the LEGO building boxes constructing a robotic structure to accomplish a new FLL mission. Mica joined her and began building his own structure for the same mission. As they worked in parallel for 35 min, Mica modeled potential ways to complete the mission, explaining his design decisions while building. He also gave Nina direct instruction about general building skills (e.g., “So if you have the [motor] here on the side, then you can actually have the motor turn…”). During this time, Nina attempted to use appropriate vocabulary to describe materials and tools (often Mica-prompted, Strand 5) and asked questions about her building techniques (Strand 2). Of particular interest were several exchanges that allowed Nina to articulate her understanding of new information and tools, connect them to prior knowledge, and generate new building solutions. For example, Nina, noticed a LEGO piece that interested her and initiated a LO to find out more. Mica explained, first describing the piece (Turn 2), then its function (Turn 4).

Nina: Is this a black [inaudible]?
Mica: No, that is actually a very interesting. It’s…a 3-stud pin that ends in a 4-stud
Nina: Mmm

Mica: Do you know how to use these?…if you have a beam (reaches for beam from building box), you can put it into the 4-stud (demonstrates), and you can take an axle (holding one up for Nina to see), and put it in through there. (fits pieces together)

Nina: That's what I've been looking for all this time! (takes the piece from Mica, removes the beam and axle, attaches piece to her robot).

Mica scaffolded information and questions, explained, and modeled with materials. He also gave Nina explicit, direct instruction to help guide her building decisions, connecting information to her prior knowledge of LEGOs and their functions. In a subsequent interview, Nina expressed that she better understood options for building as result of Mica's help: "Mica was speaking to me while I was building, so that kind of gave me some ideas", and learned new ways to use the tools because of their interaction: "he started talking to me about how to measure the axles and, yeah, he taught me something." This episode indicates that Nina valued the direct, one-on-one interaction and responded well to direct instruction from the club leaders. However, we rarely observed these types of explicit, elaborated, and persistent LOs; many instructor-afforded LOs were unrealized for Nina.

One reason for the prevalence of unrealized LOs was how the leaders viewed their roles. Research suggests the role of instructors in social contexts is to facilitate LOs through scaffolded questions and instruction until learners can demonstrate their understanding (Lenski and Nierstheimer 2002). However, even if an informal science learning environment is open-ended, learner-centered, and inquiry-based, instructors may still be limited in the extent to which they can meet these delineated roles. Thus, informal instructors frequently ask questions that are not followed up, elaborated on, or applied to participants' prior knowledge (Cox-Petersen et al. 2003; Kisiel 2003; Tal and Morag 2007), and this was largely true of the instructors in this afterschool club. We attribute this in large part to their interpretation of an FLL rule: participants "do all of the programming, research, problem solving, and building. Adults can help them find the answers, but cannot give them answers or make decisions" (FLL Coaches Handbook 2008, p. iii). This rule was in place to ensure that participants had the opportunity to meet the challenges of becoming problem-solvers, generating and finding solutions independent of instructor-provided answers or decisions.

Thus, evidence across time indicates that club leaders viewed their role as that of guides, rule-enforcers, and question-answerers and not that of formal teachers who go beyond these to further sequence, scaffold, instruct, and provide constructive feedback (Tal and Morag 2007). On Day 1, for example, Mica and Chris introduced the core values of FLL, one of which is, "Club members do all the work." Chris explained, "We're not allowed to build anything or program anything for you. We can help you, answer questions,…but it's important that you all do the work." Both club leaders expressed this role (helper, question-answerer) many times throughout the club, particularly when club members asked direct questions, which Nina did often. In such cases, they tended to provide hints about club member's ongoing problem solving efforts (e.g., "You might want to adjust that so that it's less likely to break itself"; "I think a pretty easy modification to the front of that might really help"), but these were rarely followed up with more elaborated explanations or explicit suggestions.

Both club leaders took their roles seriously, monitoring tendencies to step into solve problems for club members. Rather than providing explicit instruction, leaders frequently asked probing questions to prompt Nina's and other club members' re-consideration of actions or decisions (e.g., "So how do we like the robot we built last week?" to which Nina responded by silently looking down, and no further questions were asked). Questions like this are essential for encouraging articulation of thinking (a key component of LOs). However, the club leaders seldom persisted in scaffolding their questioning that may have helped Nina arrive at effective answers. Furthermore, instructors rarely checked for understanding, despite the fact that they were the "experts" in the room. We argue that the lack of explicit instructions, elaborated explanations, and extended questioning stemmed from a tension between club leaders' expertise and what they felt allowed to share with club members in this inquiry context where self-regulated learning and independent exploration were the ideal.

