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Public perceptions of the STEM learning ecology – perspectives from a national sample in the US

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ABSTRACT

Global interest in STEM (science, technology, engineering, and math) literacy necessitates studying public perceptions of the STEM learning ecology – the spectrum of settings where people encounter STEM. By expanding on the STEM learning ecosystem focused on youth's structured learning, we explore settings where lifelong learners encounter STEM in their daily lives. We conducted a nationwide study with the US public describing where and how people engage with STEM. Results show that the public encounters each STEM discipline with similar frequency in various informal settings. Settings resonate uniquely with the public regarding STEM disciplines, topics, and modes of learning. Specifically, science centres are the standard for informal STEM learning, and are associated most closely with the experiences outlined above. Other informal learning centres are perceived to cover aspects of that ecology. Zoos are seen as places to learn most about animals and related topics (e.g., animal behaviour), and aquariums for teaching about water quality. Comparatively, science centres are thought to provide opportunities to learn about broader STEM topics, including climate change. We highlight that informal learning settings can advance STEM learning by explicitly prioritizing each STEM discipline in programmes, and by identifying strategies to measure the public's informal STEM learning.

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Public understanding of science; learning environment; informal education

STEM in the life of the public

Around the globe, STEM (science, technology, engineering, and math) education, including access to it, and how to understand the four subjects cohesively continues to gain attention (Committee of the Regions, 2019; English, 2016; Kelley & Knowles, 2016; Nistor, Gras-Velazquez, Billon, & Mihai, 2018). Many countries including the United Kingdom, Australia, Canada, and the United States struggle to meet the growing demand for professionals trained in STEM (see Marginson, Tytler, Freeman, & Roberts, 2013; Morgan & Kirby, 2016). The United States, in particular, has historically had lower STEM literacy rates than other nations yet the demand for trained STEM professionals continues to grow (US Department of Education, 2016; Desilver, 2017). The implication is that members of the public have limited ability to recognise and use STEM concepts to understand the world and solve the complex problems we face (Balka, 2011; Thomas & Watters, 2015). This deficit has led to a flood of attention, effort, and funding geared towards strategies for improving public understanding of STEM (US Department of Education, 2016; Desilver, 2017) in different learning environments and via various initiatives in the US.

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STEM topics can be intimidating for both adults and children (Gupta, Fraser, Rank, Brucker, & Flinner, 2019). Within STEM education, science learning traditionally receives the most attention and that can result in the two terms, 'science' and 'STEM', being used interchangeably (Bybee, 2012; English, 2016; Grack Nelson, Goeke, Auster, Peterman, & Lussenhop, 2019). The remaining concepts – technology, engineering, and math – are often overlooked in education making a cohesive framework of STEM harder to grasp (Basham & Marino, 2013; Kelley & Knowles, 2016). Furthermore, in a recent study Gupta et al. (2019) found that it is often easier for people to describe encounters with science than with the three other STEM disciplines.

Current trends in STEM education in the US acknowledge that it is possible to engage with STEM in both formal and informal settings (Bevan, 2016; National Research Council, 2009). However, formal settings often fail to provide equitable access to knowledge for marginalised groups, such as racial and ethnic minority groups, and those with varying cognitive capabilities and needs (US Department of Education, 2016; Reich, Price, Rubin, & Steiner, 2010; Zouda, 2018). Relying on formal settings for STEM education also limits the opportunities adults have to engage with STEM learning, as they find themselves in formal learning environments less frequently than younger audiences (Falk & Needham, 2013; National Research Council, 2009). However, it is important for adults to engage with STEM concepts as they regularly navigate science-related issues in their lives (National Research Council, 2009). For example, adults may encounter STEM concepts in the context of workplace responsibilities, understanding healthcare, and household budgeting as well as in activities like cooking, gardening, or auto-care. Adults may also pursue STEM to fulfil personal interest or to encourage children to engage in science. For this reason, informal learning settings are key to providing learning opportunities for adults.

STEM learning in informal settings

Informal learning settings extend beyond the classroom to include spaces like cultural and science institutions, social encounters with friends or family, and engagement with public media (Allen & Peterman, 2019; Gupta et al., 2019). Settings like these provide opportunities for adults and children to engage in 'free-choice' learning, where they have agency over how and where they engage with topics like STEM (Heimlich & Falk, 2009). In fact, Mohr-Schroeder et al. (2014) found that participating in STEM summer camps that emphasise informal learning environments, increased students' interest in STEM because of the context and purpose such settings provide to support their formal learning. Benefits include access to hands-on STEM learning experiences that often aren't available for all students (Roberts et al., 2018).

People typically don't visit informal learning settings with the primary intention of learning. Though these spaces draw people in for other reasons, social involvement and enjoyment can lead visitors to discrete learning experiences (Falk, 2005; Gupta et al., 2019; Heimlich & Horr, 2010). We also know that in these informal settings, learning occurs in an assortment of styles (i.e. visual-special, interpersonal, bodily-kinesthetic) that can be beneficial to people who struggle in formal settings (Gardner, 1993; Denson, Hailey, Stallworth, & Householder, 2015).

