Biological Field Stations Promote Science Literacy through Outreach

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Biological field stations (BFSs) are well positioned through their informal STEM (science, technology, engineering, and mathematics) education programs to improve levels of science literacy and support environmental sustainability. A survey of 223 US BFSs revealed that their outreach programs strive to promote conservation and environmental stewardship in addition to disseminating place-based knowledge and/or skills. In this article, we unpack the educational approaches that BFSs use to engage learners, the aspects of science literacy most often addressed, and the perceived learning outcomes. Most notably, the BFSs reported that their participants develop an interest in and excitement for science, increase or change their knowledge of program topics, identify more with the scientific enterprise, and engage in scientific practices. The results indicate opportunities for BFSs to conduct more rigorous assessments of participant learning and program impact. By focusing on learner engagement, science learning, and participant outcomes, BFSs and other place-based informal education venues can expand their efforts and better support conservation and science learning.

Keywords: informal learning, outreach programming, biological field stations, STEM education, science literacy

Informal education is pivotal to public engagement and understanding of science, technology, engineering, and mathematical (STEM) concepts (NRC 2009). Indeed, most STEM learning experiences in our lives are informal, in that they are out of school and do not result in grades for an academic record. During grade school, we spend about 19% of our time in classrooms and just a fraction of that on STEM topics (Stevens et al. 2005, Falk and Dierking 2010). Once we graduate, only an estimated 6% of careers are related to STEM fields (BLS 2020). Therefore, for people to understand new scientific findings and use science for their own purposes, they have to seek information independently or take advantage of informal learning institutions, such as museums, nature centers, and aquaria.

In addition to inspiring STEM careers in some and exciting an interest in STEM topics more generally, informal learning provides valuable experiences proven to develop STEM skills and generate knowledge (NRC 2009, Stocklmayer et al. 2010, Stocklmayer and Rennie 2017). Although there are data supporting the many benefits of informal education, it remains a challenge for informal educators to gauge the depth of their impact on participants' science literacy gains over time (Schwan et al. 2014, NRC 2015, Fu et al. 2019). Where schools have standards to meet and annual testing by which they can measure progress, informal STEM contexts—often visited once and designed to involve low stakes and to be fun and exciting—do not.

Science literacy is a multidimensional concept and incorporates much more than knowing facts. Being science literate includes understanding how science works in practice, how scientists do research, collect data, and the processes scientists use to assure valid and reliable findings. Moreover, science literacy includes having the capacity to interpret, discuss, question, and even apply scientific findings as well as understanding science as a social process (NASEM 2016). These many aspects of science literacy can be experienced in informal learning environments, and informal learning institutions have become very adept at promoting such learning opportunities (NRC 2009, Bevan et al. 2018).

Place-based and environment-focused informal learning institutions provide an interesting way to explore science literacy gains because their outreach efforts often encourage participants to experience a particular place and be hands on with their learning—educational methods found to be associated with positive learning outcomes (Smith 2013). Place-based education grounds learning in the attributes of the local environment, emphasizes active investigation of topics, and helps produce increased stewardship of the community (Sobel 2004). Empirical evidence indicates that learners in such programs increasingly value the natural environment and science more generally and use science to make everyday decisions (Bell et al. 2016). Biological field stations (BFSs) are one such informal learning institution that promotes place-based experiences for the public.

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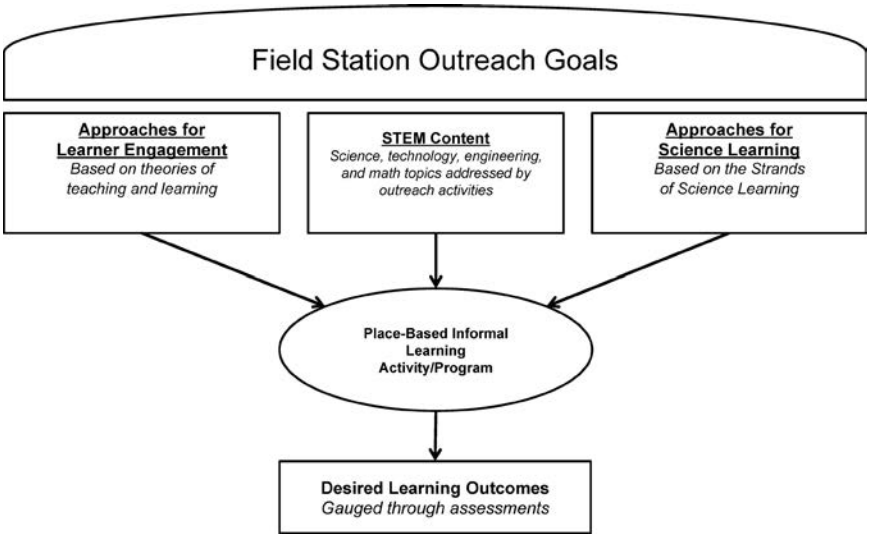

Figure 1. The ISL framework. Source: Adapted from Struminger and colleagues (2018).

Biological field stations

There are over 1200 BFSs around the world that support researchers studying a place of scientific interest (Wyman et al. 2009, Tydecks et al. 2016). BFSs are institutions that identify themselves as such and help researchers in their efforts to do scientific fieldwork (Struminger et al. 2018). They are also known for facilitating access to the environment, promoting conservation, and maintaining living laboratories where scientists and students can investigate a wide range of natural processes (Billick et al. 2013, NRC 2014, Baker 2015). Long appreciated within the scientific community as places of innovation, BFSs are increasingly recognized for their extensive outreach offerings that bring STEM knowledge and hands-on experiences to public audiences of all ages (Havran et al. 2017, Struminger et al. 2018). At BFSs, informal education efforts can vary a great deal depending on resources and commitment to educating the public, as well as the environmental setting and geographic location. To help those leading, evaluating, and studying informal STEM education programs at BFSs, we developed a learning framework that is focused on addressing six key aspects of science literacy and six approaches to meaningfully engage learners.

