Science Everywhere: Designing Public, Tangible Displays to Connect Youth Learning Across Settings

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Figure 1. *Science Everywhere* (SE) is a sociotechnical system designed to facilitate learning across neighborhood settings. Children use the SE social media app to share the science they notice in their everyday lives. Public, interactive displays placed in locations across the neighborhood facilitate awareness of children's thinking in order to coordinate support for their learning across settings.

ABSTRACT

A major challenge in education is understanding how to connect learning experiences across settings (e.g., school, afterschool, and home) for youth. In this paper, we introduce and describe the participatory design process we undertook to develop *Science Everywhere* (SE), which is a sociotechnical system where children share their everyday science learning via social media. Public displays installed throughout the neighborhood invite parents, adults, peers, and community members to interact with children's ideas to better develop connections for learning across settings. Our case study of community interactions with the public displays illuminate how these technologies encouraged behaviors such as the *noticing* of children's ideas, *recognition* of people in the neighborhood, and *bridging* to new learning opportunities for youth.

Author Keywords

Public displays; pervasive displays; community; children; learning

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INTRODUCTION

Pervasive and public interactive displays create ubiquitous computing environments that can enhance place-based communities [20]. Many researchers in Human-Computer Interaction (HCI) have explored the affordances of public displays in different settings. For example, *Plasma Posters* [15] displayed co-workers' updates and announcements in an office environment. *Digifieds* [34] showed neighborhood content typically seen on public notice boards such as classifieds, job announcements, or events. *Communiplay* [37] allowed people to play games with players at multiple, networked displays in other locations, and *Moment Machine* [32] encouraged people on a public street to snap photos or selfies through a public display installation.

These examples are just a few of many design experiments in a long history of HCI research suggesting that pervasive, public, and interactive displays hold great potential to help people develop deeper bonds with each other and raise awareness of community activities [33, 35]. However, Memarovic [36] notes a need for future research to move away from general claims about community connectedness to more detailed theorizing that links design decisions to specific domains of community behavior, such as civic action, social capital development, or learning interactions.

In line with this need, public and pervasive display research spans a vast array of domains, including bulletin-board transmission of community information [14, 15, 26]; interactions such as trivia applications or browsing of information [34, 38]; ambient awareness of information in events or co-located experiences [39, 41]; and civic, art, media, and play-based experiences [3, 24, 32]. However, few design studies have probed how to support learning for youth through the affordances of public displays [38, 46].

In this paper, we introduce and analyze *Science Everywhere* (SE), which is a neighborhood-based sociotechnical system that we developed to test specific design conjectures about how to coordinate community support for young people's science learning [18, 43]. In SE, learners in a neighborhood document the science they see through a mobile social media app we co-designed with children [2], as they participate in everyday activities, after-school STEM programs, and school. We also co-designed tangible, public displays with families in our partner neighborhoods [50] that allow the broader public to interact with the children's posts in a variety of settings, such as a local church, public school, and several after-school programs.

Our case study explores how members of our partner neighborhoods interacted with the public displays that we placed in different community areas. Our study focuses on two research questions:

1. How did members of a neighborhood come to interact with public displays of young people's engagement in science?
2. How did SE influence informal learning practices in the neighborhood?

Our study makes three major contributions. First, we build from the rich HCI literature on public displays and community informatics to articulate how these technologies can be designed to facilitate critical *learning behaviors* across a community. We highlight how the design decisions for such displays may help community members *bridge learning* for youth across settings (defined in detail below). Second, we present findings from a field deployment of SE in two neighborhoods in Rockdale, USA and Susquehanna, USA (we use pseudonyms for all names of places and people in this paper). Our findings shed light on how the public displays promoted behaviors, such as noticing children's interests, recognizing neighbors, and potentially brokering new learning opportunities because of this increased ambient awareness of children's interests and activities. Finally, we illuminate future design needs for public display technologies to better facilitate community coordination and bridge learning for youth across settings.

RELATED WORK

Our project draws inspiration for system design from the HCI literature on public displays and leverages frameworks from community informatics to glean how design decisions may relate to neighborhood interactions and outcomes. Additionally, our analysis focuses on the learning sciences-grounded phenomenon of bridging learning across settings.

HCI and Public Displays: Design Lessons

Public displays have evolved tremendously over the years. Early HCI studies examined how public information sharing occurred on community bulletin boards [15]. Findings from such studies suggest that public audiences often ignore the information on public displays, a phenomenon called **display blindness** [33]. However, the displays in these studies were one-way transmissions of information, and unless placed in novel situations that engender attention, many audiences were often not aware of the need to engage with the displays or ignored them as they would the ubiquitous advertising that is present in many settings.

In recent years, HCI researchers have identified new affordances for interactivity via sensing and touch capabilities that could shift an audience's interaction with public displays. For example, *Communiplay* was a public display experience where a person could play with virtual objects and see players at other networked displays who were also playing. The researchers found that these features contributed to a **honeypot effect**, where players at a screen attracted more viewers who would then play with the display [37].