The various informal learning settings offer a myriad of benefits when presenting STEM knowledge to a broader audience (Melber & Brown, 2008; Reich et al., 2010). Furthermore, informal learning settings are accessible for both children and adults, as well as for different racial, ethnic, and socio-economic groups (National Research Council, 2009; Tal & Dierking, 2014). Informal learning settings are also more compatible with a variety of physical and cognitive abilities, as well as learning styles (Melber & Brown, 2008). The range of where, for whom, and how STEM learning occurs suggests the need to study the structure of the 'ecosystem,' and more broadly the 'ecology,' of STEM learning that describes people's experiences in and across the various settings where they may encounter STEM.

Why a STEM learning ecology?

Earlier research indicates the presence of a STEM learning ecosystem that focuses on the rich array of places where STEM learning experiences occur in structured ways for children and young adults. The list includes the home, schools, after school/summer programmes, and cultural institutions. (Allen & Peterman, 2019; Traphagen & Traill, 2014). This study takes a step back. It considers the structured STEM learning ecosystem but then broadens out to consider other environments where people might engage with STEM. Just as in natural science where ecology is the study of ecosystems, this study expands the perspective from the 'STEM learning ecosystem' to the 'STEM learning ecology.' In doing so, we can identify how the STEM learning ecosystem functions when it is expanded to include interactions with STEM in all places, including those we encounter in our daily lives (e.g. including backyards, restaurants, non-STEM based institutions). This broader lens allows us to include learning experiences for people of all ages rather than just children and young adults. Additionally, considering the STEM learning ecology lets us examine how different locations relate to each other and differentiate places that promote similar learning experiences from those that are more unique.

Thinking in terms of a STEM learning ecology helps us more broadly consider the different settings and the nuanced opportunities for STEM learning that are available to adults and kids. Learning ecologies are comprised of the physical, social, and cultural context where learning occurs (Bevan, 2016). More specifically, STEM learning ecologies consider aspects of formal learning, non-formal learning, informal learning, incidental learning, and everyday learning (Mocker & Spear, 1982; Bevan, 2016; Heimlich, 1993; Heimlich, personal communication, 2017) and are shaped by the social dynamics, value systems, and cultural histories learned over time (Bevan, 2016). Furthermore, Bevan (2016) clarifies that a STEM learning ecology includes programmes across settings ranging from institutions to general places that provide opportunities for people to engage with STEM topics, while leveraging the social interactions that occur during these experiences.

Qualitative case studies with members of zoos and aquariums studying the STEM learning ecology suggest that visitors frequently engage with STEM not only in informal settings like science museums, zoos, and aquariums – but also in less structured environments like parks and one's own backyard, as well as restaurants (Gupta et al., 2019). Gupta and colleagues assert that the way people engage with STEM varies as much as the places where such encounters occur, and often favour socially facilitated learning such as in discussion within families. The vast variety of settings that allow potential encounters with STEM illuminates the need for studying the STEM learning ecology on a larger scale to understand how the public perceives the ecology and to encourage equitable engagement with STEM.

Study context

The current research was conducted as part of the Why Zoos and Aquariums Matter (WZAM3) study, the third wave of a long-term commitment to understand how zoos and aquariums contribute to American society. This initiative explores the relationship the public perceives between zoos and aquariums (Z/As), learning, and conservation. WZAM3 is funded by the National Science Foundation (awards DRK-1612729 and DRK-1612699) and focuses specifically on the role that Z/As play in STEM learning. As part of this study, we conducted a nationwide survey of US residents to answer the following research questions:

(1) How does the public perceive the STEM learning ecology?
(2) Where are Z/As situated in the STEM learning ecology?

This survey study explored how the US public views the role of Z/As relative to that of other settings that provide STEM learning opportunities. We use the term 'STEM learning ecology' to represent the wide range of STEM learning settings that people encounter in their daily lives in a range of contexts. We take a comprehensive approach to examine how Z/As, relative to other settings, facilitate learning on each of the four STEM disciplines.

Method

Participants

We recruited a sample of 1461 participants through the Soapbox survey-panel service. This sample was intended to match the racial and ethnic distribution of the U.S. Census (United States Census Bureau, 2016). In fact, a Pearson's Chi-squared test indicated that our data did not match the Census distribution ($p < 0.001$). The discrepancy was because there were fewer people identifying as Hispanics in our survey (3% vs. 17%), more Whites (73% vs. 62%), and more individuals reporting Multiple races (6.4% vs. 0.8%). Otherwise, proportions appear concordant: Black (10.8% vs. 12.3%), Asian (4.3% vs. 5.2%), Native American (0.5% vs. 0.7%), Pacific Islander (0.0% vs. 0.2%), and Other (0.7% vs. 0.2%). Our sample also reflected a relatively affluent group, which may be an artifact of being recruited through a consumer survey panel.

Of 1461 participants, 791 participants (64%) had encountered the acronym 'STEM' before being recruited for the survey, often in reference to school curricula ($n = 294$).

Instrument

The survey began by randomly assigning participants to one of four groups represented by the STEM disciplines (science, technology, engineering, or math). This approach aimed to identify, at a national scale, the role of each discipline in the public's lives and establish baseline markers that are currently lacking in the research literature. All subsequent survey responses were asked in relation to one assigned STEM discipline, noted as 'S/T/E/M.'

We anticipated that experience with disciplines other than science may be limited, so we aimed to document this phenomenon on a national scale. In order to ensure respondents did not terminate their participation due to limited engagement with specific S/T/E/M disciplines, survey instructions consistently reminded them their responses were important regardless of the extent of their experience with it.

