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Multi-Site Case Studies About Zoo and Aquarium Visitors' Perceptions of the STEM Learning Ecology

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ABSTRACT
Informal learning institutions like zoos, aquariums, science centers, and botanic gardens are popular among the American public. Many offer science-related activities, suggesting an "ecology" of sites varying in degree with regards to science and STEM (science, technology, engineering, math) learning in general. Understanding public perceptions of the STEM learning ecology can inform decisions about increasing STEM literacy in the United States. The current qualitative study used interactive workshops to understand the public's perceptions of zoos and aquariums (Z/As) in particular, compared to other settings, for their potential to support STEM learning. Visitors identified a wide range of settings in institutions and their everyday lives where they experienced STEM learning opportunities. The primary STEM discipline they encountered was science, even though the opportunities were not explicit. They also recognized that these settings offer the potential for learning about technology, engineering, and math through staff facilitation. They distinguished Z/As from other cultural organizations because of opportunities to learn about science as it related to animals. Implications for STEM learning in informal settings are discussed for its potential to engage the public in STEM outside of the formal education context.

Informal learning settings permeate contemporary human experiences through influences and interactions in the social, physical, and natural environments. These settings go beyond the formal K–12 education system and include, but are not limited to, cultural and science institutions (e.g., museums, zoos, aquariums, botanic gardens, libraries), social encounters with reference groups (e.g., friends, families, colleagues), and engagement with mass media (e.g., print, broadcast, social media). They are referred to as "free-choice" learning settings that offer opportunities for learners to choose and control how they engage and what they learn (Heimlich & Falk, 2009; Falk & Dierking, 2013; Rogoff, Calanan, Gutierrez, & Erickson, 2016). Learning occurs through voluntary interaction with the elements in any given setting and is inherently personal, whereby the learners' past experiences, motivations, and interests influence how and what they learn. The current study describes a qualitative research effort documenting the ways in which visitors at zoos and aquariums (Z/As) learn science, technology, engineering, and math (STEM) in different settings in their daily lives. In particular, the study aims to understand how visitors perceive the STEM learning ecology, or the spectrum of contexts where STEM can be learned, and where Z/As fall within it.

Experiences of learning in informal settings

In the United States, the popularity of informal learning institutions like museums, zoos, and aquariums is evident in the number of visitors annually at such settings, namely in the millions (Schwan, Grajal, & Lewalter, 2014). Learning is not necessarily the primary motivation for these visits, with interest in social experiences and enjoyment within these settings being the main attractions for the public in general (Ballantyne & Packer, 2016). Rather than learning being a discrete experience, scholars have drawn attention to the opportunities for socially constructed learning—most notably science learning—these settings provide, which are different from structured, curricular-based learning in formal settings like K–12 and higher education (Falk, 2005; Heimlich & Horr, 2010; Sacco, Falk, & Bell, 2014; Tal & Dierking, 2014).

A useful theoretical framework to study informal science learning emphasizes the multifaceted ways in which learning can manifest in such settings (National Research Council, 2009) describing six "strands" of science learning. This framework is especially relevant because it expands the idea of learning beyond knowledge retention to capture the socioemotional experience that includes *interest* (motivation to learn about the natural world), *inquiry skills* (the ability to test and make sense of the natural world), *scientific thinking* (reflection on science as a way of knowing), and *self-perceptions as science learners* (identification as someone who knows about and contributes to science). By conceptualizing the science learning process in informal institutions to engage the public in a holistic way, the framework highlights learners' affective, behavioral, and cognitive experiences as they engage in learning.

A key characteristic of informal science learning settings is that when in these spaces, learners control what and where they choose to process new information (National Research Council, 2009). Regardless of the various exhibits, interpretation, and programing opportunities available in these settings, learners (or visitors in institutional settings) process new information in a voluntary manner, that aligns with their interests and enables a level of ownership to their learning process. Scholars of informal science learning settings have highlighted that this volitional aspect of learning helps foster more motivated, curious, and empowered learners, who may continue to express interest in the topics they learned even after their experience within the settings (e.g., National Research Council, 2009; Rennie, Feher, Dierking, & Falk, 2003; Sacco et al., 2014). As such, informal science learning settings are ideally situated to foster science learners and enthusiasts who may potentially apply the learning in different aspects of their lives. Yet, the phenomenological experience of learning in these settings is often overlooked, focusing more on learning outcomes, such as those measured through the strands of science learning (Sacco et al., 2014; Falk et al., 2016). Given the active roles learners are presumed to play in informal learning settings, we see this as an understudied area for advancing visitor learning and institutional capacity building.