The above example illustrates another feature where public displays can be **networked** with other displays and devices [36]. This opportunity opens up a wide range of potential design choices. For example, participants can contribute content to the display via many channels. In the *UniDisplay* project, researchers demonstrated how opening up a public display for user-generated content creates many tensions and decisions [3]. For example, designers must decide through which channels to allow users to submit content, such as web forms, email, or social media services like Twitter. In addition, moderation mechanisms for this user-generated content become a rising issue. Finally, networked public displays offer opportunities to design interaction around many forms of content that **engage public audiences across a wide range of settings** – which require careful design decisions about what content is shared, through what channels, and for which purposes [35].

This body of HCI literature on public displays influenced the design of our SE project in several ways. We note that public displays may promote awareness in a bounded community, such as an office, residence hall, public street, event, or neighborhood [34]. However, coordinating participant contributions involves critical design decisions, such as how to allow individuals to contribute content and interact with the display [3]. Finally, attending to the placement and interaction potential of these technologies in public spaces will influence community use [4, 31].

Designing for Community Bonds

Community informatics research has also influenced the design and impact of public displays. Rather than focusing only on hardware and software (e.g., the public display as the focal artifact of interest), research in this area privileges community contexts and phenomena. Carroll, Kropczynski, and Han [12] observe that mobile devices, social media, online portals, and public displays can be deployed to promote smart communities. The notion of smart communities describes the ability for local entities, such as a neighborhood or city, to leverage technology to **enhance awareness** of the activities, histories, values, locations, and ideas that give meaning to a place. Technologies can also be designed to better **coordinate community practices**, such as discussion and flows of information.

Erete [23] offers additional design frameworks, suggesting that technologies are more effective for community development when they are crafted to facilitate:

- Higher social cohesion where individuals are better able to recognize and relate to one another;
- More social capital that connects individuals to others who can provide resources;
- Smaller groups of participants (versus a larger, abstract crowd) that have higher commitments to participate and reciprocate activities with each other; and
- Specific, interest-based groups that are relevant to a particular place, versus broad aims that may not motivate anyone in a given community.

Similarly, Carroll and Rosson [13] offer specific design strategies that can amplify key community features. For example, by making community artifacts visible through online platforms, media streams, or public displays, a neighborhood may discern the structure of relationships, acknowledge the activities and thoughts that are present in a place, and better recognize available community assets. Such community-focused designs can extend existing community practices, create new informal learning opportunities, and help people develop a deeper sense of meaning toward their place-based environments [13, 45].

The literatures in HCI and Community Informatics provide a robust foundation to develop conjectures about how public technologies could be designed to coordinate learning across a neighborhood. A clear evolution in the extant literature is a move away from designing and thinking about public, community technologies in a general sense – e.g., technology for every place – to better situating the design of technology to be more effective for a *specific place and function* [28]. This orientation illuminates a need in future research to articulate: (1) the places that we are designing for, (2) the people that inhabit the environment, (3) the sociocultural practices that we are trying to enhance, and (4) the technology design decisions that are expressly intended to enhance these prior elements.

A Critical Education Dilemma: Bridging Learning Experiences Across Settings for Youth

With an eye toward designing for specific places and practices, our work focuses on promoting interest-based learning across settings in a hyperlocal neighborhood. Recent scholarship in the Learning Sciences finds that learners who identify with an interest (e.g., astronomy) or domain (e.g., science) have diverse learning experiences across settings that reinforce and build upon each other continually [5, 9]. For example, a young person may participate in an after-school science program where she makes new friends and develops a social interest. She may have these interests celebrated by her science teacher, while other learners may have their interests rejected in the classroom [11]. Some learners may have parents who take them to museums, community events, and other learning settings to reinforce their interests and deepen their knowledge; others may not have access to these experiences [6, 19]. We characterize supportive activities across settings as *bridging learning* experiences – where the learning that occurs in one setting is extended in other settings.

Learners who face challenges in school and other educational settings often experience discontinuity, where their learning in one situation does not relate to other personal experiences [10]. Bridging learning is a complex and difficult practice to foster. Institutional infrastructure is necessary. Young people need access to schools, after-school programs, libraries, transportation, and other institutions in order to participate in different learning settings [40]. Social networks are another resource that is inequitably distributed among youth. Successful learners often have access to a network of mentors, peers, and other actors who can provide advice, information, and other resources as they learn a new domain like computer programming [7]. Finally, the practices that occur in a given classroom, after-school program, or community setting can propel a young person to deeper exploration of a domain, or hinder their interest or development [1].

In this project, our design conjecture is that the affordances of public displays and related community technologies can help to (a) make young people's science learning and interests visible to the neighborhood community, (b) help actors across a neighborhood – including peers, parents, teachers, and community members – become more aware of the rich array of science interests and assets that are present in the neighborhood, and (c) facilitate the kinds of bridging practices that are important for young people's learning and deepening their identification with science, such as conversations about one's interests, finding new learning opportunities, or providing needed resources.