Respondents were randomly assigned for a second time to specific but conceptually comparable sub-modules – S/T/E/M Interest or S/T/E/M Learning Value. In this way, the survey experience was no more than 15 minutes.

In the description below, we have indicated which modules were seen by all respondents with <ALL≥ next to the module name. The ones to which participants were randomly assigned, and were seen by approximately half of those who were assigned a specific S/T/E/M discipline are indicated as <HALF>.

Perceived Relevance of STEM

Participants were next randomly assigned to one of two conditions in a module category assessing their perceived relevance of S/T/E/M in their lives. The specific modules to which they were assigned were S/T/E/M Interest or S/T/E/M Learning Value.

S/T/E/M Interest <HALF>. We asked individual participants to indicate their interest in one STEM discipline (S, T, E, or M) to gauge national public understanding and engagement with each uniquely.

S/T/E/M interest was measured with questions from the STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010), which uses pairs of adjectives to measure perceptions of the S/T/E/M discipline to which participants were randomly assigned: science, technology, engineering, and math. We used this measure to assess participants' interest in each topic. Adjective pairs were randomised for each S/T/E/M discipline. We analysed how interest in these subjects correlated with visitation and S/T/E/M experiences at Z/As.

S/T/E/M Learning Value <HALF>. These questions were designed to measure the perceived value of science learning. The items were developed to align with the Next Generation Science Standards that emphasise the conceptual shifts and standard practices in science learning. These items were previously used in an evaluation study conducted by New Knowledge Organization Ltd. on youth STEM learning (NSF DRL-1503315) by Roberts, Norlander, and Flinner (2017). We adapted the items for the current survey, selecting language to make it appropriate for learning in each of the four S/T/E/M disciplines.

S/T/E/M Learning Ecology Settings <ALL>

Next, we asked all respondents about settings where they experienced the specific S/T/E/M discipline. The question aimed to identify the S/T/E/M learning ecology as experienced by the general public. The list of settings respondents could choose from were based on the findings of the qualitative study with Z/A members (Gupta et al., 2019) and a national study of the public's trust in Z/As (Rank, Voiklis, Gupta, Fraser, & Flinner, 2018). Settings ranged from places close or attached to home (e.g. front and backyards), to informal science learning centres (ISLCs) (e.g. museums of natural history), to functional settings (e.g. stores, banks). Participants were asked to rank order the top three settings where they encountered S/T/E/M.

The following sets of items #3–4 asked additional questions specifically about respondents' top three ranked settings.

Frequency of S/T/E/M Learning <ALL>

For the top three settings, we asked about the frequency with which they encountered S/T/E/M in each. They were asked to use a sliding scale from 1 (Never) to 7 (All the time) to indicate how often they encountered S/T/E/M in the settings they indicated. The goal was to describe a continuum across settings where S/T/E/M learning happened frequently. We also aimed to identify the settings where the public experienced S/T/E/M infrequently.

Those who did not list Z/As in the top three settings where they encounter S/T/E/M, were additionally asked to compare how frequently they encountered S/T/E/M at Z/As in relation to their top three settings. Based on their responses, they were asked to compare only zoos, only aquariums or both in relation to their top three.

S/T/E/M Experiences

Participants next responded to two specific modules within the category of S/T/E/M experiences: assessing S/T/E/M learning processes and S/T/E/M topics experienced.

S/T/E/M Learning Processes <ALL>. For the top settings (3–5) where they encountered S/T/E/M, participants were asked to indicate the different ways they experienced it in each setting (e.g. hands on engagement, learning content knowledge, signage, interactions with staff, sensory experiences, interactions with animals, interactions with plants). This set was informed by the qualitative study that revealed a number of mechanisms facilitating engagement with S/T/E/M. These questions were included to assess the pathways through which S/T/E/M may be learned at the various settings.

S/T/E/M Topics <ALL>. We included S/T/E/M topics that were described in the qualitative study to understand the extent to which the general public perceived their role in S/T/E/M learning across settings. We used the themes that we coded in the qualitative study where Z/A members explicitly described or suggested S/T/E/M topic areas. These included topics such as Ecology, Sustainability, and Water Quality. With this module, we aimed to study the extent to which specific S/T/E/M topics feature in settings where the public encounters S/T/E/M.

Favorability <ALL>

Both Modules#5 and #6 were borrowed from the recently completed study to understand trust in Z/As that drew upon past studies on favorability of Z/As conducted by the PRIME group in their work with the Association of Zoos and Aquariums (AZA).

All respondents were asked to rate their favorability towards a series of seven informal learning settings. Unlike the earlier study, though, the items were included at the end of the current STEM learning ecology survey as background questions rather than as screener questions. The response category of this scale was revised to include an additional one that said 'I have never visited this setting'. Respondents could answer this category, irrespective of whether they provided a favorability opinion.

Demographics <ALL>

We collected demographic information to verify how representative the results were of the US population. We asked for gender, age, state of residence, area type where they lived (e.g. urban, rural), highest level of education, race, and ethnicity.