The informal STEM learning framework

The informal STEM learning (ISL) framework (Struminger et al. 2018) was designed to help BFSs become more purposeful in their outreach offerings (figure 1). Given the centrality of place in the research at BFSs, place-based informal programs are at the heart of the ISL framework and contribute to the context within which programs are developed, implemented, and evaluated. In addition to place, these programs are informed by the STEM content addressed, as well as the approach or approaches for learner engagement and for science learning employed in the outreach. Although it was designed for BFSs, this framework can be applied at any informal learning institutions focused on providing place-based education experiences.

Approaches for learner engagement profiled in the ISL framework are based on six distinct pedagogical approaches and act to scaffold learning for program participants by helping them interact with subject matter in a variety of ways. These approaches may overlap in their application and summarily can be described as follows: community based is when learners are oriented around a topic of community interest (Falk and Harrison 1998); contextualized is when learning happens by applying previous knowledge or skills in a new situation or context (Rivet and Krajcik 2008, Perin 2011); experiential is when learners gain insight through the process of a learning experience, with a focus on experimentation and reflection rather than specific outcomes (Kolb 2014, Jose et al. 2017); discovery based is when learners pose and answer their own questions (Alfieri et al. 2011); inquiry based is when learners are presented with a problem and guided through the process of solving it (Hmelo-Silver et al. 2007); and service oriented is when learning occurs through a project that benefits a community (Bringle and Hatcher 1999, Newman et al. 2007).

The science literacy BFSs address in their outreach can be understood through the six strands of science learning developed by the National Research Council (2009). These strands can be described as cognitive, social, developmental, and emotional learning goals intended to bring together insights gained from informal with formal settings to help educators organize and assess science learning (NRC 2009, p. 4). The ISL framework summarizes these strands as strand 1, sparking and developing interest and excitement in science; strand 2, understanding scientific knowledge or content; strand 3, engaging in scientific explanation and argument; strand 4, understanding the scientific enterprise; strand 5, engaging in scientific practices; and strand 6, identifying with the scientific enterprise. By being focused on which approaches for learner engagement and science learning BFSs incorporate in their outreach activities, along with which topics, the ISL framework captures how BFSs are working toward their program goals and intended participant learning outcomes. In this article, we examine informal STEM education practices at BFSs by aligning key aspects of their informal learning programs with the ISL framework. Using new survey data from BFSs, we describe the outreach strategies and perceived outcomes to show the contribution these venues make to engaging the public with science. Other place-based informal learning institutions will be able to gain insights into their own offerings through this analysis. Specifically, we ask the following research questions:

Table 1. Approaches for learner engagement aligned with the outreach survey.

Approaches for Learner Engagement	Survey Statement (Strongly Agree to Strongly Disagree/I do not know)
Community approach: Learners create an outcome they collectively care about.	Statement 1: Participants build knowledge and collectively create an outcome they care about.
	Statement 2: Participants are encouraged to work together to develop collective understandings.
Contextual approach: Learners build on prior knowledge and interests to learn.	Prior knowledge and interests are integrated into the learning.
Discovery approach: Learners pose and answer questions.	Participants learn by posing and answering their own questions.
Experiential approach: Learners gain knowledge through experience.	Participants' learning experiences are more important than specific outcomes.
Inquiry approach: Learners are given a complex problem to solve or address.	Statement 1: Participants are guided as they solve a problem.
	Statement 2: Participants explain or justify their work.
Service approach: Learners focus on the needs of the community.	Statement 1: Community needs are central to the activity. (Community can be those participating in the program, those who share an interest, or those living near the field station).
	Statement 2: Participants increase their understanding of their community's needs.

How are BFSs designing their outreach programs? How are the components of the ISL framework applied in each outreach program? What are the program goals and perceived impacts of outreach programs on the participants?

Outreach survey and respondents

To gather data on outreach programming at US BFSs, we developed an online outreach survey in which we asked the BFSs to describe their informal STEM education offerings. The outreach survey was administered via Qualtrics (Provo, Utah, United States) between 2017 and 2019; the complete survey is available as supplemental material. The outreach survey was built iteratively, first on the basis of a preliminary survey (Struminger et al. 2018) and then modified on the basis of feedback from an informal education evaluator. Finally, eight BFS leaders helped validate the questions in terms of clarity of meaning, especially around the approaches for learner agreement and science strands, as well as whether the questions were a reliable way of capturing their outreach efforts. These eight BFSs' responses are included in the final analysis presented below.

Outreach survey design. The outreach survey asked general questions about each BFS, including how much effort the station put into informal educational outreach programs relative to formal education courses, research, and fundraising. The survey also asked how many informal STEM outreach programs the BFS offered to the public each year and how many they would detail on the survey. To ensure that a program was an informal learning experience for the participants, the survey asked the BFSs to tell us only about programs that promote public awareness of STEM knowledge and are considered informal. Within the program detail section of the survey, we determined whether course credit was given for the program and excluded any for-credit programs.