It is noteworthy that the research on learning in informal settings primarily emphasizes experiences with science, relative to the other disciplines subsumed under STEM (i.e., technology, engineering, and math (e.g., Basham & Marino, 2013; Bybee, 2010). As a result, there is limited knowledge in the literature of how informal learning settings foster learning of all STEM disciplines. This trend points to a critical gap in efforts to advance STEM learning, despite it being a major focus of federal investment (National Science Board, 2015). As such, the vision to foster knowledgeable, skilled, and motivated STEM learners and problem-solvers, seems to rely on advancing science learning, whether as a discrete discipline or to encompass the other STEM ones. To fill this gap, the current study explicitly studied visitors' perceptions of their experience learning all STEM disciplines and their perception of the learning ecology where they occurred.

STEM learning ecology

Very generally, a learning ecology has been defined as a spectrum of physical, social, and cultural contexts where learning occurs (Bevan, 2016). Similar to natural ecosystems, learning ecologies are characterized by their physical characteristics and the interactions that occur there, which include social dynamics, the role of value systems, and cultural histories that people can learn over time. Bevan suggests a rich STEM learning ecology would include a range of programs, across institutions and places, that present multiple opportunities to engage with the topics associated with individual STEM disciplines. In essence, the socio-cultural aspect of the learning ecology is key to the framework Bevan describes, and captures the following types of learning as presented in Table 1.

Table 1. Types of learning.

Types	Description	Citation
1. Formal	Most closely associated with elementary and secondary education and most degree and certificate programs offered by colleges and universities	Mocker and Spear (1982)
2. Nonformal	Facilitated by an educator who is responsible for the outcome, the methods, and the setting and includes all programmatic, structured, organized learning efforts outside formal education, such as shows, programs, workshops, lectures	Heimlich (1993), Heimlich, personal communication, June 30, 2017
3. Informal	Learning opportunities are present and typically self-directed, but may or may not have clear and explicit learning objectives associated with them. These include interpretive programing, signage, and in-person interpreters.	Heimlich, personal communication, June 30, 2017
4. Incidental	Mediated learning when individuals construct meaning from a definite message, with the caveat that what people "learn" is incidental to their engaging with specific kinds of media (TV, movies)	Same as above
5. Everyday	Learning from conversations, random exchanges, and overheard things that happen during everyday life	Same as above

The learning types in this table are not necessarily discrete in nature and are possible in different settings. Nevertheless, they provide insight into how learning occurs in interaction with the content, format, contextually relevant social actors, and the learner and suggests a diverse learning ecology. In the current study, we aimed to explore public perceptions of the STEM learning ecology in particular, to understand where and how STEM learning occurs. Perceptions of Z/As in relation to other settings for their STEM learning potential were of particular importance in this study to expand on past research on favorability of these institutions (Falk, Heimlich, & Bronnenkant, 2008; Falk et al., 2007; Fraser&Sickler, 2008; Schwan et al., 2014) to learn about other ways the public views them.

Method

Study context

The study was conducted as part of the National Science Foundation-funded STEM Matters: Investigating the Confluence of Visitor and Institutional Agendas initiative (DRK-1612729 and DRK-1612699) led by researchers from three institutions—Knology, Oregon State University's Center for Research on Lifelong Learning, and COSI's Center for Research and Evaluation (CRE). The project aims to study the public's perceptions of Z/As as part of nonformal and informal STEM learning ecology.

Study design

A qualitative exploratory study was conducted by Knology through a series of six interactive workshops comprising participants that have memberships at one of six purposefully selected Z/As located across the United States. We started the selection process by identifying institutions with which we had had recent professional affiliations and selected six that covered a wide geographic region across the United States. The institutions represented the Northeast, Southeast, Midwest, and Southwest. Researchers emailed professional contacts at the six purposefully selected Z/As to solicit interest in supporting the study. A specific category of visitors, members, were chosen for this research. Z/A members were the focus of the research because of their potential to visit the institution on multiple occasions and engage closely with their affiliated Z/A, suggesting they could reflect critically on their STEM learning experiences. Two main questions guided this research:

1. What STEM learning opportunities do visitors experience at Z/As?
2. Where do visitors situate Z/As within the STEM learning ecology?

Participants and recruitment

Workshops were held in three zoos, two aquariums, and one combined zoo and aquarium facility, across the U.S. Northeast, Southeast, Southwest, and Midwest. These institutions were selected to reflect a range of demographic and regional voices. We provided partnering institutions with an invitation message to be sent out to

Table 2. Workshop attendees at six zoos and aquariums in the United States.

Zoos and aquariums in order of workshop date	Location	Attended	Affiliated with STEM field
Zoo	Northeast	4	3
Zoo	Southeast	5	1
Aquarium	Southwest	8	2
Zoo and aquarium	Midwest	12	0
Aquarium	South	11	0
Zoo	Midwest	7	3

Note. STEM = science, technology, engineering, and math.

members. The institutions randomly selected between 200 and 400 members to receive the invitation email. In some cases where the initial invitation did not yield sufficient response, the institution invited a second group of randomly selected members.