Few technology design projects have examined how to foster the bridging of learning across contexts from a community perspective. However, there are several projects that inform our approach to developing sociotechnical systems for bridging learning. For example, in the *Zydeco* project, children used a mobile app in out-of-school settings (e.g., museums) to take photos and make claims about research topics [27]. Teachers then used these artifacts in the classroom to foster further inquiry and discussion. The *Connected Messages* project engaged youth in libraries in maker activities using foam boards, LED lights, and controllers [46]. The youth then combined their artifacts to create a community mural or public display, controlling their LED lights through a web interface. However, this study focused on maker activities for youth, not on designing public displays to promote community coordination of learning for youth.

Finally, work by Leong and Horn [29] illuminates how families learn together in public places – specifically, doctor's waiting rooms. Their study suggests novel designs for public display and interactive technologies that could enhance family learning activities during these everyday moments. The SE project leverages core ideas from these efforts: using devices to capture learning across settings, harnessing the affordances of community-focused public displays, and leveraging spaces and moments like waiting rooms or, in our case, churches, schools, and other neighborhood spaces, for informal learning.

DESIGN PROCESS

To design SE as an integrated sociotechnical system, we employed an iterative, human-centered design process over six years (from 2011 to this writing). We co-designed key elements of SE with children and neighborhood partners.

Sharing with Social Media

The SE project began with the development of a social media app that enables children to capture, develop, and share the science interests, questions, and curiosities they encounter in everyday life. We refer to such everyday, personally meaningful, science practices as *scientizing* one's world [17]. Scientizing includes asking questions about how the world works, recognizing gaps in one's own understanding and investigating personal scientific questions. The children in our project use the social media app to share these questions, observations, and personal reflections ubiquitously.

We co-designed and iteratively tested our mobile app with children (from 2011-2014) in an out-of-school program called *Kitchen Chemistry*, where children learned science through cooking [16, 48, 49]. Our iterative design process validated that children found the mobile social media app to be an engaging multimedia tool for sharing their science experiences and creatively expressing diverse aspects of the inquiry process including asking questions, designing investigations, sharing results, and making claims [2, 49].

Public Displays to Promote Neighborhood Awareness

We also set out to develop ubiquitous, tangible displays to facilitate community-wide sharing. The public display designs used in this study were a culmination of two years of co-design with our partner neighborhoods in Rockdale, USA (in the Mid-Atlantic) and Susquehanna, USA (in the Pacific Northwest) from 2014-2016. Our neighborhood co-designers included children, parents, teachers, community volunteers, and informal educators [50]. To conceptualize the design of our large display, we conducted early ideation sessions, where children, adult community members and researchers co-designed display prototypes for sharing posts and interacting with community members.

We conducted three ideation sessions with an intergenerational design team in Rockdale and an intergenerational design team in Susquehanna that focused on developing new types of display interactions that would be relevant across contexts. Additionally, parents in our partnering neighborhood in Rockdale participated in a focus group where they (1) shared questions, ideas, and opportunities for community displays, and (2) envisioned how such displays could enhance their day-to-day experiences and help their children engage in science in their local community. Concurrently, we held bi-weekly meetings with a partnering teacher in Rockdale to solicit her ideas for using such a display system in her school to enhance the formal science curriculum. Our co-design work illuminated the need for three main design features:

- **Tangible Browsing:** The ability to easily scroll, browse, and search for people and topics was a major theme across design sessions. We focused design efforts to organize posts first by search categories that participants could quickly select without typing, which significantly reduced UI/UX complexity on a large, multi-user, touch screen display. We also created an "infinite" scroll in the large tangible displays so that users of any height could access the posts and scroll through at any position.
- **Events and Groups:** Another major theme, given our population of children and families, involved their concerns about privacy and safety. Most children made posts across various settings and events (e.g., in a classroom, informal program, at home). Thus, we designed SE around the idea of private groups and events that are created and moderated by an adult such as an educator or parent. Children can post to their groups in private or choose to promote posts to the public neighborhood displays. We developed moderation flows that enable flagging and removal of inappropriate or privacy-sensitive posts when needed.
- **Feedback:** Participants wanted to give positive feedback to learners in novel, playful ways. Feedback emerged as a major organizing theme, resulting in a set of badges that participants could award on the public display for children's creativity, insightfulness, collaboration, and investigation ideas.

Through our extensive co-design process, we encountered and addressed a wide variety of issues that are present in the extant literature [4, 26, 34, 36]. For example, through our neighborhood partners, we were able to see first-hand (a) the privacy, safety, and moderation issues that must be addressed when designing public, community technologies, (b) the community's desires for sense-making and meaning-making of children's posts by browsing or searching on people, groups, and events, and (c) how children wanted feedback on their ideas.