This tension led to many unrealized LOs for Nina. For instance, on September 18, Nina's group made little progress over a 40-minute work session, frequently talking over one another and failing to respond to repeated requests for peer feedback. Chris observed carefully, as exhibited by his interjections (e.g., "Ten minutes, you guys are going to show what you got. Who's in charge of keeping track of the clock?"; "You can use the instruction manual or you can just make it up."). Yet, he made no attempts to provide explicit information about or modeling of how to use the materials. His aside to the observing researcher, however, that "the most difficult part is sitting back," indicated that he saw the group's collaborative interactions as problematic. Perhaps had Chris interjected to help the group articulate their thinking or show them how to use the instruction manual to find and connect new information to their prior knowledge, he could have helped shape successful LOs for Nina.

Although this afterschool engineering club was a resource-rich environment, participants (including Nina) needed help learning to use the resources, but instructors offered little explicit instruction or modeling. We identified this as an additional tension that influenced how club leaders shaped LOs for Nina and how Nina took them up. When club members asked for help, the club leaders directed them toward other resources (e.g., YouTube resources, FLL specifications, each other). Because the FLL rules discouraged leaders' direct help, this was often their best option for providing assistance. However, without scaffolding and explicit direction for how to use the resources, participants often simply continued their trial-and-error actions or accessed resources briefly to little effect.

In October, for example, Chris observed Nina's group somewhat aimlessly using trial-and-error strategies to attempt a mission. Chris conveyed that they were off-track and pointed them to a resource ("I think you guys should read the mission [specifications]…There's something specific in there that might make this *easier*"). Nina read the specifications with another participant and said, "Oooh, we need one more." However, this vague assertion did not fix the group's problem, and they spent the next 15 minutes using unsystematic trial-and-error strategies. Had leaders scaffolded instructions or questions to guide members in *understanding* how to use the resources available, Nina may have learned to approach the iterative task of testing and troubleshooting more systematically (Strand 2). However, our analysis rarely showed instances of this kind of scaffolding.

Nina was explicit and persistent about her desire to learn how to program on several occasions, thus showing the club leaders that she was not taking up the LOs previously provided. However, her requests were not met with the instruction she felt she needed. For example, at the beginning of one club meeting, Nina said, "We have robotics in class and I really want to work on programming, so I can do something [with it in class]," [February 6]. Mica suggested that Nina "grab a laptop and work with someone who's programming." Mica, upholding his perceived responsibility to avoid being directive, guided Nina to another resource, her group members. This and similar episodes reflect the reluctance to provide direct instruction we saw from the club leaders. Like other episodes in which club leaders responded to Nina's requests by directing her to peers, this did not result in learning, as will be shown in the following section.

Peer-afforded LOs

Social interaction among peers is an important tool for learning in informal environments (Hofstein and Rosenfeld 1996). Therefore, our analysis of Nina's LOs must include a discussion of the LOs in peer-to-peer interactions, particularly from socio-constructivist perspectives that emphasize LOs of social discourse in complex social environments (Rex 2006). In this section, we discuss how club members responded to the instructors' expectation for participants to work collaboratively and to Nina's requests for LOs. We present comparative examples of Nina's peers shaping LOs, showing how these were largely unrealized as a result of the tensions participants faced in the club.

Helping peers learn was an integral part of this club, as evidenced by leaders' explicit messages. At the club's onset, for instance, Mica said, "I'm going to ask everyone that has programmed before to help everyone who hasn't… Because, remember, part of this whole thing is sharing our experience…" [September 26]. Further, supporting their explicit expectations that club members work together to accomplish engineering tasks were LOs directed at facilitating collaborative scientific practices (Bell et al. 2009, Strand 5), in which the club leaders reminded participants, "Remember, we want to work as a team, so you want to talk to each other" or urged them to be inclusive, "We can't discuss team tactics if you don't have all your members."

Possibly as a result of club leaders' expectations to work and learn together, there were several examples of realized peer LOs for Nina as members worked collaboratively, manipulating materials (e.g., creating attachments, discussing as they worked) or reflecting on testing outcomes (e.g., discussing why the robot did not run as planned, making arguments and suggestions for further testing). For example, on October 10, Nina worked with two team members on a robotic arm attachment designed to move two balls through the field. Billy explained an alternative design to Nina, a motorized arm that could be raised after collecting the balls in order to avoid hitting obstacles on the field when making a sharp turn required to complete the mission. Nina responded with implicit and explicit requests for elaboration.