To associate outreach program activities with the approaches for learner engagement and science learning in the ISL framework, the survey provided statements and a five-point Likert scale asking the respondents their level of agreement with each statement. The statements for each approach for learner engagement were designed to capture the essence of the approach (see table 1). To fully capture the nuance of community, inquiry, and service approaches for learner engagement, the survey uses two statements, as is shown in table 1. The statements in the survey are designed to avoid interpretive confusion by the survey takers and to make it easier for them to identify how their programming may or may not align with the pedagogical concepts being presented. The approaches for science learning statements replicated verbatim the six strands of science learning, because these are less conceptual. An external evaluator and eight BFS representatives validated the survey and did not express confusion about the statements representing approaches for learner engagement or science learning.

The respondents were also asked about the role of place in their programming (see the supplemental materials for how the ISL framework aligns with individual survey questions). The respondents could select among 38 topics for each program and could add others. These topics were organized into two broad STEM categories on the basis of guidance from the National Science Foundation (BTAA 2014): the natural and environmental sciences (e.g., ecosystems, biodiversity, natural history) and the core sciences (e.g., biology, chemistry, physics). Topics also included the arts, STEM careers, and social sciences. Given the conceptual and applied overlap between many STEM disciplines, to differentiate natural and environmental sciences from core sciences, we relied on the specificity of the topic and how closely it was associated with a focus on natural and environmental sciences, issues, or applications.

Additional questions provided a list of options for the survey takers to select from and revealed who the programs recruited (e.g., age groups, groups underrepresented in STEM careers), to what extent scientists were involved in the outreach implementation, how the program and participant engagement

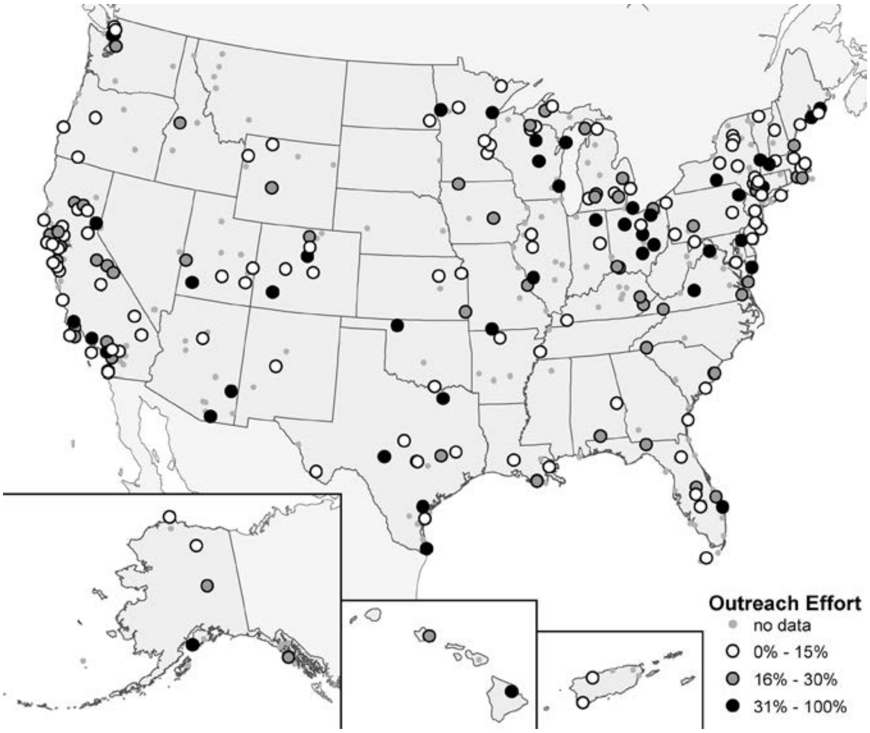

Figure 2. Map of BFSs and their self-reported outreach effort. Out of 406 BFSs in the United States (Struminger et al. 2018), 223 responded to the outreach survey and 209 estimated what percentage of effort they dedicate to outreach.

were evaluated (e.g., observation, questionnaires), and what the possible impacts of the program were on the participants. The survey respondents were given a list of goals for each outreach program and could add a goal not listed.

Many of the questions allowed the respondents to select multiple options to capture the breadth of the outreach offerings. This allows us to present a general, aggregate picture of the informal STEM education opportunities that BFSs bring to the public and enables us to explore correlations within and between elements of the ISL framework.

Survey participants and commitment to outreach. Representatives of the BFSs were recruited to take the survey in person at the 2017 and 2018 Organization of Biological Field Stations (OBFS) annual meetings, via emails sent to the OBFS listserv, and with promotional links on the research project and OBFS websites. Using a master list of BFSs compiled from the OBFS directory and Tydecks and colleagues (2016), we identified any station that had not completed the survey after a few months and emailed each a reminder about the survey. To incentivize the stations, we entered them into a drawing if they completed the survey for one of five $100 gift cards. These efforts resulted in approximately 55% of US BFSs responding to the outreach survey (n = 223); of the completed surveys, 80% of the BFSs (n = 179) confirmed that they offer STEM outreach to the public.

The survey respondents varied in their roles from outreach coordinators or educators (8%) to station directors (36%) or some combination of these titles (39%), and anecdotally, we know that some of the BFSs asked for input from multiple staff members who could answer the array of questions we were asking. Because this survey asks questions about BFS activities and does not reflect personal or sensitive information, the Texas A&M Internal Review Board did not deem approval necessary. Accordingly, given the nature of the questions and the focus on program descriptors, we were not concerned with self-reporting issues, such as social desirability bias.