In our resulting design, learners create posts on the mobile app that are then shown on the display where users can filter and scroll through posts. Users can select posts and give curious, insightful, collaborative, and investigator badges to posts as they see fit. For this study, we then placed the displays in specific locations across our partner neighborhoods that provided us an opportunity to explore community interactions in public, classroom, and after-school settings (detailed below).

Learning Partners and Practices

As scholars of community informatics observe, merely creating technology is not enough to enhance community behaviors [12, 23]. These technologies must be integrated in a sociotechnical system with the existing practices and the social and cultural institutions in a local setting. Our efforts to establish partnerships in two USA neighborhoods and embed our co-design work into their communal social structures proved to be a key component of our design process. Both partner neighborhoods of Rockdale and Susquehanna include Title I schools that serve students from predominantly low-income families. In Rockdale, we partner with a local church, Grace Covenant Church, that hosts various learning programs for youth within a two-mile radius. The church also serves as the community-meeting place for most of our SE activities, which include an after-school and summer science-learning program. SE community programs include hands-on projects, investigations, and experiments that are relevant to everyday life such as Kitchen Chemistry, Minecraft, and engineering projects. Additionally, we work with the outreach pastor at the church, Pastor Hicks, to coordinate learning activities and incorporate SE in the church community.

Our Rockdale neighborhood ecosystem also includes Westland Middle School, the local public school in this radius that houses one of the public displays. Several children in our SE programs at Grace Covenant Church attend Westland Middle School. We also invite parents of children participating in the SE after-school program to engage in design sessions and science-learning activities approximately once per month. Members of the church have also served as volunteers and visitors to SE sessions.

In Susquehanna, USA, we partnered with a local Title I school, Soaring Eagle Middle School, which has a rich after-school infrastructure with several STEM learning programs, including a Science Olympiad competition team and a support network for girls in STEM. The weekly SE after-school program in Susquehanna includes activities similar to our Rockdale program. We also partnered with a science teacher at Soaring Eagle Middle School – Mr. McDonald – who implemented the tangible displays in his classroom. More recently, we conducted Science Everywhere sessions in a three-day summer day camp program with incoming Soaring Eagle Middle School students. Finally, we held monthly *Family Science Nights* (FSN) at Soaring Eagle Middle School for interested parents and their children. FSN was an informal learning context in which families from the Soaring Eagle Middle School community would gather on Friday evenings and participate in science learning activities with our research team. Families met once a month for FSN from February to May 2017.

METHODOLOGY

We conducted a field study of our SE public displays, similar to recommended methodologies of past public display research [13, 25]. From February to July 2017, we implemented the SE public displays in Rockdale and Susquehanna (Table 1). As noted earlier, all names of organizations and individuals in this study are pseudonyms.

Site Choices

Since context plays a major role in how public displays are used in the community, we chose to deploy the SE public displays in a variety of settings to provide a rich analysis across community uses. This methodological choice provided us with rich information about how neighborhood members came to, interacted with, and made sense of the SE displays in public, classroom, and after-school settings.

In Rockdale, we implemented the tangible displays in Grace Covenant Church (public setting). The church hosts approximately 300 members (children, families) who also interacted with the public displays during Sunday attendance. At the church site, we observed the public interactive screen during five Sunday services (before, during, and after service). We examined how church community members of all ages interacted with the display in a public setting. Several other after-school and summer programs also run in Grace Covenant Church, providing different contexts for the display in this space. Six researchers, one science teacher, and two community leaders served as facilitators in our after-school program. Thirty-six learners, twelve families, and ten parents regularly participated in the Rockdale program. Twenty of these learners attended our summer program with six researchers who served as facilitators.

In Susquehanna, we focused on three different settings at Soaring Eagle Middle School. The first setting was FSN, which included four events where families used the tangible displays. A total of seven families participated in FSN with the tangible displays. The second setting was Mr. McDonald's science classroom at Soaring Eagle Middle School. Mr. McDonald used the tangible display two consecutive days with his class of 30 students during lessons on interpreting data and graphs from climate science. Finally, we implemented the tangible displays in a week-long STEM summer program at Soaring Eagle Middle School in which two researchers facilitated the SE program for three days with three different periods (75 minutes each period, 225 minutes each day). Each period had between 8 to 10 children. A total of 28 children participated during the summer program.