Nina: Hmm, so are you saying that we should program it to go up when we go through (gestures with arms moving up) and down when we tell it to?

Receiving confirmation, Nina then invited Billy to demonstrate his solution at the field, where he explained how their robot could maneuver around obstacles to accomplish two missions in one and how the motor would manipulate the arm attachment.

Billy: What if we get it to go around the house and come back? (gestures, showing the path of travel) Then we can have arms that are already down. (imitates imagined arm motion)

Billy continued to explain and demonstrate after Nina expressed uncertainty ("I still don't understand"). By responding to Nina's requests for further explanation, Billy shaped a LO for Nina to learn about science concepts, engage in scientific reasoning, and use scientific materials and vocabulary while working collaboratively (Strands 2, 3, and 5). Nina's subsequent behavior exemplified her successful take up of this LO through her subsequent adoption and adaptation of Billy's ideas.

Following this exchange, Nina rearticulated Billy’s ideas to Andrew who was building while they devised their plan on the field. Nina contributed as the three of them worked through this idea for the rest of the session, modifying it to incorporate two additional missions. Nina communicated her ideas verbally and physically, manipulating the robot as frequently as her collaborators (11 times). Nina contributed new design ideas (“Make it sturdy; put a whole bunch of bushings on each side”), initiated testing (“We’re going to have to test it because it might run into all this stuff right here)”, engaged in scientific argumentation (“We have to make this [arm piece] sturdy because it’s a little fluffy [demonstrates by moving it up and down]), and critiqued actions (“…those arms are going to be too big to fit”). In doing so, Nina met all six of Bell et al. (2009) strands in this rare, fully realized LO.

Generally, however, peer-to-peer LOs were of short duration (i.e., most lasted only a few talk turns) and limited quality (i.e., little elaboration or modeling, did not facilitate Nina’s articulation of her thinking, connect to her prior knowledge). We saw little evidence that such unrealized LOs helped Nina deepen her ability to discuss critical features of new concepts or increase her flexibility with engineering practices.

As illustrated by the example of Mica’s response to Nina’s desire to “work on programming” on February 6, the club leaders *tried* to facilitate LOs for the club members to learn through working with experienced members. Immediately following Mica’s encouragement of Nina to “work with someone who’s programming”, for instance, Nina focused on her peers as possible sources for LOs, requesting assistance from her group. When no club members volunteered to teach Nina how to program, she sat with a laptop for 10 min while other group-members worked with the robot. After the group devised a plan to complete the mission, Nina asked her peers, “Who’s gonna teach me, so I can learn for my class?!” Despite her requests for explicit instruction, Nina then sat beside Charlie while he silently programmed the robot and Nina watched. Eventually, Nina drifted away from the computer and began building, a practice with which she was more familiar. In an interview following this session, Nina only talked about building and said nothing about her programming experience, perhaps feeling that it was nonexistent. Hence, in this unidirectional display of information with few interactions (Tuyay et al. 1995), another programming LO was unrealized.

This example is representative of many of the peer-to-peer LOs we identified. Nina did not receive peer *instruction* from her interaction with Charlie on what was happening in the moment, how that connected to her prior knowledge, or how she could use information to generate solutions either immediately or in the future. Charlie, for his part, volunteered to help but did not seem to understand that helping Nina learn might require explicit explanation of the actions he was making. Although club members expressed willingness to cooperate on engineering challenges, opportunities to facilitate one another’s learning were limited. We see this as a result of two tensions of this student-centered environment. Although participants were expected to help each other learn, (1) they did not know how to best shape LOs for each other, and (2) they likely had their own goals for the club and these sometimes conflicted.

Many club members did not have much knowledge of how to help others learn and seemed not to recognize the need to engage in co-constructive discourse (as above where Charlie “helped” Nina by silently programming while she watched). Because the expectation was for peers to work and learn together, this created a tension that inhibited Nina’s take up of LOs. Nina often asked questions and requested help from her peers, as she noted on several occasions (e.g., “…that’s what I usually do. It helps me learn how to get past what I don’t know” [interview October 3]) and as we observed numerous times across all club meetings. However, the help offered was rarely sufficient in both our and Nina’s opinions.