Interested invitation email recipients followed a link to fill out a Qualtrics survey with their name, email address, age, ZIP code, race and ethnicity, gender, and availability for the workshop date at their institution. They also indicated the frequency of their visits to the Z/A on a multiple-choice question and an open-ended one about their favorite part about visiting the Z/A. The questions were part of a screening process to help select participants representing a range of demographic factors.

Most of those who filled out the Qualtrics survey were invited to participate in the interactive workshop. Some respondents were excluded based on their lack of interest or scheduling conflicts. Where multiple individuals represented the same demographic categories (e.g., the same age, race, education level, and approximate income as inferred by ZIP code) and there was an adequate recruiting pool, a few respondents within the common demographic category were randomly excluded from receiving an invitation email. The final group of attendees were mostly Caucasian, reflecting the original group of respondents who expressed interest in participation. Of the 47 members who participated, nine were affiliated with a STEM profession, as they described in response to a question about their profession during the workshops (Table 2).

Instrument and data collection

Pairs of researchers conducted the workshops—one facilitated the workshop and the other recorded hand-written notes of the discussion. No audio recordings were made because it would be difficult to capture the conversation during the dynamic, interactive nature of the workshops, where participants were often moving around. We structured the workshop so that participants wrote on flip charts and post-it notes that they organized on walls or tables, as they moved around the space. The protocol[1] was developed to engage small groups of members (8–10) in an interactive discussion covering the two research questions. We aimed to leverage the dialog among the participants as part of the workshop process where they used each other's hand-written notes to help discuss and construct meaning about the idea of STEM learning and where they encountered it. We developed the protocol so that participants would be able to respond to each other's comments as they found commonalities or differences in perspectives.

After the first three workshops, researchers revised the workshop format for the remaining three groups to refine the flow and ease of the activities. The protocol changes also allowed researchers to assess the framing that most effectively helped participants to think about the STEM learning ecology. In both versions of the workshop, the discussion started by asking participants to define the STEM acronym. Participants were then asked the following questions to initiate the first interactive activity:

1. What is STEM learning?
2. At the [name of Z/A], what are some STEM learning experiences you have had in programs?
3. At the [name of Z/A], what are some STEM learning experiences you have had from exploring the Z/A?

In the original version of the workshop protocol, the second activity involved asking participants where they learned STEM in their daily lives beyond the Z/A. They were asked to use post-it notes to indicate the different settings in their daily lives where they encountered STEM learning, and then as a group organize the settings by clumping them based on themes. Groups followed this activity with a discussion of how and why they perceived similarities across the settings. Researchers also facilitated a similar discussion about the settings that were not grouped together, to understand how they were distinguished from the others.

In the revised version of the workshop protocol, the order of the two main activities was reversed. As a result, after the question about the acronym STEM, and how participants thought about STEM learning, the first interactive activity asked about where they encountered STEM in their daily lives. They were again given post-it notes to write out and reflect on the STEM learning ecology in their daily lives. We anticipated that initiating the workshop to consider the STEM learning ecology broadly would help them more effectively situate Z/As within the ecology. That is, the frame of reference would help them articulate the parameters of where and how STEM learning occurs. We noted that for the last three workshops, the conversation flowed more smoothly compared to the preceding three—that is, they were better able to transition to thinking about STEM learning at the Z/A after having thought about the STEM ecology in general. Even though we changed the order of activities, in our first pass reviewing the data, the quality of the data was similar across all six workshops.

Analysis

The analysis was initially undertaken using the framework that described the spectrum of learning opportunities. The framework described formal learning, nonformal learning, informal learning, incidental learning, and everyday learning. We acknowledged the implied continuum suggested in the learning types, starting with the most and continuing to the least structured experiences possible. In addition, based on the definitions, we acknowledged that institutions such as Z/As offer opportunities for all five kinds of learning.

Within each of these experiences, we identified the different kinds of settings, the STEM discipline and topic that could be learned, and the specific experiences and processes that helped the learning. Through an iterative analysis process we discussed the research process and emergent findings with colleagues to check for credibility of the findings (see Krefting, 1991). As a result of this peer examination process, we identified the need to reorganize the results to reflect the multidimensional experience described by visitors, encompassing the settings, learning modalities (processes and activities that help people learn), and educational impacts of these experiences. For the learning modalities, in particular, we used Gardner's (1993) theory of multiple intelligences that describes people's intellectual strengths and the multifaceted ways in which we process information and engage with it. The intelligences include verbal-linguistic, logical-mathematical, visual-spatial, and bodily-kinesthetic among others. In this study, we used the framework of multiple intelligences post hoc as a way to interpret the complex interactions that workshop participants described. This helped us describe the different modalities through which people describe learning STEM in a range of places. In addition, we used the Framework for Evaluating Impacts of Informal Science Learning (Friedman, 2008) to help organize the learning impacts described by the Z/A members who participated in workshops when they mentioned informal science education institutions. Five major categories of impact (knowledge, interest, attitudes, behavior, and skills) from this framework were used to identify themes related to learning at Z/As in the workshop data. We looked at how engaging with STEM in these informal science settings helped people foster knowledge (awareness or understanding of a STEM-focused topic, concept, or phenomenon), develop interest (enthusiasm about a STEM-focused topic, concept, phenomenon), influence attitudes (expressed through beliefs, emotions, and behaviors towards a specific STEM topic, concept, or phenomenon), promote behaviors (actions related to the STEM topic, concept, or phenomenon), and develop skills (ways of doing and thinking, often manifest in engaging in scientific inquiry skills or practicing very specific skills related to scientific activity).