Analysis

We used fuzzy cluster analysis (Reynolds, Richards, de la Iglesia, & Rayward-Smith, 1992) and multidimensional scaling (Torgerson, 1958) to map the STEM learning ecology and to situate zoos and aquariums within that ecology. Fuzzy cluster analysis helped us discover groupings of similar settings in the data; multidimensional scaling helped us project those multidimensional similarities between settings onto a two-dimensional coordinate plane. In order to choose which data reliably differentiated groups of settings, we aggregated all the data modules relative to each setting. For example, we calculated the Favorability values (data from the survey module described in section 6, Favorability) for each setting as the arithmetic mean of the ratings provided by participants who included that setting in their top three settings where they encounter S/T/E/M.

Using this aggregated data representation, we simulated six fuzzy cluster solutions, ranging from 2 to 7 groups of settings. We chose this range of groupings using the gap statistic (Tibshirani, Walther, & Hastie, 2001), which estimates the maximum number of potential clusters in the data set. The seven-cluster solution was the point at which groupings started to break down into single-setting groups; specifically, the setting Science Centre split off into its own group. Zoos and aquariums did not split off from their group until the number of clusters started approaching the total number of settings.

We used discriminant function analysis (Lebart, Morineau, & Piron, 2006) to test which survey items and modules reliably discriminated between groups of settings across cluster solutions (i.e. a correlation ratio $\eta^2 \geq .5$). Three modules met these criteria:

- the weighted frequency of encountering S/T/E/M in a setting (a combination of the modules described in section 2. S/T/E/M Learning Ecology; and section 3. Frequency of S/T/E/M Learning),
- the S/T/E/M topics participants reported learning in these settings (as described in section 4.2. S/T/E/M Topics), and
- the modes of learning these topics that participants reported using in these settings (as described in section 4.1. S/T/E/M Learning Processes).

The Results on Perceptions of the STEM Learning Ecology and Z/As in the STEM Learning Ecology are based on these three modules, from which we derived a seven-cluster solution: six groups of settings plus the single-setting, Science Centre group.

To test differences between the settings groups, we used regression analysis on the weighted frequency of encountering S/T/E/M at a setting and logistic regression analysis on topic and modality selections.

Results

Perceptions of the STEM learning ecology

In order to situate Z/As in the STEM learning ecology we constructed a data representation of that learning ecology from the settings where participants reported encountering S/T/E/M (as described in section 3, Frequency of S/T/E/M Learning), the S/T/E/M topics participants reported learning in these settings (as described in section 4.2, S/T/E/M Topics), and the modes of learning these topics that participants reported using in these settings (as described in section 4.1. S/T/E/M Learning Processes). This data representation allowed us to calculate distances between settings across the three sets of variables, create a map of settings based on those similarities, and situate Z/As among groups of similar settings. Before mapping the learning ecology, we first summarise the constituent data modules.

Overall, both the frequency with which participants selected the 23 available settings and the frequency of encountering S/T/E/M did not differ significantly by STEM discipline ($\chi^2 \approx 0$ for selection frequency, $p \approx 1$, and $F(3) = 0.22$, $p = .88$ for encounter frequency). This is a noteworthy finding: no single STEM discipline dominated the STEM learning ecology. Figure 1 shows the relative weighted frequencies of encountering S/T/E/M across settings that were thematically similar.

In which settings do people encounter S/T/E/M?

Overall, participants included science centres in the top three settings more often than any other setting; it was selected by 622 participants (43%) who rated the frequency of encountering STEM greater than sometimes (.63 on a scale from 0 to 1). The next most frequently setting, Home, was selected by 286 participants (20%), though the frequency of encountering STEM fell short of almost always (.74 on the scale from 0 to 1). Zoos and aquariums were selected, respectively, by 174 (12%) and 199 (19%) participants – a difference that exceeded chance ($0.90 \leq OR \leq 1.21$, $z = 3.14$, $p = .002$). Those participants rated the frequency of encountering STEM at either setting as less than sometimes (respectively, .42 and .43, a chance difference). Figure 1 compares the weighted frequency (frequency of inclusion in top three, weighted by the frequency of encounter) of zoos and aquariums

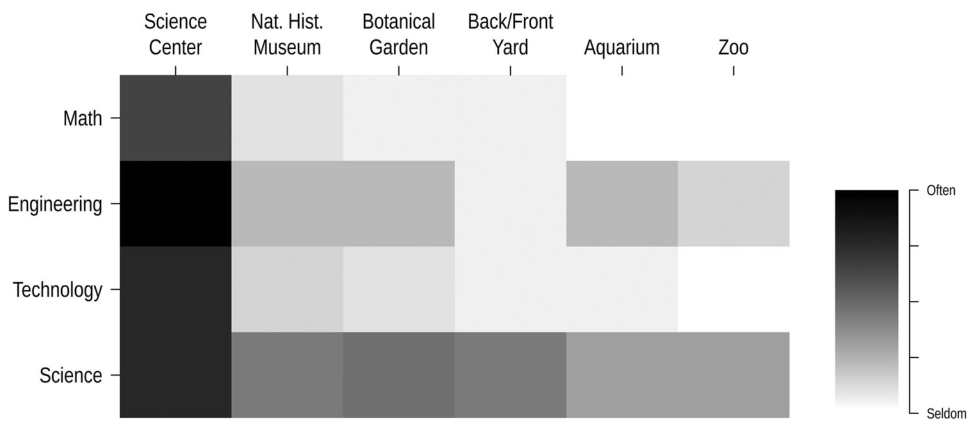

Figure 1. Relative frequency with which participants selected Z/As and comparable informal learning environments as one of the top three settings where they encounter S/T/E/M, weighted by the relative frequency of encountering S/T/E/M at those settings.

against thematically comparable informal learning environments – science centres, natural history museums, botanical gardens, and back and/or front yards. This comparison highlights that people conceptualise science centres as the prototypical setting for encountering S/T/E/M. Zoos and aquariums, like other informal learning environments, are most associated with science and engineering.