So we could determine how the BFSs were prioritizing outreach relative to their other commitments, the survey asked them to indicate by percentage how their resources are allocated. On average, the BFSs reported dedicating 45% of their resources to research or student training. They dedicated nearly the same amount of resources to education outreach (e.g., volunteer, not-for-credit courses, community service, or informal education; 22%) as to formal education (20%). The remaining resources are dedicated to fundraising and development (6%) or other activities (8%). Figure 2 shows which BFSs responded to the survey and which of those indicated making outreach a priority through dedication of effort. Altogether, the BFSs that responded to the survey described 396 programs, and, of those, 316 were explicitly informal and reached an estimated 1.1 million participants.

Outreach survey coding and analyses. We asked Likert scale questions corresponding to each approach for learner engagement and science learning (see table 1 and the supplemental material). The responses were converted to ordinal numbers one to five associated with Likert scale responses of *strongly disagree*, *somewhat disagree*, *neither agree or disagree*, *somewhat agree*, and *strongly agree*. When two questions were asked for a single approach, they were averaged and then rounded to the nearest integer. When the response to either statement or to both statements were at least *somewhat agree*, the program was considered in alignment with that approach. All other Likert scale responses were coded the same way for the correlation analyses. Bollen and Barb (1981) showed that Pearson's correlations with coarsely categorized measures, such as those on a Likert scale, do not greatly differ from the continuous variables from which they were derived. Pearson's correlation coefficients were used to evaluate the association within and between all approaches. We also used Pearson's correlation coefficients to evaluate the association between perceived program impacts and the methods of program assessment (see the supplemental material).

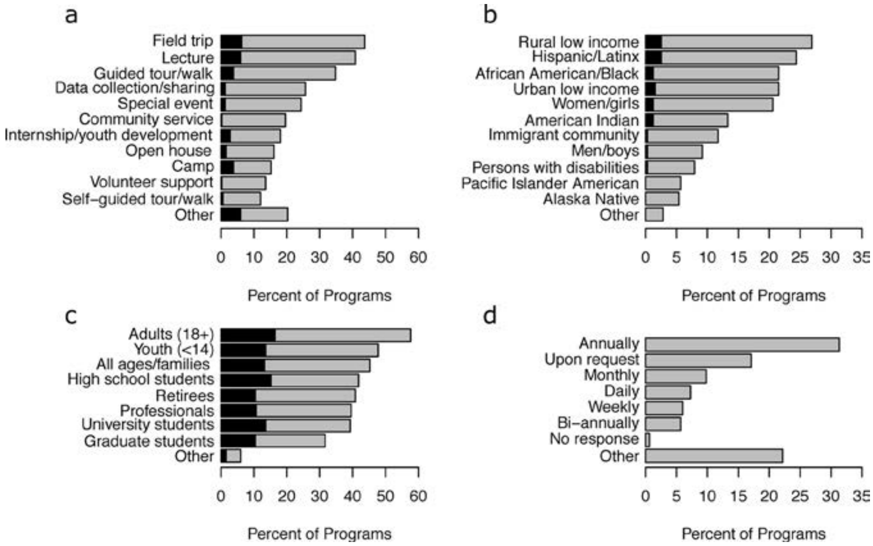

Figure 3. Bar plots showing design elements of 316 informal learning programs at BFSs, including the program type (a), the program's recruitment of underrepresented groups in STEM (b), the program's target audience (c), and the program's frequency (d). The gray bars indicate nonmutually exclusive selections, and the black bars indicate programs that only selected one program type, underrepresented group, or target audience.

How are BFSs designing their outreach programs?

Two features of informal education experiences are that they are voluntary (learners decide to participate on their own) and that the learners are self-motivated to join in the activities (Stocklmayer et al. 2010). A large majority of the surveyed programs (n = 316; 88%) had both attributes. The BFSs also reported that most of their programs (88%) were implemented after a great deal of planning, indicating a clear commitment to their efforts. Many of those programs (65%) were planned and implemented at the BFS, whereas about a quarter of them (26%) relied on outside groups to plan and implement them. Although we didn't ask which outside groups were used, we know, anecdotally, that these groups can include boy and girl scouts troop leaders and master gardener organizers. Most outreach program topics (87%) were directly tied to the place where the program was situated, and primarily focused on ecology (86%), conservation (80%), and ecosystems (80%), with the environment (78%), animals (75%), and biodiversity (75%) rounding out the most popular subjects. Seventy percent of the topics were related to either the environment or natural sciences, and approximately 19% of the programs covered topics in other core STEM disciplines (e.g., mathematics, physics, chemistry). Another 7% were focused on social sciences, 2% on STEM career awareness, and 2% on the arts.

When asked who leads each of their outreach programs, the BFSs reported that it is mostly their staff (71%) or professional scientists (59%), with nearly half led by professional educators (48%); less often, volunteers (28%) or graduate students (22%) would take the lead. Seventy five percent of the programs had a combination of these groups as program leaders, suggesting collaboration during implementation. Scientists were involved in outreach programs as teachers and facilitators (67%), guest speakers (57%), organizers (51%), participants (32%), or content reviewers (24%). One unique element of BFSs among institutions of informal STEM learning is that they are places in which nonscientists and scientists come together.