All data was analyzed at the workshop level, such that all reported numbers in our results denoted the number of workshops where a theme or idea was presented.

Results

In all six workshops, at least one participant in the group was able to explain the STEM acronym. This response resulted in minimal conversation about the meaning of the acronym, once it was described as including science, technology, engineering, and math. In one workshop, an attendee with a STEM background also mentioned the derivatives of STEM (e.g., STEAM, including the arts; STEM + CS, including Computer Science; and E-STEM, where the environment is a pathway to STEM).

Participants articulated how they understood a STEM learning setting by describing the physical context, modalities of learning, and the topics learned. They often described these aspects as connected, indicating the complex processes at play in a STEM learning setting. For this reason, we reorganized our initial analysis with the learning types to emphasize the settings, learning modalities, and educational impacts that occur as we describe the STEM learning ecology.

What is STEM learning?

Five of the six workshops discussed this question about STEM learning. In these workshops, participants conceptualized STEM learning in a number of ways. We present the nuanced ways that workshop participants described STEM learning in the following sections.

Content knowledge was brought up in four workshops in relation to science (e.g., learning how our bodies work), math (e.g., in calculating population density, ecoload), engineering (e.g., how we build things), and technology (e.g., computer modeling), as well as learning unspecified STEM content (e.g., playing video games). The applied emphasis was evident in how the content related to human life, such as how doctors help patients and how buildings are designed.

Two workshops brought up **building things in relation to engineering**. In one of them, participants provided the example of a STEM-focused camp, that involves hands-on experience as a place where STEM learning occurs. Hands-on learning was alluded to in another workshop, where a participant referred to Waldorf learning (Barnes, 1991), engaging learners holistically through body and mind.

Scientific thinking was identified in three of the workshops. One workshop characterized STEM as the basis for inquiry, the common ground between the four STEM disciplines. In a similar way, one workshop discussed the potential of STEM to encourage exploration and inquiry. Rather than using STEM merely as a buzzword, they asserted the term can help bring curiosity into the classroom rather than initiating a one-sided lecture with information, as is typical in classrooms. To illustrate this point, one participant described how an educator might simply present the periodic table, without applying it to real life situations. Workshop participants also suggested that STEM learning helps develop broad problem solving or logic skills not specific to a particular discipline and applicable across disciplines.

All workshops mentioned STEM's role in **fixing social and environmental problems**. For instance, they said the field could impact the job market by providing employment opportunities; they also described it as a means to address global challenges such as climate change. The social implications of STEM did not stop there, however. Participants in two workshops reflected on the gender imbalance in STEM fields. Even though they did not necessarily reflect on the causes or meaning of this imbalance during the discussion, the different implications for men and women were very salient for them. In a separate workshop, engaging girls in STEM-focused camps was highlighted as a way to use hands-on learning to pique interest in STEM topics (e.g., engineering) and future careers. One participant that was a parent spoke about her daughter explaining that "she came back [from the camp] with a whole new sense with [sic] what she could do in the future. She wanted to be an art teacher, but then said, 'I can be an engineer.'"

Another social implication discussed was the accessibility of STEM subjects. In two workshops, participants called for STEM topics to be better presented so kids and adults can relate to them. This theme also came up in relation to the value of experiential learning through which STEM subjects, such as math and science, could be brought to life in an immersive way.

The **collaborative experience** of learning STEM was brought up in two workshops. Examples given by participants included being part of a family of engineers who learn by sharing or group observations of a specific phenomenon. Participants noted that when the phenomenon is observed by a group, the group talks about it with each other.

STEM learning ecology

We note that workshop participants were not prompted with the phrase "STEM learning ecology" at any point during the workshop. Rather the researchers interpreted the discussions during the workshop to identify the ecology or the range of settings, modalities, and topics the participants felt were part of their STEM learning experience. A key observation was that workshop attendees discussed different aspects of STEM learning, without identifying *the extent to which* different settings facilitated STEM learning. For this reason, we were unable to assess the relative extent of STEM learning in these various settings; rather, our intent with organizing the STEM learning ecology into settings, learning modalities, and STEM topics was to document the richness of the learning experience that visitors perceived when they engaged with STEM. Just as ecology is the study of the interactions of living and nonliving things, so too the STEM Learning ecology encompasses the interactions of a variety of physical (e.g., settings) and nonphysical (e.g., STEM topics or learning modes) elements. Although the following sections are presented as discrete experiences, we emphasize the interconnectedness of each in the ways workshop attendees described their STEM learning experiences. Settings are presented first to reflect the frame that helped contextualize where and how they occurred.