What STEM topics do people learn in these settings?

Figure 2 shows the relative selection frequencies of the topics that participants reported learning in zoos, aquariums, and thematically comparable informal learning environments. Overall, the distribution of topics differed significantly by Setting ($\chi^2_{(22)} = 3849.1$, $p < .001$) and S/T/E/M discipline ($\chi^2_{(3)} = 49.9$, $p < .001$). Science centres garnered the broadest selection of topics; compared to the rate of topic selection for zoos or aquariums, selecting any given topic was 35% more likely for science centres ($1.28 \leq OR \leq 1.42$, $z = 11.48$, $p < .001$). The topic selection difference between zoos and aquariums was small – the likelihood of selecting any given topic was 7% higher for zoos than for aquariums – but exceeded chance ($1.02 \leq OR \leq 1.11$, $z = 3.14$, $p = .002$). Otherwise, noteworthy and statistically significant ($p < 0.5$ by the Exact Poisson test) cooccurrences between topics and settings include the following: animal behaviour with zoos, aquariums, and back/front yards; geography with natural history museums; species names and reproduction with zoos and aquariums; and water quality with aquariums.

What modalities do the settings offer for learning STEM topics?

Figure 3 shows the relative selection frequencies of the learning modalities that participants reported are available in zoos, aquariums, and thematically comparable informal learning environments.

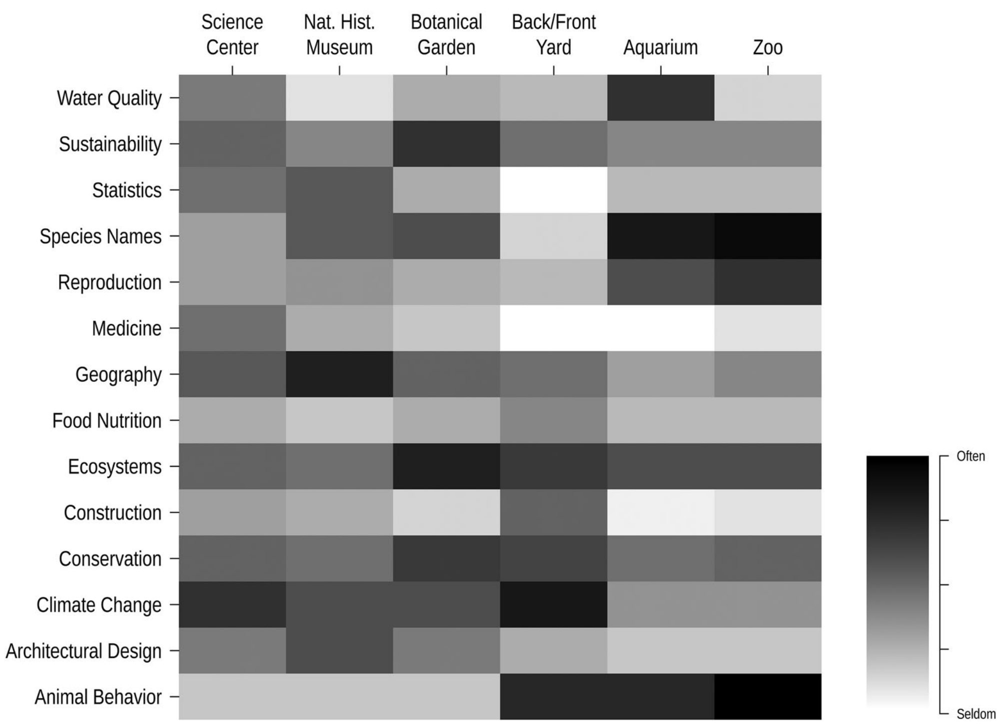

Figure 2. Relative frequency with which participants selected topics they learn at the top three settings (plus zoo and/or aquarium) where they encounter S/T/E/M.