Most of the outreach programs (75%) had learning objectives, and many (74%) guided their participants through each part of the learning experience with instructional materials or a leader, clearly providing some structure and support for their participants. Another 28% of the programs let their participants choose for themselves how to spend their time but intrinsically provided ways to connect to a particular place. The most popular types of programs that BFSs organized for the public were field trips (48%), followed by lectures (42%), and guided walks (32%); one quarter (25%) of the programs involved data collection and sharing (e.g., citizen science and BioBlitz events). About a third of the programs (34%) used a single program type, and just 15% offered only lectures (figure 3a). By using multiple formats, the programs engage their participants with a variety of activities.

Of all the informal STEM programs offered at the BFSs, only 120 (38%) recruited groups underrepresented in the sciences. Of these, just 76 (63%) said their recruitment efforts were successful (i.e., that the participants who attended were those they were targeting). Altogether, only a quarter (24%) of the outreach programs offered at the field stations targeted—and the respondents thought they were successfully recruiting—underrepresented groups, indicating an opportunity for them to broaden participation in their informal STEM programs. Figure 3b shows that Hispanic or Latinx populations (29%) were most often the focus of these recruitment efforts, followed closely by rural low-income groups (28%), urban low-income groups (25%), and Black communities (24%).

The audiences that the BFSs targeted for their events mostly combined learners of all ages (figure 3c). Although the most commonly targeted audience was people 18 and older (53%), only 15% of the programs exclusively targeted adults. The frequency of outreach programs varied considerably, and the more popular annual event (31%) likely reflects BFSs' reliance on field seasons and their visiting researchers, who help with the outreach programs (figure 3d). Many of the programs were also marked *other* (22%), which mostly included seasonal programs (e.g., offered daily or weekly during the summer) and quarterly programs.

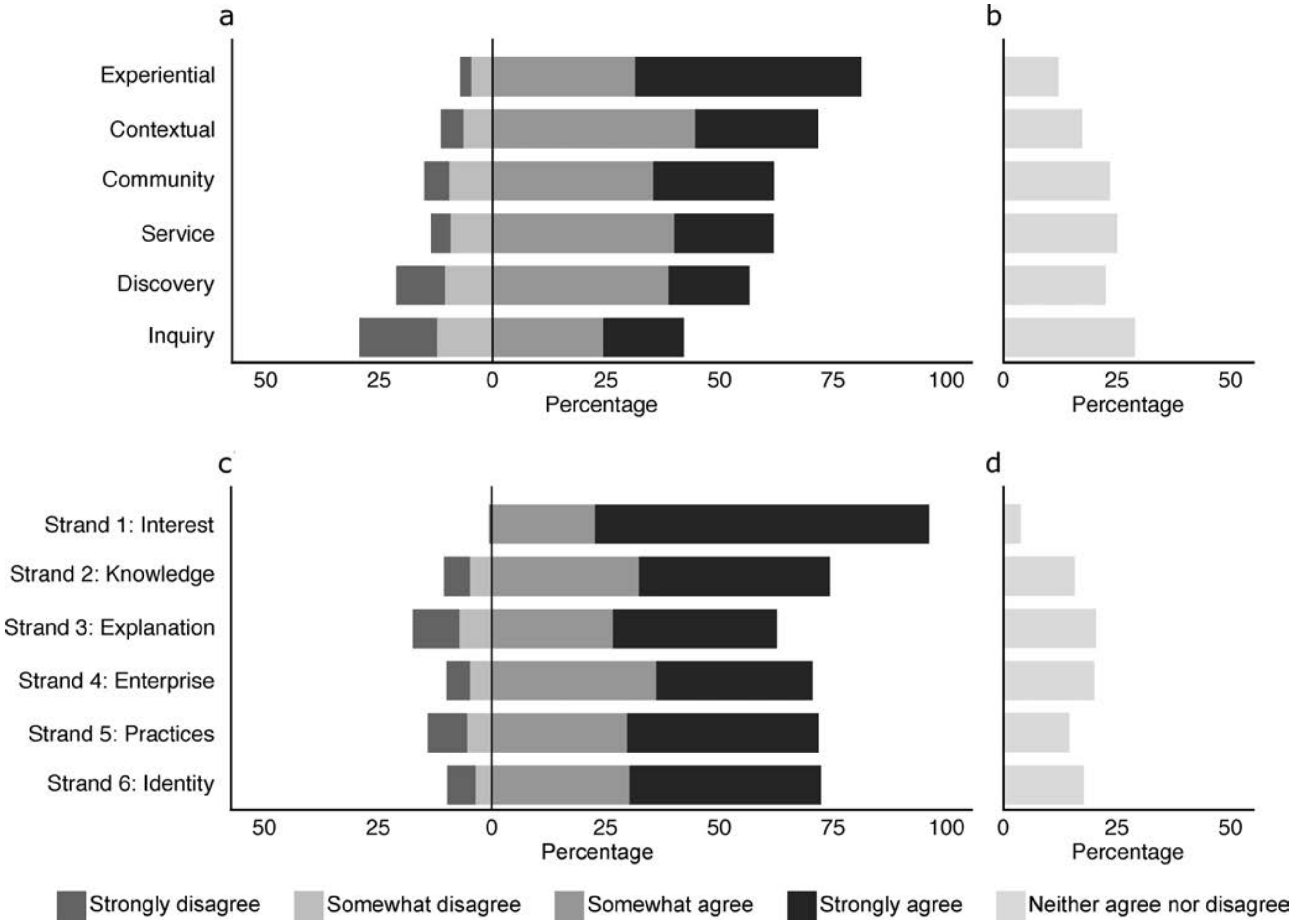

Figure 4. The approaches for learner engagement (a) and science learning strands (c) used in outreach programs. Panels (b) and (d) indicate the percentage of the respondents who neither agreed nor disagreed that the approaches were used in the outreach program.