Region	Neighborhood site	Types of activities	Number of observations	Number of participants
Rockdale (Mid-Atlantic USA)	Grace Covenant Church religious services and community events	Church members' interactions with the display before, during, and after service, and during community events such as concerts	Five Sunday observations for 150 minutes each day, and one community concert event	Approximately 300 members (children, families)
	Grace Covenant Church afterschool science club	Children's interactions with the display during afterschool and summer science programs.	11 observations for 90 - 120 minutes each	One science teacher from Westland Middle School, two community leaders, 36 learners, 12 families, 10 parents, and six researchers
	Grace Covenant Church summer programs	Interactions with the display of learners in a variety of summer programs held at the church	6 observations for 180 minutes during the summer programs	Three community leaders, three teachers from Westland Middle School (day 4 only), 20 SA learners, 60+ learners in other summer programs not related to SA, and six researchers
Susquehanna (Pacific Northwest USA)	Family Science Night at Soaring Eagle Middle School	Family interactions around science inquiry activities	Four observations for 90 – 120 minutes each	Seven families, composed of 20 children (ages 5 – 14) and 14 adults
	Classroom at Soaring Eagle Middle School	Students and teacher working on climate change data	Two observations for 75 minutes each day	30 students (ages 11 – 13) and one teacher
	Summer program at Soaring Eagle Middle School	Participant observers of a summer science program.	Three days of observations for three different periods (75 minutes per period)	2 researchers and a total of 28 children (ages 11 – 13)

Table 1. Summary of sites that utilized the Science Everywhere display

Data Collection

Field observations and analytic memos. In each context, the research team scheduled observations of public display interactions and wrote a corpus of field notes and analytic memos after each session.

Video recordings. In Susquehanna, we placed a single camera on the public displays to record interactions with the screen. In addition, other cameras captured the interactions of participants as they engaged in the activities. For classroom implementations, we focused cameras on activities that involved the teacher and the students interacting together. In Rockdale, we placed an audio recorder at the public displays to record conversations and also stationed members of our research team at the display to take detailed field observations.

To analyze videos, a primary viewer (a co-author) watched five to six videos and took notes on the activities and interactions with the screen. Next, a secondary viewer (another author) watched the same videos and added to the primary viewer's notes. Audio recordings were also transcribed for analysis. Altogether, our data corpus included over 60 pages of field notes and memos, over 24 hours of audio recordings, and over 34 hours of video recordings.

Interviews. We also conducted 16 interviews with 12 parents, youth, teachers, and community members on their engagements with the display across both Rockdale and Susquehanna neighborhoods. We were able to conduct interviews with four of these participants before (pre) and after (post) our display deployment. We interviewed 8 other participants after our display deployment (post only) until we achieved saturation in understanding our participants' experiences and perceptions. We asked questions about participants' engagement in community learning activities, reasons why they posted to the display, and personal thoughts on their interactions with the display. We also showed the interviewees samples of SE posts from the community to elicit their reactions and thoughts about posting and interactions with the tangible screens. Interviews lasted between 30 to 60 minutes. All interviews were audio recorded and transcribed.

Data Analysis

We employed a case-study approach, treating our deployment of SE displays as the bounded case [47]. Our selection of sites across our neighborhood partners was purposeful to provide us with comparison points that illuminated how public, classroom, and after-school contexts influenced the community interactions with the displays. We began by synthesizing our analytic memos, noting important aspects of the community interactions with the public displays as they unfolded over time. We selected pertinent moments based on (1) when participants interacted with the displays; (2) the context of display interactions, such as after a church service (public), during an after-school program, or in a classroom; and (3) the kinds of interactions that occurred with the public displays such as socializing, conversation, or presentations to audiences.

For our corpus of video and interview transcriptions and field notes, the project leads (first three authors) directed an open coding process with the larger research team. Using *Dedoose* [21], we open coded a select sample of data types including video, interview, and observation field notes, for different settings (public, informal, formal) from our corpus. From this process, we generated a codebook that tagged data based on the contexts of use (classroom, church, Family Science Night, etc.), types of practices with the display (directed and peripheral interaction, socializing, brokering connections, etc.), and people (parents, children, public) who interacted with the displays. As we applied the coding scheme to the rest of the data corpus, we amended the codebook when a new theme was identified. In a collaborative axial coding session, our research team then compared and contrasted codes to identify the emerging themes on the use of the displays. We triangulated these data with analytic memos, photographs, interviews, and recordings to ensure all evidence was supported by at least one other data source. From this process, we established common patterns and emergent themes.

FINDINGS

We organize our findings by first documenting the ways in which our partner neighborhoods interacted with the public displays. Then, we outline the community sensemaking that occurred around the public displays and its influence on bridging learning for children.

Community Interactions with the Display

Peripheral Participation. We observed many instances in which members of the public did not directly interact with the SE displays. Some instances of this behavior were in line with prior research on display blindness [33] where individuals did not notice or glance at the displays. However, we documented more nuanced ways in which neighborhood members came to the display and unearthed unique factors that influenced peripheral participation. In our field notes, we observed many adults in the two neighborhoods walking by the displays and not noticing or glancing at the displays as they passed. These behaviors were particularly prevalent in public contexts, such as Grace Covenant Church. For example, walking and glancing occurred after a church service as members walked through the hallway to leave. Even in formal situations such as community meetings at the church, we observed that parents kept their distance from the display.