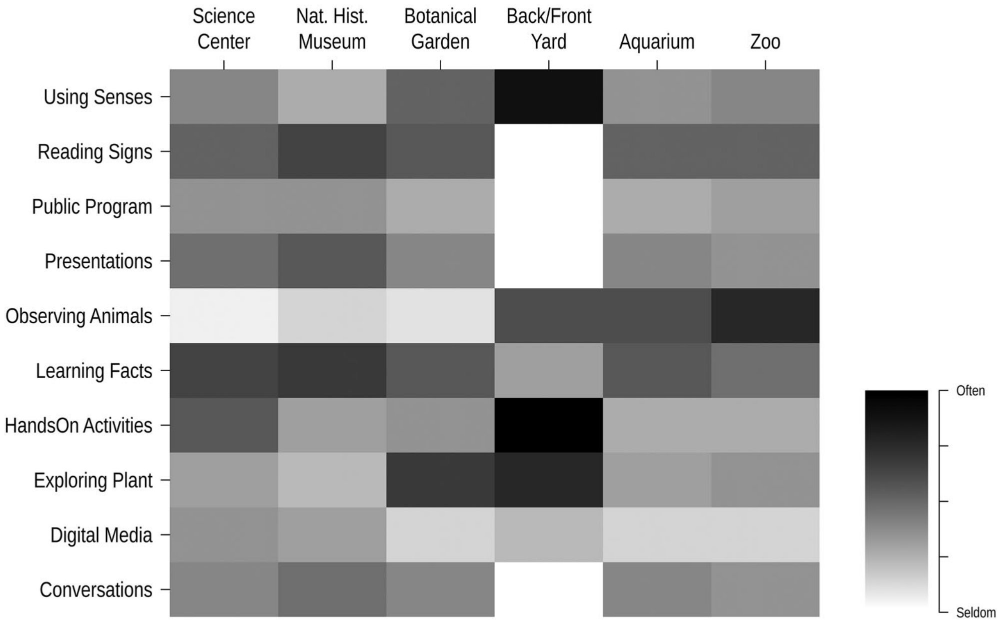

Figure 3. Relative frequency with which participants selected learning modalities available at the top three settings (plus zoo and/or aquarium) where they encounter S/T/E/M.

Overall, the distribution of modalities differed significantly by Setting ($\chi^2_{(22)} = 1352.2, p < .001$) and S/T/E/M discipline ($\chi^2_{(3)} = 86.9$, $p < .001$). Science centres again garnered the broadest selection of learning modalities; compared to the rate of modality selection for zoos or aquariums, selecting any given modality was 72% more likely for science centres ($1.62 \le OR \le 1.82$, $z = 0$, $p < .001$). The modality selection difference between zoos and aquariums was again small – the likelihood of selecting any given mode was 14% higher for zoos than for aquariums – but exceeded chance ($1.08 \le OR \le 1.19$, $z = 5.40$, $p < .001$). Otherwise, noteworthy and statistically significant ($p < 0.5$ by the Exact Poisson test) cooccurrences between learning modalities and settings include the following: observing animals with zoos, aquariums, and back/front yards; exploring plants with botanical gardens and back/front yards; and hands-on activities and using senses with back/front yards.

Mapping the STEM learning ecology

We combined the three subsets of data shown in the previous three figures into a single data representation of the learning ecology (Figure 4). Each row of the data representation in Figures 1–3 serves as a profile for each setting, revealing the setting's association with each STEM discipline, each STEM topic, and each learning modality. We used these profiles to calculate distances between pairs of settings using the Minkowski distance metric[1] (Gan, Ma, & Wu, 2007), the inverse of calculating correlations. Using a multidimensional scaling algorithm, we mapped the distances onto coordinates in a 2-dimensional plane (Torgerson, 1958). Finally, we used fuzzy clustering analysis to identify the six groups of multiple settings, plus the single-setting, science centre group. Figure 4 shows the resulting map of the learning ecology with ellipses marking the groups of settings. Science centre, marked with larger type, serves as a point of comparison for other groups of settings (distances between settings on the plane illustrate conceptual [dis]similarities in their profiles). Z/As, the objects of study, are set off in larger type and brighter colour. The next section addresses how the location of the Z/As reveals how people think about these institutions in relation to other settings in the STEM learning ecology.

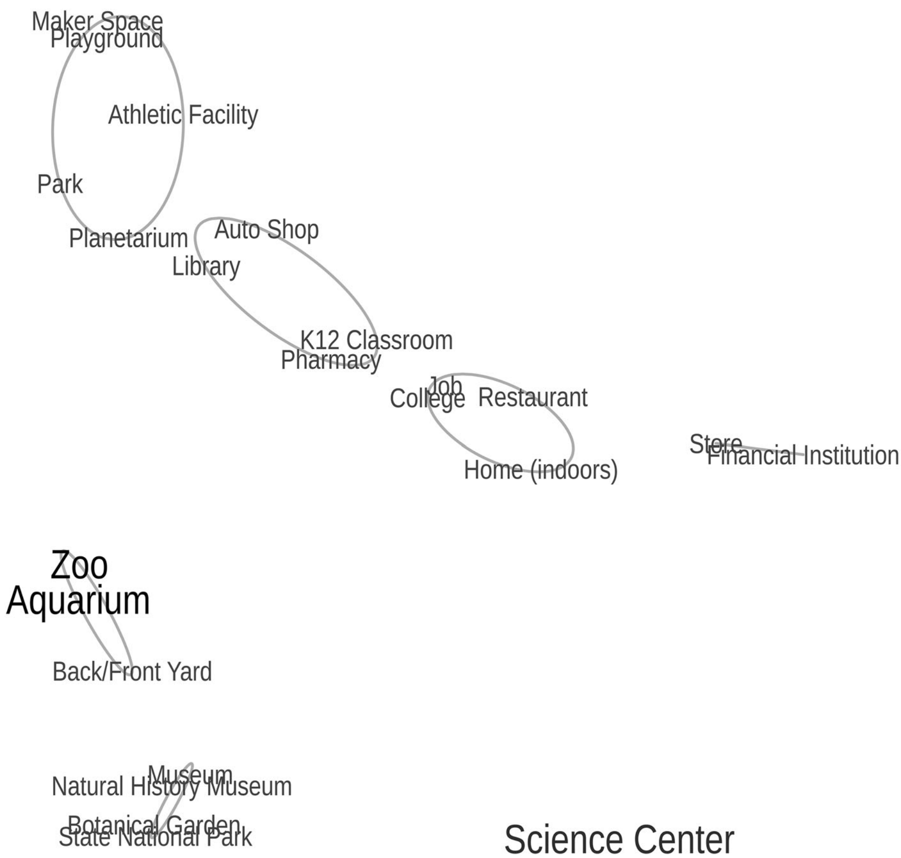

Figure 4. STEM Learning ecology resulting from a cluster analysis of data about STEM learning settings. Note that the coordinates for Science Center fall outside this plot and have been moved closer to the other settings for easier viewing.