Settings. Participants described STEM experiences in a variety of settings including in established, institutional settings such as science centers. They felt that informal science education institutions (ISEIs) were a particularly valuable source of STEM experiences, especially science. The following two examples demonstrate how participants reflected on STEM learning in different ISEIs, in these cases, at a science center and at a local historical society.

> [The science centers] have educational standards … and the things in the exhibit are aligned with those standards … You could do a math activity based on the exhibit. There are ways to take the topic and you can still tie it into learning.

> At the historical society, they had a room and setup like a pharmacy and they had [a local health care provider] there and they had the pharmacist … and a person who would answer the question like you were back in that era. I thought it was really interesting to see how you can learn that way.

One of the workshop groups highlighted that informal STEM-based institutions cater to different learning styles (e.g., children with attention deficits) who may have difficulty with traditional classroom or reading-based learning.

In addition, they felt that information provided through online resources could also provide STEM experiences. For example, participants discussed videos, either live-streaming (e.g., footage of bald eagle nests that teach about animals) or of educational information via YouTube. They also mentioned online newsletters of organizations, like World Wildlife Fund, for news and information.

Broadcast news stories and TV programs (including trivia game shows) were mentioned as vehicles that highlight STEM through both current issues and more historical coverage. Three workshop groups mentioned physical places that engaged people in hands-on creating and building, including maker-spaces (do-it-yourself spaces for communities to create and learn).

Participants also described places where the general public encounters STEM activities but may not necessarily fully engage in the activities. These settings included maintenance and auto repair shops, IT shops, hospitals, pharmacies, general business offices, biomedical shops, grocery stores, restaurants, and at home. At stores, engagement with math was described as follows:

> In the store you are using math. With my son we have him calculate how much we are spending total, as we add things to the cart, and then we see how close he is when we check out.

Engagement at home can happen both inside and outside in the residential property. The following exchange demonstrates participants' different views of science learning through cooking.

> X: For cooking, you didn't use math?
>
> Y: Cooking is chemistry—not algebra
>
> X: What about measurements?
>
> Y: They are labeled.

The next illustrates how science learning can happen in the backyard.

> In the backyard we have a rock collection and [the kids] are learning about science. Even [with] my two-year-old, we have a ball in a tube and we talk about how the ball in the tube goes down.

Three groups described STEM experiences in "impromptu settings" that were "pleasure-based," such as during nature walks, or participating in cleanups at a local river site. That is, even though the motivation to engage in these settings was not to learn STEM, they perceived opportunities to do so anyway.

In the next section, we present workshop groups' reflections on the modes through which their STEM encounters occurred across the various settings. We emphasize these are not discrete experiences, rather they often happen simultaneously.

Learning modalities

Three groups identified a common thread between the informal learning settings (including museums, zoos, aquariums, nature centers, botanical gardens, libraries): their role in presenting information in a strategic way (e.g., through exhibits and interpretation) to engage visitors in learning. Participants distinguished libraries from museums, because they were seen more as places that offered information, without necessarily having interpretation opportunities (e.g., intrapersonal learning).

Interpersonal. Interpersonal learning highlights how learning occurs through interaction with other people. Five workshop groups highlighted facilitated experiences. Participants shared that a variety of ISEIs, like nature centers, can provide nonformal learning in the form of instructor-facilitated programs or staff-facilitated interactions, in addition to self-directed informal learning. They also recognized the value of facilitated learning in out-of-school spaces. Participants in the workshops felt that engaging with docents, volunteers, or tour guides who help explain signs aid engagement in various ways. These include personalizing the learning experience, explaining complex biological information, or relating biology to conservation in simple ways (science focused). Examples include engagement with tour guides or speakers (e.g., on a tour about migrating cranes) to dig deeper into specific topics and make the content material more engaging. As one participant described, "Interactions with well-trained volunteers provided an immediate answer to my kid's question."

Visual-spatial. In all six workshops participants described the role of signs in informing visitors about the animals. One group mentioned how artistic creations can also support learning. Digital experiences such as interactive online learning was described in relation to Google Earth as an opportunity for free-choice learning. Similarly, playing video games (e.g., Minecraft) was thought to develop engineering, problem solving, and spatial skills. An exchange between participants demonstrated how they were thinking about video games and STEM:

> X: For Minecraft, you have to have a plan for what you want to build.
>
> Y. Does it take hand/eye coordination?
>
> Z: I would say Engineering too. It isn't just hand eye coordination, you are problem solving too.

Intrapersonal. Intrapersonal learning can occur through introspection, a function of the learner rather than the learning materials themselves. Participants alluded to such learning when they described how content in signs can provide in-depth information about animals in Z/As that visitors can reflect on privately. In other words, signs may be considered more than just a tool for visual-spatial learning.