How are the components of the ISL framework applied in each outreach program?

We used the ISL framework to explore approaches for learner engagement and science learning that the BFSs used in their outreach programming. These strategies provide a useful lens for understanding how BFSs position participants in the learning experience and for identifying which aspects of science literacy BFSs are focused on in their efforts to educate the public. Showing which approaches are used to address which aspects of science literacy can further deepen our understanding of how BFSs are implementing this work. We then look to the STEM topics addressed in these programs.

Approaches for learner engagement. Most of the respondents (81%) indicated that they used the experiential learning approach when implementing their programs (figure 4a, 4b). Specifically, the majority of the BFSs strongly or somewhat agreed with the statement "participants' learning experiences are more important than specific outcomes." Contextual and community learning (72% and 62%) were the next most popular ways of engaging learners, followed by service and discovery learning (62% and 61%); inquiry learning was less common (42%).

The programs at the BFSs cited multiple approaches for learner engagement (the approaches are not mutually exclusive), and nearly all of the approaches correlated at some level (figure 5a). All significant ($p < .05$) correlations were positive and were in the range of $.13 < r < .65$. Most programs that emphasized inquiry learning strongly aligned with programs that used community ($r = .65$, $p < .05$) or discovery learning ($r = .60$, $p < .05$) approaches. Inquiry learning programs are those for which the participants are guided as they solve a problem and are asked to explain or justify their work. Such programs should provide ongoing scaffolding for learners and likely require more attention from those implementing the outreach activities than the other approaches do; this may explain why it was selected least among the educational strategies (figure 4a). Community programs incorporate collaborative elements, whereas the discovery learning approach,

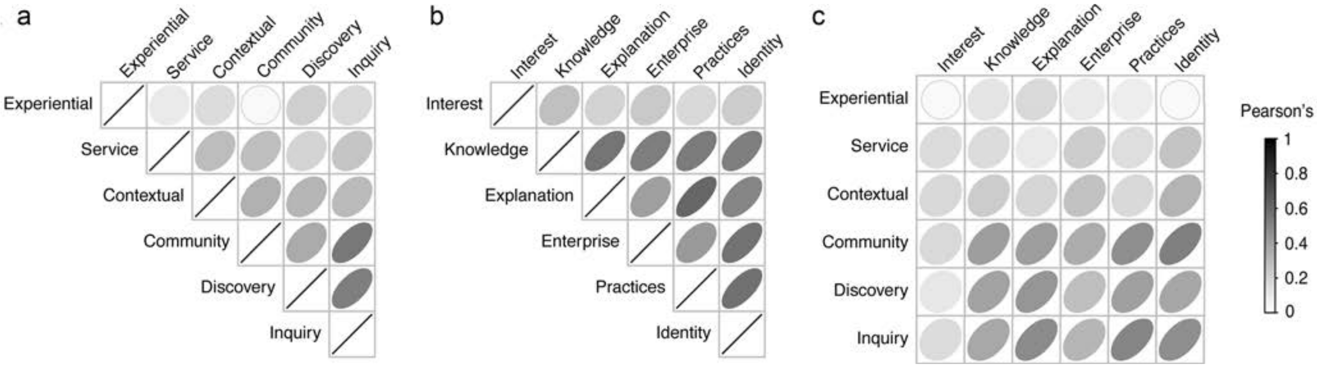

Figure 5. Correlations among the six approaches for learner engagement (a). Correlations among the six strands of science learning (b). Correlations between approaches for learner engagement and strands of science learning (c). The grayscale gradient and ellipses are calculated from Pearson's correlation coefficient. Ellipses represent the strength of the correlation coefficient. Thinner ellipses and darker color indicate a stronger correlation. Nonsignificant coefficients are shown with circles outlined in gray.

as it is applied within the ISL framework, engages learners by asking them to pose and answer their own questions. The strong correlation between inquiry and community implies that the participants are being asked to collectively focus on topics they are interested in while getting help along the way (figure 5a). The strong correlation between inquiry and discovery suggests that, when discovery or inquiry approaches are implemented, the participants are supported as they ask questions of their own choosing.

Strands of science learning. Each of the six approaches for science learning is aligned with no fewer than 60% of the reported programs (figure 4c, 4d). This suggests that, across all outreach programs and all age groups, the BFSs were actively promoting key aspects of science literacy. Strand 1 (interest) was by far the most popular, with 96% of the programs reportedly generating "participant excitement, interest, and motivation to learn about phenomena in the natural and physical world." The BFSs also reported addressing strand 2 (knowledge), strand 4 (enterprise), strand 5 (practice), and strand 6 (identity) in 70%–74% of their programs. This suggests that the BFSs' informal STEM programs invited their participants not just to understand new content (strand 2) but also to think about themselves as science learners with a scientific identity (strand 6), to participate in scientific activities (strand 5), and to reflect on science as a way of knowing (strand 4). When asked their level of agreement with the statement "Participants manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world," the BFSs strongly or somewhat agreed for 63% of the programs (strand 3). Although this is less than the other strands, there is still a clear commitment to giving the participants opportunities to engage with science in a multitude of ways.

Strands of science learning correlate with one another (figure 5b). The popular strand 1 (interest) is only moderately related to the other strands ($.24 < r < .36$, $p < .05$). All other strands are more closely associated with each other ($.49 < r < .72$, $p < .05$), indicating that programs including any of strands 2–6 typically feature some combination of the other strands. Noteworthy is the stronger correlation between strand 3 (explanation) and strand 5 (practice; $r = .72$, $p < .05$). These strands are complementary, because they are both focused more on methodology and scientific practice than the other strands.