However, an interesting nuance was the important role that children played in facilitating adult comfort and interaction with the displays. We observed vastly more instances of children walking by the displays and pointing or briefly touching and testing the interactive features before moving onward. Most importantly, we noted that children were often the initiators of the honeypot effect. Their noticing of and quick interactions with the display facilitated parental participation. A research team member wrote in a note:

> *"Maddie (1-year-old) walks by, stops at the screen and points. Her mom Caira responds to her, 'Cool! You want to watch the show? [referring to the display] ... When they walk back, Maddie points again."*

These brief interactions were important as they positioned children as the initiators and leaders. The children then involved more adults in the community who responded to them, watched them in the periphery, or even began to interact with the displays together with them.

Play and Socializing. The most common way that neighborhood members interacted with the public displays was through play and socializing. We observed much casual looking and scrolling through posts. A church member from Rockdale noted in an interview:

> *"So I was looking at different postings and playing around with it just to see – partly I think just experimenting, particularly when it was new and novel you want to come see how it works. I got to see just the kinds of questions children were asking about science in general..."*

The children in both neighborhoods often gathered around the display in social groups. For example, at the summer day camp in the Susquehanna site, we noted groups of three to four youth interacting together with the display with more youth watching. We observed our youth learners playfully scrolling through posts and giving each other badges. A common occurrence was "funny" uses of the display. For instance, we noted youth at the Susquehanna summer program rapidly scrolling through posts with both hands (on the split screen) and joking around as they played with the display. At Grace Covenant Church, we documented how a parent staged selfies of herself and her children using the display, and a father jokingly threatened to remove his daughter's badges (from her posts).

The children also crafted silly games with the display. In one instance, two brothers played together by using both halves of the split screen to mimic each other on the display at the same time. Using the display in this way meant that they could cancel out badges as one person gave a badge and the other immediately removed it. Children also conversed around the display, asking their friends, "Why did you do that?" or "What are you doing" as well as joking with each other socially. Finally, children spent time deliberately pushing the boundaries of our public display interface and trying to "break" the display. In three instances, we observed that children explored many distinct ways to touch the display (e.g., down the middle of the split screen, swiping to the side, using multiple fingers, etc.). We also documented an instance where a group of youths identified a bug in our software when they assigned badges too rapidly.

Overall, we viewed these forms of play and socializing as vital community behaviors that led to more comfort using the technology and serendipitous opportunities for other community coordination around the children's science posts, such as joking around, socializing, parent-child interaction, and more directed learning activities.

Performances with the Display. One example of a more directed activity was the different kinds of performances and presentations that occurred. By examining the display in different settings, we also observed how the nature of performance differed dramatically across public, after-school, and classroom contexts. For instance, in informal settings, the public displays sometimes served as a launch pad for different individuals to share stories with others or communicate their science observations. Youth, especially the younger children, were eager to share their posts with their friends and relatives. They enjoyed recounting experiments they had done or activities they experienced that were reflected in their posts. In the informal learning programs, educators or facilitators would often use posts on the displays to explain a program like Family Science Night or SE to new youth. Facilitators in these programs used the displays as a spark to ask certain children to explain their posts or interests. Sometimes children would also look for specific events or their friends' posts to show newcomers or family members. During Family Science Night, we observed children explaining their scientific posts when responding to questions by family members.

In contrast, within our formal classroom deployments, we observed that the displays tended to be used in a much more teacher-driven way. Our partner teacher often had very structured lesson plans, with time limits on tasks, and clear instructions for what students should – and should not – be doing in any given moment. In these contexts, we saw that the teacher often asked students to share very specific information on the displays, such as showing their answers to a question or their procedures for the class activity. Then the teacher used the display to refer to students' thinking, ask students to explain their thinking, and then move on to the next phase of a lesson. These uses of the display are not surprising in retrospect, as existing technologies such as blackboards, smartboards, and projector screens are common in classrooms – and thus teachers may transfer those mindsets of use to our public displays.

Community Sensemaking around Children's Science Learning

Our analyses began to illuminate how the interactions with the public displays related to community sensemaking and coordination to support children's learning.

Noticing the Richness of the Neighborhood: People and Assets. Children and families placed great value in noticing themselves and people that they knew throughout the neighborhood reflected on the public displays. For example, one parent noted that their daughter:

> *"became really interested in the app when she saw her own pictures on there and her own questions. She's like 'oh, what is this?' Because at first it was like 'oh, this is like a cool tablet', and now it's like 'wait, my questions and my pictures are up here'."*

Learners were also excited to show other adults such as facilitators, teachers, and peers where they appeared on the displays or posts they had made. In other cases, some facilitators would show learners where their posts or the learners themselves were shown on the display. Through their interactions with the public displays, the actors in our partner neighborhoods began to recognize the richness of the *people* and *assets* of the community, particularly around science learning.

Through interviews, we found that as community members and learners recognized their friends and neighbors, they began to relate the science ideas and activities that were expressed on the displays with the people and places they already knew. By recognizing other people, the displays oriented neighborhood members to note each other's ideas, afford opportunities to ask questions, have conversations, or build awareness of one another in the context of science. Neighborhood members also noticed the assets of the community such as the rich array of activities and learning opportunities that were present for their children. For example, church goers in Rockdale used the children's posts to learn more about the informal learning programs that were happening in that location.