That peer-to-peer LOs were largely unrealized may be also attributed to a tension between the expectation to work together to help each other learn and the open-endedness inherent in informal learning contexts that allowed participants to focus on their personal goals. More especially, the competition-based nature of this informal environment led many club members to take FLL competition success as their primary goal, not necessarily teaching other club members, which would have benefited Nina's personal goals. Furthermore, Nina often reinforced these dynamics, deferring to peers she deemed as experts. She viewed herself as a novice in relation to her more-experienced peers and instructors, stating so at least four times during the duration of the club (e.g., "I was unsure at the computers because I'm still new to programming…I was asking questions to Billy and Derrick because they have more experience" [October 17]).

Nina's deference stemmed not only from how she saw herself relative to others, but also from her own commitment to the group's collective competition goals. This sometimes inhibited her from focusing on her own learning goals or pressing her peers for further instruction that could have prompted them to shape more effective LOs. For example, following a club session in which Nina worked with Kumail, the sixth-grade team leader who members positioned as an expert, Nina discussed how the robot chassis "morphed" into the newest version: "I don't know how that happened. I know Kumail was working on [the chassis]…that's why I said he kind of took over. But that's alright, he made it better" [February 9]. Rather than help the novice participant, Kumail took over to re-structure the robot for his goals and did not articulate his process of doing so. Thus, Nina did not obtain the scaffolding and direct instruction that might have helped her learn and was unaware of why certain changes were made to her group's robot. However, she deemed this action "alright" because the robot was now "better." In doing so, Nina did not realize the potential LO from Kumail, as she was then unable to connect information to prior knowledge and understand it in a meaningful way. Both Nina and Kumail treated this space as a more formal learning environment wherein novices defer to experts and their goals instead of an informal inquiry-based environment where learning is student-centered and co-created (Hofstein and Rosenfeld 1996).

We wish to also acknowledge that gender bias and/or stereotype threat, common to female and minority students in science learning contexts (e.g., Guzetti and Williams 1996; Jamieson and Harkins 2007) may be a contributing factor in Nina's learning. We found little evidence of such positioning, and Nina maintained that this was not a problem ("I'm usually with boys, so it wasn't very uncomfortable"). Yet, an alternatively focused analysis might reveal such bias, potentially positioning Nina in less agentive ways relative to her peers and inhibiting her participation. Further, we did not find reason to attribute Nina's deference as resulting from a shy or retiring nature. She built good relationships with members of the club as evidenced by her own admittance, the words and actions of her peers, and in our judgment based on video and in-person observations. The second author and club leaders described Nina as socially competent, a "connector" in her team who involved all members.

Discussion

Our analyses indicate that Nina had many opportunities to participate in science-related practices and disciplinary content in this robotics engineering afterschool club. However, while Nina gleaned small bits of knowledge from peer and instructor-shaped LOs, she did not consistently come to fully understand many of the science-related concepts, and her learning did not encompass the rich complexity embedded in the robotics materials. Thus, Nina was unable to make sense of her experiences in ways that could serve her to make better scientific decisions in the club and in the future.

Evidence negates interpreting Nina’s failure to significantly increase her ability to build, program, or systematically test her group’s robot as simply attributable to her motivations or abilities. She was as capable as other club members, did well in school, participated successfully in other afterschool activities, and exhibited motivation to participate during club meetings. Thus, understanding her self-perceived lack of learning, a perception that our observations confirmed, requires looking beyond Nina. Although we saw limitations in the way club leaders and members shaped LOs, Nina was singular among her peers in the extent to which she expressed that these limitations restricted her learning. This signified to us that the meaning placed on similar LOs was different for them than for Nina. Thus, we see the observed failures of learning as arising in a mismatch between Nina’s goals and expectations for her club participation and the instructor and peer-afforded LOs, which were driven by tensions in this informal science learning environment.

In the remainder of the discussion, we explicate contributions of this study to illuminating tensions that instructors and participants may experience as they navigate learning in informal science learning environments. We argue that many of the potential LOs in this rich inquiry-learning environment were not fully realized because the people who shaped them (i.e., instructors and peers) were constrained in their ability to offer them in ways that were explicit, elaborated upon, or persistent, and because Nina was not necessarily attune to potential LOs in the informal context. We conclude with implications for instructors in informal science learning environments.