Correlations of approaches for learner engagement and science learning. The correlations between learning engagement strategies and the strands of science learning reveal how the BFSs approached teaching different aspects of science literacy (figure 5c). Most of the BFS programs described in the survey use an experiential approach and apply strand 1 (interest) to their outreach programs. Unsurprisingly, there were no significant correlations between either experiential or strand 1 and any other learning approach or strand, because they were nearly always present. Community and inquiry approaches for learning correlated significantly with all of the strands, except strand 1. Community approaches most strongly correlated with strand 6 ($r = .59$, $p < .05$), which is focused on the participants thinking of themselves as science learners, and the programs that used inquiry approaches most strongly correlated with strands 3 ($r = .56$, $p < .05$) and 5 ($r = .57$, $p < .05$), which are focused on scientific explanation and argument and on engaging in scientific practices.

What are the program goals and perceived impacts of outreach programs on the participants?

The most popular goals of the outreach programs that the BFSs offer are not mutually exclusive (table 2). The BFSs indicated that encouraging conservation or environmental stewardship was the most important goal (78%), followed by teaching about the environment generally (74%), disseminating knowledge or skills (72%), and inspiring curiosity (67%). Raising awareness of the field station's work (67%),

Table 2. Goals of the informal STEM education programs at BFSs (n = 316).

Program goal	Count	Percentage
Encourage conservation or environmental stewardship	246	78
Teach about the environment generally	233	74
Disseminate knowledge or skills	226	72
Inspire curiosity	213	67
Raise awareness of the field station work	212	67
Build community	184	58
Reach a particular audience	176	56
Promote STEM careers	147	47
Make field station resources available to the public	139	44
Teach researchers how to communicate with the public	55	17
Raise money	53	17
Other	18	6

building community (58%), and reaching a particular audience (56%) were also very popular. Nearly half of the programs reported promoting STEM careers (47%) and making field station resources available to the public (44%).

Perceived impacts of outreach on the participants. The survey respondents were asked to indicate their level of agreement with a series of statements about the possible impact of their informal STEM programs on their participants. The BFSs strongly or somewhat agreed that their outreach activities were primarily achieving three things: The participants experience an increase or change in knowledge of a topic (98%), their interest in a topic increases or changes (97%), and they exhibit an interest in returning to the field station (89%; figure 6a, 6b). A majority of the BFSs also indicated that their outreach participants become more excited about spending time outdoors (79%), change their attitude or behavior (74%), and become more aware of STEM careers (63%).

Assessing outreach program success. To explore how the BFSs measured the success of their informal STEM programming, the outreach survey presented the respondents with a list of methods for evaluating program success and assessing the learning of their participants. Most of the BFSs (77%) gauged success by estimating how engaged their participants were with the program or through unsolicited feedback (76%; table 3). Attendance levels (72%) or observations (72%) were the third and fourth most popular methods. Surveys or questionnaires of their outreach participants (39%) and ongoing follow-up with the participants (37%) were much less common assessment tools, perhaps because they require more time and resources than are available to those implementing the outreach.

The field stations always applied more than one method of assessment when evaluating their programs. Pearson's correlation coefficients were used to gauge whether any particular assessment type was used to measure particular program impacts on the participants, and none were strongly correlated. However, when the participants created a product as part of a program, the BFSs more often reported seeing a change in the participants' data collection, field, or interpretation skills, or indicated that their participants learned the difference between anecdotal and empirical evidence (see supplemental figure S1).

Summary and recommendations

Biological field stations are actively and meaningfully working toward creating informal STEM learning experiences that engage the participants and promote science literacy. Informal education centered at field stations takes many forms but whether a field trip or guided walk, programs are often structured to help direct the participants through an experience with clear learning objectives. The considerable popularity of the experiential learning approach for engaging learners and strand 1 (interest) is not surprising, given that environmental educators promote experiential learning methods (Ballantyne and Packer 2009; https://naaee.org/eepro/learning/eelearn/what-is-ee/lesson-2/experiential-learning) and suggests that, in the aggregate, the BFSs cared a great deal about their participants having a positive experience in nature. Moreover, through these informal, outdoor-oriented STEM programs, the BFSs were not using formal assessments even though they had identified learning objectives. Rather, on the basis of the survey responses, their programs appear to have been focused on motivating and inspiring curiosity in their participants—two factors known to support lifelong science learning and sometimes STEM careers (Sacco et al. 2014, Bell et al. 2016, Stocklmayer and Rennie 2017).

The survey results show that the BFSs think that most of their program participants become more interested in and knowledgeable of science. This aligns nicely with the key program outreach goals of disseminating knowledge or skills. By contrast, a key remaining question is how well these experiences achieve field station leaders' top goal of encouraging conservation or environmental stewardship. Because BFSs cover such a wide range of STEM topics and are focused on the features of their geographic location, they present opportunities to raise awareness and insight into environmental issues that could be addressed through local decision-making and civil engagement. Future research could explore the role of BFSs in promoting viable strategies for conservation and conservation education in their local communities.