We posit that this type of noticing – of what people in *my neighborhood* are doing and are interested in, or the opportunities that are latent and present in *my community* – is a fundamental building block for helping to support children to see how science relates to their everyday lives, relationships, and places. Since our design choice was to have individuals post about the science they saw in everyday life, neighborhood members began to expand their notions of what science was to also include the social, personal, and cultural ways that children represented their science learning.

Seeing Science in Everyday Practice. Similarly, parents and other community members reported that as they observed the display in use, they began to reflect more broadly about how science could be enjoyable and infused into everyday activities around the neighborhood. One adult acknowledged,

> *"Seeing like what all the students did ... I was like 'oh my gosh, science is like fun now'. I would probably do more science stuff if that were what science had been to me."*

The posts about SE projects also gave adults an opportunity to reframe science as an enjoyable, everyday activity, and began to shift some individual mindsets:

> *"... the students had done some project in terms of, was it the milk? The eggs... Eggs you buy from the store versus fresh eggs and how it impacted the baking of a cake. I was like, I really wanted to know the results… These aren't things we think about… but… that is obviously science right? ... So yeah, things like that I think are really interesting because then we are seeing [science] literally everywhere when you tie it in that way."*

A grandparent in the Rockdale neighborhood provided us insight into her shifts in thinking as she observed the display. Before we implemented the displays, she remarked to us that her perspectives about what science was:

> *"Science to me is the background of how something works or being able to dig through and find out how, for instance how the lights work. What happens back there? What elements have to go in place in order to make it work? I could be dead wrong…"*

And when asked if she saw children engaging in science in their everyday life, she stated, "I do not. I don't see kids in my community doing science projects.” However, when we interviewed her after our field deployment of the public displays, she described her perceptions as such:

> *“… we have a display in our church, and that people have been very interested, especially the kids, with seeing what’s going on… it’s amazing all of the little things that you can use to help implement science… I think it really helps the kids, kind of tweaks their curiosity.”*

She also noted some subtle shifts in her own thinking about the children in the neighborhood:

> *“… before this came along, I haven’t always thought of [science] in that manner, but it’s kind of really, I guess piqued my curiosity as well. I’m like, oh you’ve got kids that are actually being curious about life and learning how to… invent and look at things and see how it works. I think that it’s something that’s really wonderful.”*

Bridging Learning Opportunities Across Settings. The awareness of people and learning opportunities also related to neighborhood members beginning to act as bridges of learning opportunities for the children in different ways. For example, we note in our previous sections all of the instances where children explained their thinking and family members asked questions about their child’s activities as they noticed them on the displays. In these instances of conversation and storytelling, parents, educators, and other adults play an important role of learning from the children in the neighborhood; often asking young people to recall the learning they did in one setting (and reflected in the public displays) and explaining their learning in another setting.

Another role that adults can play in support of their child’s emerging interests, is to be a resource provider and engage in activities with their child [8]. We began to see parents in our partner neighborhoods think about opportunities to engage with their children and organize resources to support them. For example, several parents in the Rockdale neighborhood expressed a desire to volunteer for the SE church program after seeing the children’s posts about their activities. Additionally, in our interviews, one adult remarked that she began to think about what opportunities there might be to get funding for school activities, after being aware of the projects the children were engaged in. Parents also described making connections to home activities. One mother described how she facilitated science-learning experiences at home that were related to experiences she and her children had during FSN.

These instances provide vignettes into how parents and children can start to connect learning in one setting to another and to begin to see science as infused in experiences across settings. Adults also reported in interviews how they began to connect the topics and activities they saw in the posts to their own interests and experience. For example, one grandparent remembered a time she noticed posts on the public displays and noted to herself how her husband’s work as a repairman (plumbing, handyman jobs, etc.) involved investigation and problem-solving skills that are important in science learning.

One member of our neighborhood, Pastor Hicks at the church, provided us numerous instances of deeper forms of bridging practices. Pastor Hicks assumed the role of *broker* using the large display at the church in Rockdale, to connect children to new ideas, imaginations, and potential opportunities in other settings. We observed him on several occasions asking children questions about their posts on SE (e.g., where they were, what they were doing) and linking learners across contexts. In one instance, Pastor Hicks showed Rockdale learners some of the posts on the display from facilitators and researchers in Susquehanna. He then told the youth stories about the Susquehanna setting, which was across the country for them, to imagine how children and adults in other neighborhoods were doing these activities together with Rockdale.