Environmental tensions

Multiple environmental tensions inhibited how club members and instructors shaped LOs for Nina and how she was able to take them up. For the instructors, these tensions arose between (1) their expertise and what they felt they could share with the participants, and (2) their propensity to direct participants to the rich resources of the club and participant’s need for instruction for how to use those resources. The club leaders’ perceived mandate to avoid giving direct instruction seemed at odds with Nina’s need for explicit teaching and with the goals she communicated, i.e. to learn robotics. Although scholars suggest effective roles for instructors in inquiry-based, informal science learning environments (e.g., Bell et al. 2009; Tal and Morag 2007), the open-endedness of informal learning environments and the loosely defined nature of those roles inadvertently creates a tension for instructors. Thus, in trying to respect participants’ need for autonomy, and rightly working to afford challenge and independent, self-regulated learning in inquiry contexts, informal instructors may not always provide the just-in-time instruction that some participants, like Nina, need.

As inquiry-based informal learning environments are learner-centered and interest-driven, there is a tension surrounding the appropriateness of direct instruction (Bell et al. 2009). Informal instructors may avoid explicit explanations and elaborated modeling because they perceive themselves as facilitators rather than teachers. For some participants, this is beneficial and allows them to explore science freely without being inhibited by restrictions that can accompany school-like procedures and practices (Bell et al. 2009; Tal and Morag 2007). However, some participants may need explicit, elaborated instruction in order to progress, as instruction can help learners understand content and procedural knowledge (Schwartz and Bransford 1998), and also how to use resources and frame problems. We believe that Nina would have benefited from direct instruction to meet her own learning goals for club participation, especially considering she requested it numerous times from both her peers and instructors. Like video gamers pausing to watch YouTube videos tutorials when stuck on a challenging level, participants in informal learning environments need to be able to pause and get further direct instruction when needed (Gee 2015; Holmes 2015).

Nina's peers also faced environmental tensions when shaping potential LOs for Nina. Although club members were expected to work collaboratively and learn collaboratively, (1) they did not know how to effectively shape LOs, and (2) each individual had their personal goals for the club in addition to the collective goals for competition success. Effectively shaping LOs for peers is a complex endeavor that may require intentionality, coupled with developed competencies in scaffolding LOs for others to make sense of and compound on interconnected scientific tenets (Herrenkohl et al. 1999). Yet, club members perhaps had never before been tasked with or taught how to help peers understand complicated science principles and processes. Furthermore, in negotiating multiple personal and collective goals, club members focused on collaborating to meet competition goals at the expense of collaborating to learn, which Nina reinforced through her deference to her peers whom she perceived to have more expertise. Within this informal environment, participants were able to prioritize their own goals, and perhaps some did not prioritize teaching peers the skills that they already had and were using to further the group's engineering projects. Stopping to provide instruction or articulate thinking in order to teach someone with little experience might slow down progress on the missions.

Scholars have identified difficulties with collaborative learning around the tensions among people collaborating to get things done (e.g., prepare for a competition) and collaborating to figure things out (i.e., learn) (Schauble et al. 1995; Zuiker et al. 2016). Complicating this tension is the need for collaborators to learn to manage interacting spaces, navigating power relations and access associated with productive collaboration (Barron 2003; Engle et al. 2014). These triadic tensions of getting things done, figuring things out, navigating social relations are further complicated in informal environments because voluntary participants bring their own goals to these participant-led, participant-centered contexts. Thus, we concluded that peer-to-peer LOs for Nina were limited because participants were *collaborating to do* (the impending competition) over *collaborating to learn*, and the tensions of this informal learning environment reinforced these tendencies.

LO attunement

From a socio-constructivist perspective, learners assign meaning to LOs through their interpretations of them (Bloome et al. 2009). Therefore, LOs presented and taken up to greater and lesser extents within the social context of the afterschool club were given meaning through participants' interpretations and goals. Nina assigned her own meaning to LOs, wanting to grow as an engineering student, builder, and programmer, expressing these goals explicitly and requesting help from club leaders and members. When these goals were frequently not met, it led to her frustration and decreased interest.

Some learners may need more help than others to learn how to attune to affordances of a new environment (Gibson 1977) and the LOs shaped within. If a learner is unable to recognize a potential LO, it is not a LO for him/her. Nina did not take up some of the potential LOs that both her peers and instructors shaped for her, perhaps because she was not attuned to the occasions for social interaction and flexible participation structures

(Crowley et al. 2014) that facilitated the LOs in the informal club environment. Furthermore, when directed to potentially helpful resources for LOs such as peers and materials, Nina knew that they were information sources, but perhaps not how to leverage them for learning. As a result, we rarely observed Nina take the appropriate actions to fully realize potential LOs (e.g., requesting additional help, asking peers to articulate their thinking, asking how new information connected to prior concepts learned).