Zoos & aquariums in the STEM learning ecology

Z/As group together with Back/Front Yard (the 'ZAY' group). The ZAY group was characterised by the topic of Animal Behaviour and the learning process (modality) of Observing Animals. The odds of selecting Animal Behaviour from among the topics was more than 7 times higher for the ZAY group than for the average of the other settings groups. Other likely topics included: Species Names (4.9 times higher), Reproduction (2.5 times higher), Ecosystems (2.3 times higher), Water Quality (1.8 times higher), Conservation (1.6 times higher), Sustainability (1.2 times higher), and Climate Change (1.1 times higher); all other topics were less likely for the ZAY group than for the average of the other settings groups. All contrasts in the logistic regression on selecting the topic exceeded chance (ranging from $4.29 \geq |z| \geq 33.28$, all $p < 0.001$).

Likewise, the odds of selecting Observing Animals from among the modalities was almost 10 times higher for the ZAY group than for the average of the other settings groups. Other likely learning modalities included: Exploring Plant (1.8 times higher), Public Programmes, Using Senses, and Reading Signs (all a little more than 1 times higher); all other modalities were less likely for the ZAY group than for the average of the other settings groups. All contrasts in the logistic regression on selecting the modality exceeded chance (ranging from $13.09 \geq |z| \geq 39.93$, all $p < 0.001$).

As reported above, measures for frequency of encountering S/T/E/M differed significantly by discipline. Nevertheless, the weighted frequencies present some noteworthy differences between groups. The weighted frequency of science was 60% higher for the ZAY group (46.17) than for the average of the other settings groups ($M = 28.84$). The weighted frequencies of the other disciplines were between 23% and 79% lower for the ZAY group than for the average of the other settings groups: Technology, $M_{(ZAY)} = 11.27$ vs. $M_{(Other)} = 36.93$; Engineering, $M_{(ZAY)} = 22.44$ vs. $M_{(Other)} = 29.29$; Math, $M_{(ZAY)} = 7.95$ vs. $M_{(Other)} = 37.78$.

Within the ZAY cluster, no differences between the weighted frequency of encountering of S/T/E/M exceeded chance ($F \approx 0$, $p \approx 1$, for all contrasts between settings by STEM discipline). For topics and modalities, on the other hand, frequency differences exceeded chance for all contrasts between settings ($\chi^2_{Topic} \geq 157.40$; $\chi^2_{Mode} \geq 73.20$; all $p < .001$). Compared to Back/Front Yards, Z/As dominated in the selection of several topics: Species Names (3 times higher), Reproduction (2 times higher), Animal Behaviour (2 times higher), Ecosystems, Statistics, and Water Quality (all roughly 1.1 times higher). Z/As also dominated in the selection of several learning modalities: Reading Signs (almost 10 times higher), Conversations (9.2 times higher), Presentations (8.3 times higher), Public Programme (4.8 times higher), Learning Facts (1.6 times higher), and Observing Animals (1.9 times higher). When contrasting zoos against aquariums, selecting the topic of Animal Behaviour (1.5 times higher) and the modality of Observing Animals (1.7 times higher) were more likely for zoos than for aquariums; the topic of Water Quality (.2 times lower) and the modality of Digital Media (.5 times lower) were less likely for zoos than for aquariums.

Discussion

STEM learning ecology

This study highlighted US adults perceptions of the STEM learning ecology. Although the sample deviated slightly from a nationally representative one, we ended up with a more representative group of visitors to informal learning centres (a greater proportion of whites than other races and ethnicities). Contrary to our expectations, this group of the general public similarly encounters all disciplines captured in the term STEM in various informal settings in their daily lives. They see the settings where STEM learning happens as grouped into meaningful clusters. These settings ranged from places close or attached to home (e.g. front and backyards), informal science learning centers or ISLCs (e.g. museums of natural history), and functional settings (e.g. stores, banks). Of all these settings, science centres were seen as the epitome of STEM learning, and served as the point of comparison for all other clusters. The STEM topics people learn and the modes through which they engage in them characterised the STEM learning experience. We suggest that the STEM learning ecology is richer than we originally conceptualised it to be, and that the public's experience is more nuanced than being based on settings alone.

These findings suggest that the STEM learning ecology is made up of a complex interplay between the phenomenological experiences of the learners as they engage with topics in multiple modes in various settings. This finding also resonates with our earlier qualitative study, where we heard visitors describe their STEM experiences as intertwined across topics, modes, and impacts on themselves (Gupta et al., 2019).

Though this study focused on informal STEM encounters in the US, implications generated from these findings are relevant internationally owing to the similar struggles with STEM engagement and interest around the world (Thomas & Watters, 2015). Furthermore, the breadth of locations considered as opportunities for STEM engagement ensures that these findings have implications in a variety of contexts, and that practitioners in informal learning institutions inside and outside of the US can harness them to inform their educational approach.