In another instance, Pastor Hicks described a time when he attended a basketball game where two elementary-aged members of the church were playing. He noticed that one of the Science Everywhere participants (who is not a member of the church) was also on their team. When he asked the church members’ father if he knew the Science Everywhere participant, the father responded, “No, but I’ve seen him on the screen (i.e., the large display).” Pastor Hicks’ immediate thoughts went to connecting the families from his church to this new family based on their shared participation in Science Everywhere and the basketball team. In this way, Pastor Hicks often used the public displays to facilitate connection between different members of the neighborhood and to places and programs that were happening at Grace Covenant Church.

DISCUSSION: DESIGN OPPORTUNITIES TO COORDINATE COMMUNITY SUPPORTS FOR SCIENCE LEARNING

Our analyses have surfaced how our design choices integrating neighborhoods, learning programs, social media, and public displays, created an environment where neighborhood members could recognize the rich assets and opportunities for science learning that are embedded across settings. Not only do our analyses point to several design insights, they also offer new ideas for future research.

1. **Provide opportunities for “noticing” as a necessary ingredient to coordinate neighborhood supports for learning across settings**. Our work demonstrates that interactive public displays can spark individual and community awareness of science in everyday contexts. Through interactions with the neighborhood displays, we saw the development of productive seeds for community *scientizing* [17], where people began to see science as happening everywhere in the community and through their friends and neighbors. The SE displays functioned as a mirror for the community, helping individuals notice the richness of the people, places, and activities that were in the neighborhood.

2. **Public displays afford some bridging practices: conversations and sensemaking across settings**. As noted earlier, children used the displays as opportunities to explain their thinking from one setting to another. Family members noticed posts on the displays and asked their children about their interests and learning experiences, which they may not have been aware of without this public sharing. Past research in the learning sciences suggests that parents and adults can play important roles as teachers, collaborators, and co-learners with children [8, 22, 30, 42]. We found that public displays readily provide these opportunities for conversation, questioning, and explanation that enable adults and children to begin to learn together.
3. **Reflecting on public posts surfaces new potential roles for neighborhood members**. Learning sciences scholars note that adults can also play roles as resource providers, consultants, and brokers to new opportunities [8]. Our findings suggest that some parents began to see opportunities to volunteer, link their job and career experiences to the children's learning, or conceptualize ways to mobilize resources – such as financial or material support – for the children. In the case of Pastor Hicks, he illuminated for us how he used the displays as opportunities to connect children to new ideas or foster deeper connections between people in the neighborhood.

We also observed a key limitation and design need for future studies. In several of our interviews, parents revealed that many were not fully confident about what they could actually do to support the children's learning in the neighborhood (even if they were now aware). Thus, a design consideration to explore in future work is:

4. **Explicitly guiding community members to relevant roles they can play may better coordinate community support for children's learning**.

Our findings offer future researchers new sociotechnical design opportunities: How do we leverage the increased awareness that the public displays afford, and translate this awareness to inspire action by community members? What practices can we design, and amplify with community technologies, to help local neighborhoods further act to support science learning for children?

CONCLUSIONS: FROM BRIDGING LEARNING TO SMART AND CONNECTED LEARNING COMMUNITIES

This study contributes deeper insights around recent movements to design and study "smart and connected learning communities" (SCLC) [44]. The overarching vision of SCLC's is to leverage technology (mobile, sensing, big data tools etc.) to help facilitate learning across settings, build from community needs, and "smartly" coordinate human and social capital to support learning. One might imagine a future world in which learners can find relevant learning opportunities on the fly as they move about their neighborhoods or cities. Individuals may engage in projects that are deeply meaningful to them and have impact on their local community. They may also be recognized for these activities as markers of learning. Finally, learners could – in this far future vision – find help and social support more efficiently and equitably to further spur their learning forward.

How do we design to realize this far-term vision? Our current study explores a few design conjectures and illuminates some future needs. We show how technologies that deepen awareness of a neighborhood and its rich assets is a fundamental need, and our findings support past research, such as Carroll and Rosson's work on community technologies to build connectedness [13]. We build from Erete's framework of community technologies [23] and show that SE was well designed for social cohesion (helping people recognize each other and assets), small group interaction (within a classroom, church, or afterschool program), and interest-based groups (promoting science awareness in the neighborhood). However, we found that another major challenge is the promotion of social capital or translating this cohesion, interaction, and interest into *action* that can bring more resources to support children's learning.

Overall our study offers design and qualitative accounts that may be translatable for future SCLC projects. Designers can build from the design decisions we made, and the prior HCI literature on creating public displays and social media [2, 4, 31], to coordinate the sharing of learning in communities. Decisions about technology, interaction design, and the issues of designing for community practices, privacy needs, and the unique contexts of children and families will be important to realize any future initiative. Furthermore, we hope that our documentation of how we embedded SE technologies in partnership with neighborhoods, can provide templates to build upon for future community-facing, design research around SCLCs [28]. Our findings point to the complex challenge of coordinating factors such as awareness, social connection, institutions, learning practices, and social capital to realize the full potential of smart and connected learning communities of the future, that provide equitable and innovative learning ecosystems for learners everywhere.

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