Nina’s lack of attunement to potential LOs in the afterschool club may have arisen from the tensions that occur between informal and formal learning environments. Perhaps Nina based her expectations for how LOs would be shaped in the afterschool club on her learning experiences in formal environments. Participants like Nina may experience difficulties recognizing subtler and student-driven LOs in informal environments as distinct from those of the formal environments in which they spend much of their time, and may struggle to adapt learning behaviors and strategies accordingly.

Implications for practice

While acknowledging the inherent limitations of this qualitative case study with its restricted focus on a single participant in one context, we submit suggestions for practice evoked by our findings. Particularly, we see a need to design informal science learning environments toward LOs that are more explicit, elaborated, and persistent when initially unrealized. This recommendation may seem antithetical to the participant-centered, hands-on, inquiry-based practices that are rightly held as the hallmarks of productive informal learning environments. We contend, on the contrary, that expanding the adaptive flexibility of afterschool instructors by encouraging them to incorporate direct instructional tools into their accepted practices for shaping LOs could enhance the effectiveness of these central aspects of informal learning by countering some of the potential tensions that learners face.

We are in agreement with other scholars’ assertions that the unstructured, participant-driven, collaborative nature of informal science learning has great potential to recruit, develop, and sustain diverse participants’ interest and learning in science and engineering (e.g., Bell et al. 2009; Rahm and Moore 2016; Tan et al. 2013). Additionally, in solidarity with Nina, we argue that there is a time for telling (Schwartz and Bransford 1998), even in informal environments where instructors are not supposed to tell. While not arguing for the organization of more pre-determined, pre-planned LOs in informal learning, we are suggesting that informal instructors might become better able to craft just-in-time LOs. To accomplish this, we suggest a model where instructors move across contextual boundaries to best address learners’ interests, abilities, and identities as they flow between roles of mentors and teachers to address learners’ needs (e.g., Austin and Pinkard 2008; Bevan and Dillon 2010). Integrating teaching strategies like explicit instruction, elaboration, modeling, and explanation may not only increase learning for diverse participants, but also increase how they are able to help each other learn as instructors model effective teaching. Including these strategies into informal experiences might help meet the needs of learners, like Nina, whose motivations, abilities, and goals for participation may put them in need of such instruction.

We also urge researchers and instructors to consider the need to help learners attune to the affordances of informal science learning environments. Because informal contexts are less familiar, and intentionally less structured and organized than school contexts in which participants are embedded daily, learners may not recognize their potential LOs as easily. Therefore, instructors may need to provide explicit instruction for how to attune to these affordances, for instance, explicitly addressing confusion about what participants’ expectations for learning and participation should be, or about what range of goals are appropriate for them.

Finally, an important implication of our findings is that researchers, program designers, and instructors should consider *participation* and *learning* as distinct outcomes in informal contexts (See Herrenkohl et al. 1999; Moje and Lewis 2007). Although Nina and her peers were engaged and interested, their ability to help each other learn was less successful than hoped for from the flexible participation structures in informal learning environments. Further, the instructors may have mistaken Nina's enthusiasm and continued participation for understanding and learning as a result of the multiple learning pathways inherent to informal learning environments. Engagement and interest may be necessary, but are not sufficient alone to induce relatively long-term changes in understanding and practice that are the hallmark of learning. A LO must afford more than the chance to participate; it must include information to help a participant modify existing knowledge for immediate and future use (Moje and Lewis 2007; Tuyay et al. 1995).

Instructors wishing to enhance the productivity of informal learning environments for individual participants' learning might cultivate their ability to distinguish learning from participation, discerning when participants appropriately need direct instruction to further their learning goals. Instructors could expand their awareness of the ways in which members are participating, checking for how individual participants are interacting with information while connecting it to prior knowledge and articulating their thinking, as well as what participants think they are learning throughout the process. This kind of metacognitive reflection on science learning processes (Bell et al. Strand 4), might also help participants better attune to affordances of the informal learning environment, thereby noticing, taking up, and realizing more LOs for themselves and better supporting one another's diverse goals for learning and participation.

We recognize the need for further study to substantiate the efficacy of these claims and to check the transferability of our findings to other informal contexts and participants. Future research is needed to examine the influence of varied LOs on diverse participants' learning and motivation in a variety of informal learning environments. Future studies should also investigate how instructors attempt to meet the varying goals of participants in informal environments as well as their success in doing so, and whether and to what extent explicit instruction plays a role in the uptake of LOs.

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