Evaluating the success of an informal learning activity remains one of the biggest challenges for ISL practitioners (Allen and Peterman 2019). Our results indicate that the programs at BFSs rely primarily on informal, observational methods of assessment. We recommend embedded assessments as one means of addressing this challenge. Activities associated with the six approaches for learner

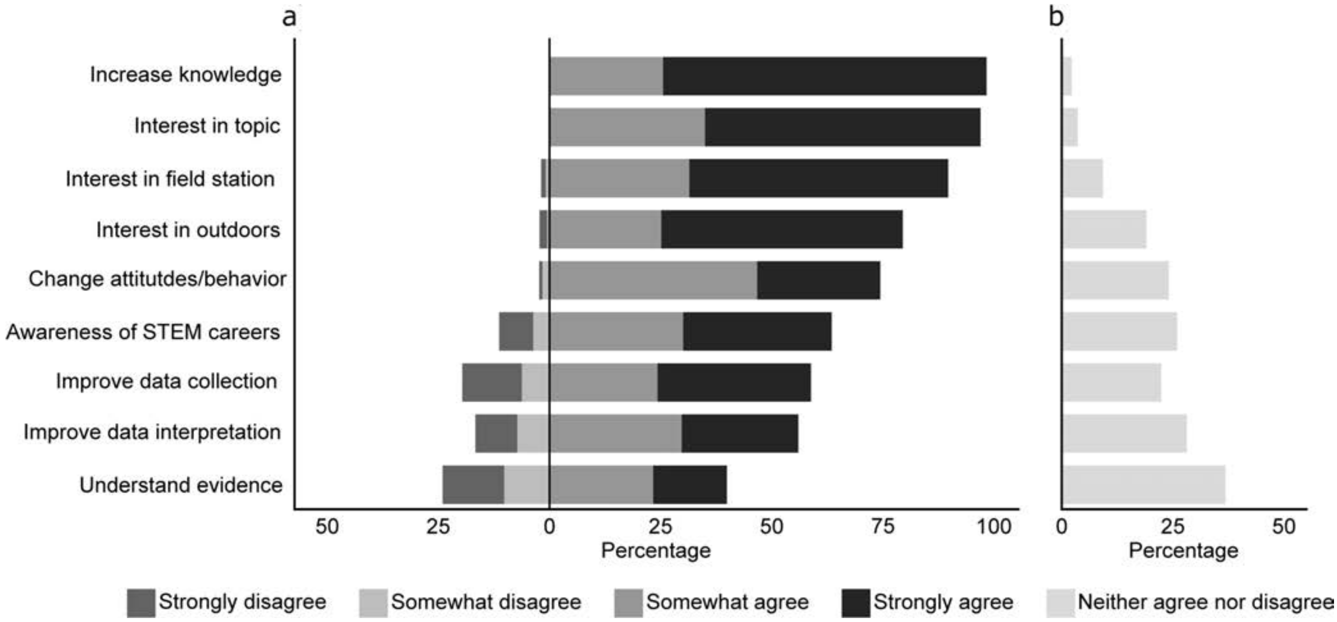

Figure 6. How BFSs perceive their outreach programs affect their participants (n = 316).

Table 3. Methods for assessing informal STEM program success by BFSs (n = 316).

Method	Count	Percentage
Participation levels (i.e., how engaged are the participants with the program?)	244	77
Participant feedback (unsolicited)	239	76
Attendance levels (i.e., how many participants are there?)	227	72
Observation or perceptions	226	72
End-of-program survey or questionnaire	124	39
Ongoing or follow-up contact with the participants	118	37
Review of the participants' work	83	26
Tests or formal assessment	30	9
Other	24	8

engagement presented in the present article often require their participants to do or create something that could serve as an embedded assessment for measuring the impact of the outreach experience on the participants (Becker-Klein et al. 2016). Embedded assessments are part of activities and do not disrupt learners' experiences as tests or surveys do, creating opportunities to gauge participant achievements such as an ability to perform a new task, gain a new perspective, or explain a new concept (Fu et al. 2019). BFSs are already using multiple assessment methods for their programs, which suggests they are trying different ways to measure outcomes from their outreach. Finding creative ways to evaluate the educational impact of the programs without diminishing the informal nature of the events is an area for future research and innovation.

One quarter of the BFSs reported successfully recruiting groups underrepresented in the sciences, and 57% did not report recruiting any to their informal outreach programming. Even when the BFSs successfully recruited underrepresented groups, we do not know how well the outreach was received by these participants. According to a 2017 Pew Research Center survey (Funk et al. 2017), an estimated 62% of the US population goes to at least one informal STEM learning venue (e.g., state park, zoo, natural history museum) annually, but informal learning institutions disproportionately cater to or are geographically near advantaged segments of the population (Dewitt and Archer 2017, Dawson 2018, Short et al. 2020). This is unfortunate, because groups underrepresented in the sciences are responsive to learning in informal contexts (NRC 2009). BFSs do have a unique opportunity to reach these populations because they are located in areas underserved by other informal learning institutions; this especially affects Indigenous populations (Short et al. 2020). However, the BFSs reported that Indigenous groups were among the least recruited (figure 3).

When field stations reported devoting as many resources to their informal programs as to their formal ones, they signaled that informal STEM learning is as much of a priority as their formal education offerings and, subsequently, have the potential to affect the public broadly. By focusing on the unique informal STEM education at BFSs, researchers, practitioners, and scientists alike can engage the public with their work, advance science literacy generally, and ultimately broaden support for conservation and stewardship efforts. Clearly, BFSs are not just making significant efforts to educate the public; they aim for successfully engaging learners and promoting science literacy in exciting ways. Other informal learning institutions with a focus on place-based education can benefit from these insights by evaluating their efforts in terms of learner engagement, science learning, and participant outcomes.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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