STEM learning at zoos & aquariums

While places like science centres and even frontyards and backyards helped the public learn about a variety of STEM topics, it came as no surprise the role of Z/As was especially appreciated for teaching about animals. Through information about topics relevant to animals, Z/As engage visitors in learning science, as they relate to topics such as their behaviours and reproduction. Even though Z/As, like other ISLCs, typically focus on applied STEM topics like conservation and climate change resilience, the main learning the public experiences at these institutions, centres around animals.

These findings suggest an opportunity for Z/As to strategically refine how they engage their visitors in STEM topics as they directly relate to animals. Our qualitative research with Z/A visitors points to how conservation learning at these institutions tend to overlap with learning about the interdependence of flora and fauna with the ecosystems they live in and the need to take care of nature for animals' welfare (Gupta et al., 2019). Based on this earlier finding, we expected that STEM learning at Z/As would manifest as science learning focused around animals primarily. The current study reinforces this finding and suggests that Z/As need to make the connections between their animals and STEM learning more explicit, and that perhaps conservation is a way to facilitate that. We anticipate that this approach will advance visitors' STEM learning, and at the same time will be aligned with the continued priority for conservation set by the AZA (2019).

A promising finding from this survey is the role of science centres in exemplifying STEM learning – we propose that there may be opportunities for Z/As to complement their pedagogical approaches with those used by science centres and tailor programmes for visitors at Z/As. As was demonstrated with the travelling Wild Minds exhibit about animal cognition co-hosted at science centres and zoos in two cities, professionals at both types of institutions perceived great value in fostering collaborations on topics such as climate science and animal behaviour despite acknowledging distinct pedagogical approaches (Fraser, Weiss, Sheppard, & Flinner, 2013). In fact, engaging all staff, including volunteer docents, in blending pedagogical approaches will likely be a productive strategy to advance science learning among the public (Gupta & Plemons, 2012).

Implications of self-evaluations of STEM learning

The survey very purposefully did not use the word 'learning' when asking the public about their experiences with STEM. Rather, we asked them about their 'encounters' with STEM in various contexts in their lives. By employing this approach, we sought to avoid biases or preconceived ideas of what learning is, which is often associated with curriculum-based formal education outcomes (Sharma & Choudhary, 2015). It also allowed the respondents to be expansive in their idea of how and where they engaged with STEM in a range of informal settings.

Under these circumstances, the general public of the US indicated that they engage in STEM in diverse contexts in their daily lives outside of formal educational settings. The results raise this question: How do these self-evaluations relate to more objective STEM outcomes, through standardised tests, for example? While our surveys did not gauge STEM outcomes directly, we did assess the relationships between interest and perceived value of STEM as they relate to STEM learning in various settings. We found that these individual-level characteristics depicting a predisposition towards learning STEM did not relate to how people engage with STEM across settings. That is, STEM learning in diverse settings as reported in our survey does not depend on the public's predisposition to STEM disciplines. This finding suggests that the multimodal opportunities afforded in these settings enable STEM learning in a democratic way, so that everyone, regardless of their penchant for STEM, can engage in it.

For researchers of informal learning, there are ripe opportunities to study how STEM learning manifests across the ecology, using measures of informal learning, such as the strands of science learning (National Research Council, 2009). The six strands of science learning capitalise on social experiences in informal settings and conceptualise the science learning experience to be richer than the growth of content knowledge. This more expansive conception includes the affective, cognitive, and behavioural impacts. Given the voluntary nature of engagement in informal learning settings, learners' socio-emotional experience as they interact with programmes, exhibits, and staff is considered a critical part of the learning. The strands of science learning capture these multi-faceted learning experiences in six ways. These are interest (motivation to learn about the natural world), understanding concepts (generate, remember, and utilise models, arguments, and explanations relating to science), inquiry skills (the ability to test and make sense of the natural world), scientific thinking (reflection on science as a way of knowing), participation in science activities (use scientific language and tools in learning practices and experiences relating to science), and self-perceptions as science learners (identification as someone who knows about and contributes to science).

As far as we know, informal STEM learning has been conceptualised primarily as science learning, with limited approaches to understand how to address and assess informal -TEM learning (English, 2016; Grack Nelson et al., 2019). This study helps document the unique ways that STEM learning manifests across different types of settings, and highlights the implications for promoting a STEM literate citizenry. As national assessments continue to indicate low levels of STEM literacy (US Department of Education, 2016), we speculate that conducting in-depth studies of how the public learns STEM in informal settings may provide a more holistic view of the public engagement in STEM.

Conclusion

Our study is one of the first to comprehensively assess public perceptions of where and how they engage in STEM learning in their daily lives. The results from this study in the US indicate that the public engages in STEM in a range of informal settings through multiple modes and topics. Importantly, this opportunity is afforded to everyone regardless of their interest in STEM, suggesting the role of informal learning settings in providing equal opportunities for all to learn STEM. We also discuss approaches for the informal learning sector to support more research into how learning manifests for the global public in ways that are meaningful in their daily lives.

Note

1. The Minkowski distance metric provides a normalised (between 0 and 1) approximation of the psychological discontinuities in how people conceptualise category members and properties.

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