Bodily-kinesthetic. Participants in five workshops identified informal learning settings as offering opportunities for kinesthetic learning, an interactive process engaging the body in learning (e.g., manipulation of objects through touch). Informal learning settings like science, aerospace, and natural history museums were described as offering tactile experiences. Participants of one workshop discussed the Kennedy Space Center as enabling immersive learning, where visitors can feel and experience the launch of the Apollo 8 mission, with the help of a simulator. They thought the interactive and entertaining experience helps kids engage with space technology.

Bodily kinesthetic learning was emphasized in settings beyond informal learning settings. Three workshops described how sports can engage people in STEM. Spectators and announcers use math to keep score. Playing sports immerses individuals in kinesthetic learning that can lead to understanding the laws of physics. For example, in baseball, one participant described how players must judge how fast to run, based on how far the ball is thrown. Similarly, the body is used to judge water resistance while swimming, as described below:

> It is figuring out how to get better at the sport and how to make your body do what you want it to do. I feel like it is experiential like driving. Understanding some basic physics principles, understanding how water resistance works.

Three workshops saw Z/As as having slightly different roles in supporting STEM learning. Participants felt aquariums have a slight advantage over zoos. Aquariums were seen as more effectively creating and supporting the natural habitats of flora and fauna, compared to zoos. They felt being immersed in the animals' environment helped them better learn about habitats and ecosystems. We explore these themes in greater detail in the following section, honing in on the unique experiences at Z/As.

Learning at zoos and aquariums

Participants' experiences at Z/As indicated some specific themes related to Friedman's framework on impacts at informal science learning settings that differentiated these institutions from other ISEIs. Although participants did not mention these themes themselves, our research team noted them during the analysis process. In addition, these themes reflected the learning modalities from Gardner's framework, often with overlapping experiences, that characterized STEM learning across contexts. We have indicated explicitly how the impacts related to the learning modalities as appropriate.

Knowledge growth

At Z/As, participants in all workshops felt that learning primarily focused on new information, facts, and content related to animals and their habitats. A typical example of this is demonstrated in the following statement:

> It is more about the ecosystems and what makes them that way and why [they are] the way they are. The chats that they do during the day, and you can dive deeper into the specifics of one animal or biome.

Learning at exhibits could be supplemented with a focus on technology, through the use of phone apps, or on engineering, with descriptions of how animal habitats were built, or on math, through calculating the amount of food needed to feed the animals or counting animal interactions. We recognized that learning at exhibits provides visual information and the opportunities for intrapersonal learning. Participants discussed the value of exhibit labels about animals, including their scientific names and natural habitats (science-focused), or information about their numbers such as comparisons of human and animal population growth (math-focused).

Exhibits focusing on science topics (e.g., local ecology) may also be designed and structured (e.g., a desert dome) to highlight how engineering, science, technology, and math are all evident in its built presence.

Flora at the zoo, especially in constructed garden areas, was also identified as building awareness of STEM. Specifically, zoo flora highlights engineering in the design and landscaping, and helped participants understand the plants' role and impact in the ecosystem.

Attitudes

Participants pointed out that animal encounters can help reduce fear about certain species. For example, a participant in one group shared that an aquarium creatively used "scary shark music" with dolphins and cheerful music with sharks to demonstrate how impressions can be created. We see that the learning experience was tied to auditory information, highlighting how sensory experiences (similar to visual ones) can influence attitude formation.

Live animals in particular are seen to influence emotions such as empathy, as one participant described:

> It elicits different emotional responses when you see the live animal compared to a dead one in a museum. There's a recognition that there's this living animal here, but look what we've done to its habitat or we're going out and killing them for trophies. Essentially, conservation is what it's teaching you. We're connecting the animal that's here and alive to what's happening in its home environment.

In this case, the participant reflected on the emotional connections made in the exhibit and how it may foster positive attitudes towards environmental protection.

Interest

Participants felt that the interactive experiences with animals at Z/As help children engage with different aspects of STEM. They perceived interacting with animals as emotionally charged, offering opportunities to reflect on humans' place in the ecosystem and how their own actions and that of humans as a whole can have negative environmental impacts. We see that interest and enthusiasm in continuing to learn about the animals was fostered through close contact with the animals, including at petting zoos and touch tanks. A participant described how visits to the local zoo had fostered enthusiasm and interest in their children:

> My kids have learned a LOT of things about the world because of the Zoo. My son wants to have a farm because of the Zoo. When my husband comes, he pays attention to the construction of things and talks about how they've made decisions with the architecture. I know [husband] said he doesn't understand how it ties in, but without STEM, we wouldn't have any of this stuff at the Zoo.

Behavior

Workshop participants felt that learning about animals is strongly linked to learning about conservation and the role Z/As play in it. A participant in one group said that restaurants at Z/As can publicize information about food sources and create opportunities to discuss the source of the food. They pointed to additional ways that Z/As can engage visitors' learning whether through information provided visually through signs, resources, or interpersonal communication. Such restaurant experiences could be extended to other ISEIs that publicize their sustainable and/or local cuisine culture to facilitate behavior change.

Skills

Skill development can manifest as general (e.g., questioning or inquiry) or very specific skills (e.g., measuring dissolved oxygen levels in water). Participants felt that Z/As offered opportunities to practice and observe these skills. They also acknowledged the value of certain skills such as engineering for creating plans and drawings; technology for ensuring water availability, climate control, and power; and math for calculating space needed for people or animals. One workshop discussed how lack of adequate parking at the institution that they visit helps to think about math and engineering in problem solving to provide greater access to disabled and older visitors. These examples of skills developed or needed indicated intrapersonal learning, through the experience of close observation and reflection.

Discussion

The results of this exploratory study revealed a STEM learning ecology as perceived by members of a purposefully selected set of Z/As, who participated in workshops. They described their experiences of STEM learning in different aspects of their lives, indicating the learning potential in diverse contexts and settings. Their responses reflected an implicit awareness that the settings were on a continuum of possible STEM learning experiences, ranging from settings with limited opportunities to those with an abundance. In fact, workshop participants found it challenging comparing the extent of learning in the settings they described. Although not intuitive at the start of the study, the results indicate a possible reason for this as described next.

A complex phenomenological experience

Participants described their STEM learning experiences as a complex interplay between settings, modalities, topics learned, and the outcomes they perceived as learners. In a way, this finding reinforces the richness of the learning experience, as described in the informal science learning literature (e.g., Falk, 2005; Falk, Dierking, & Adams, 2006; Falk & Needham, 2013; Sacco et al., 2014) and further underscores the holistic engagement of learners' social, emotional, cognitive, and behavioral faculties in these settings. The guiding question for the research suggested a focus on the physical setting as a way to understand the STEM ecology and *where* it is situated; this question needs to be reconsidered in light of the data available regarding aspects of learning that manifest (e.g., modalities) regardless of the physical context. Consequently, it led to rethinking the analysis to describe the intricate and interconnected ways in which participants described STEM learning, referring to skills, attitudes, and knowledge gained, as well as the modes through which learning occurred.

The findings thus raise questions about the way to conceptualize and describe the STEM learning ecology. Specifically, the definition of ecology in this term needs further evaluation, as a start. On a related note, the dimensions that best describe the STEM learning ecology experience need to be examined further, to understand the profiles of learning experiences that characterize informal STEM learning. Such profiles could better identify the exact nature of the relationship between the topics, modes, and outcomes. For example, the modes through which people engage with STEM topics (e.g., visual-spatial, interpersonal) could explicitly connect learning to specific intellectual abilities as captured through Gardner's (1993) framework of multiple intelligences. Moreover, the profiles may identify modes of learning that best characterize learning in a particular setting. Though speculative at this point, these learning profiles may offer insight on the varied intelligences people rely on in specific settings. Given the prevalence of potential learning opportunities in multiple contexts of people's lives, it may benefit the field to be able to document the degrees of STEM learning possible in each. From the public's point of view, further research may provide additional opportunities for people's engagement through places and experiences that support more STEM learners.

Structured and organized settings

Though they didn't explicitly mention it, research participants' responses suggested that STEM learning occurs most explicitly at structured and organized contexts in informal learning settings (e.g., museums, science centers, zoos, aquariums, and nature centers) compared to those where learning is more self-directed (e.g., nature walks, at home, shops, banks). They felt the learning happens through signage, facilitators, immersion, interactions within their group, and encounters with animals. They stated that these informal opportunities offer similar learning outcomes to those of organized programs, talks, and workshops that enable more nonformal learning possibilities. In fact, nonformal learning options were intertwined with informal opportunities, the few times the former was raised. Participants rarely mentioned formal settings, which may be due to their completion of formal education. Extending the continuum, they also felt that Z/As provide greater STEM learning opportunities—including both in-person and virtual—than cultural organizations like art museums and libraries.

Everyday STEM learning experiences are common

Everyday experiences were described as a prominent context for participants to learn about STEM concepts. Interactions with money, hands-on learning through building things, and sports featured commonly in group discussions about daily life activities that promote STEM learning. Participants acknowledged that although STEM learning through these everyday settings is possible, it needs to be developed through facilitated discussion, as a result of its implicit nature. The gap between learning implicitly and awareness of this process from a subjective point of view has been pointed out (Cleeremans, Allakhverdov, & Kuvaldina, 2019; Frensch & Rünger, 2003). They argue that even though researchers acknowledge that implicit learning is critical to attend to stimuli in our environment and engage in relevant actions and thoughts, the extent to which it is a conscious experience is unknown. Based on the results from this study, we suggest that for STEM learning outside of structured informal settings, there may be opportunities to study mechanisms that enable people to be more aware of how they learn.

Science learning is the primary focus

Of all the STEM disciplines that participants considered, they found it easiest to describe encounters with science. In contrast, workshop facilitators had to ask follow up questions and probe further about experiences with technology, engineering, and math. Discussions about technology suggested the definition was unclear, and that it is a medium to advance science learning in various settings, rather than a topic of intrinsic educational value. When technology was discussed it was typically conflated with experiences of the role of media in creating a more interactive, engaging learning experience. Although there is a conceptual and practical overlap between technology and media, they are also distinct fields of studies (e.g., Bates, 2015). Results of the current study reinforce observations in the literature that there is a lack of understanding about the fundamental value that technology adds to people's lives beyond facilitating information access and engagement (Buckingham, 2007). To ensure that STEM learning represents all the disciplines the term covers, a more nuanced understanding of those disciplines less salient in the public's mind will be essential.

Social implications of STEM learning

The results reinforce the value of socially facilitated learning within the wide spectrum of STEM learning settings. In general, the Z/A members that comprised the workshop thought of STEM learning to encompass content knowledge related to specific disciplines, scientific thinking (in terms of critical thinking and inquiry), and hands-on learning. Participants saw STEM learning as collaborative, in that it occurs through group engagement and in discussion with others, whether it be informal conversation with family or facilitated through thoughtful classroom instruction. The conversation about STEM learning also touched upon access, with the acknowledgment of a gender imbalance as well as limited opportunity for young children or those with developmental disabilities. The latter two groups specifically could benefit from more thoughtful and innovative presentation of STEM to align with their learning needs. In fact, the field of informal science learning highlights how ISEI settings provide opportunities to make learning inclusive and explicitly consider the needs of disadvantaged audiences, like those with disabilities (Fenichel & Schweingruber, 2010; Lussenhop et al., 2016; Melber & Brown, 2008; Reich, Price, Rubin, & Steiner, 2010).

STEM learning at Z/As

Participants provided additional insight on how STEM learning manifested at the six Z/As where the member workshops took place. Across the workshops, it was clear that participants saw the potential for STEM learning at Z/As but acknowledged that it was not an explicit reason for visiting a Z/A or an anticipated outcome of engaging with a Z/A. They expressed learning at Z/As is being largely connected to enjoyment in the visit, often pointing to the voluntary nature of STEM engagement, where applicable. We infer the underlying theme here is that a level of agency and volitional engagement is necessary for STEM learning.

The main STEM learning experience that participants described was learning about animal behaviors and habitats. They most often referenced live animals and how direct contact with them helped make emotional connections. Learning about the habitat of the animals and their relationship to the local ecologies was a pathway to learn about humans' impact on animals. This perspective was closely related to their appreciation of conservation and how it relates to protecting animals. Participants also saw the emphasis of Z/As in solving environmental problems as key to fostering the public's critical inquiry thinking skills, which are integral to STEM learning. Workshop participants considered zoos to be a key player in upholding the welfare and care of the animals. They also acknowledged that zoos are an authority in animal care, although they simultaneously expressed a moral conflict in viewing captive animals.

Similar to what emerged for the STEM learning ecology, learning STEM topics other than science (i.e., technology, engineering, and math) was not overt at Z/As. Even though participants identified opportunities to explore these disciplines at Z/As, they had to stretch their imagination to reflect on them. This result resonates with the fact that the focus of STEM research has been largely on science, with engineering receiving minimal emphasis (Bybee, 2010; Basham & Marino, 2013). It appears that learning technology, engineering, and math at Z/As is not intuitive but needs some purposeful structure, instruction, and guidance to enable it.

Conclusion

This exploratory study revealed a number of nuanced settings and modalities through which the public, specifically members of Z/As, encounter opportunities for engagement with STEM concepts. Our analysis indicates both an appetite for learning about STEM among members of the public and opportunities in a range of settings to foster improved understanding of all four disciplines. ISEI practitioners can play a leading role in this regard by strategically discussing their exhibits, collections, and programs in ways that advance STEM learning that includes more than science. Z/As, specifically, can make explicit the complex relationship between STEM topics, modes of engagement, and learning possible at an animal exhibit. One approach could include, for example, highlighting an aquarium's sophisticated life support systems to spark conversation about technology. A reasonable strategy for each institutional type could be to focus on learning associated with their unique areas of expertise. For example, zoos might focus on STEM learning around animal behavior rather than on water quality which is a more accessible concept for aquariums.

We see these as experiments in trying out new strategies as well as in doing some soul searching about institutional identity. The immediate payoff will be a stronger institutional capacity around supporting public good. Longer term, there may be a opportunities for cross-institutional collaboration through joint programs focused on various aspects of STEM learning. The strength of the STEM ecology is in its relational features, where learning experiences across different settings are intertwined in rich, multifaceted ways.

Note

1. The workshop protocol is available upon request from the first author at RupuG@knology.org

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