Evidence & Impact: Museum-Managed STEM Programs in Out-of-School Settings

Bernadette Chi, Rena Dorph & Leah Reisman

THE LAWRENCE
HALL OF SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

The National Research Council's Committee on Successful Out-of-School STEM (Science, Technology, Engineering, and Mathematics) Learning has been tasked with writing a consensus report on the value of and evidence for out-of-school STEM learning programs. As part of its charge, the committee has posed the following questions to be addressed in this paper:

> *What evidence is there for the impact of museum- (and other designed setting) managed programs on STEM learning and interest? What is known about the impact and value of such programs on school-age children's understanding of STEM concepts and practices as well as their interest and engagement in STEM?*
>
> *What is known about the characteristics of successful programs? Does the relevant literature provide enough evidence to point to design principles for such programs?*

This paper responds to these questions focusing on the evidence of the impacts and features of STEM learning programs run by museums and other designed environments, such as science and technology centers, planetariums, zoos, aquaria, etc. For the purposes of this paper, we use the definition of "programs" set out by the National Research Council (NRC) (2009) report, *Learning Science in Informal Environments* (LSIE):

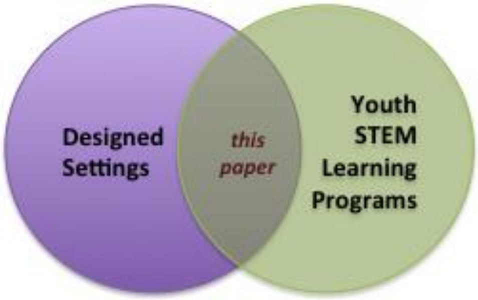
> *What these programs have in common is an organizational goal to achieve curricular ends—a goal that distinguishes them from everyday learning activities and learning in designed environments…. [P]rograms are typically led by a professional educator or facilitator, and, rather than being episodic and self-organized, they tend to extend for a period of weeks or months and serve a prescribed population of learners* (p. 173).

To examine evidence of STEM learning programs managed by museums, we conducted a literature review of peer-reviewed journals and books. To build on existing work of the NRC, we focused on articles that have been published since the writing of *Learning Science in Informal Environments* (2009) and on a limited set of literature written before 2009 that were not included in LSIE. Given the limitations of the published body of evidence in this area, we also draw from a selected set of evaluation reports and emerging research to enrich our treatment of this topic. We have organized the paper in five main sections: (1) Introduction, (2) Evidence, (3) Impact, (4) Features of Successful Programs, and (5) A Way Forward.

Introduction: The Lay of the Land

Given the growing interest in supporting STEM learning opportunities for youth, museums and other designed settings offer extensive experience and expertise as resources to support youth and communities in deepening and expanding such opportunities. Museums provide a continuum of STEM learning experiences within local communities to support a range of youth interest in STEM, from drop-in spaces that foster awareness to immersive experience that deepen and extend youth learning. The range of opportunities also support a diversity of student interests in STEM, from those who are not interested in STEM to those who seek experiences that deepen their STEM interest and conceptual understanding or that expand their skills and practices. As researchers and evaluators housed within a science museum, we fully acknowledge the rich and diverse array of such institutions and opportunities, and so offer a few caveats for the purposes of this paper.

First, for the sake of brevity in this paper, we consistently use the term, “museum,” to speak to the many types of designed settings or environments that may offer STEM learning opportunities within a community, even if they do not consider themselves museums in a



technical sense. These STEM-rich cultural institutions include science and technology centers, natural history museums, planetariums, botanical gardens, zoos, and aquaria, among other institutions that perceive their mission to be providing STEM-relevant informal learning opportunities for the larger public. Although designed settings or environments are typically experienced episodically and are set up to be participant-directed, the influence of designed environments continues to expand to support sustained engagement of participants through longer duration STEM learning programs; thus the impetus for this paper is to examine emerging evidence of outcomes for museum-managed STEM learning programs at a time when there is great interest in supporting STEM learning across settings. Second, as stated earlier, this paper focuses on the longer-duration programs managed by museums rather than those of a drop-in nature that is more typical of exhibits and brief one-shot floor programs.

Third, we focus on the types of programming that these types of institutions design, manage, and/or host within their facility walls and beyond. For example, museums have long partnered with many other organizations to provide STEM learning opportunities (Center for Informal Learning and Schools, 2006; Institute of Museum and Library Sciences, 2002; Inverness Research Associates, 1996), and there is tremendous diversity along a variety of dimensions to these partnerships (Bevan et al., 2010; National Research Council, 2009). For example, these opportunities vary in terms of settings (within schools, homes or community-based settings including labs or outdoors), times of the week (after school or weekends, during the school year or summer), frequency and duration, disciplinary focus (science, technology, engineering, arts and/or mathematics), how participants spend their time, and most especially, with a wide diversity of goals as will be discussed further in this paper.

Based on our experience studying informal STEM education and a review of the literature (Bevan et al., 2010; CILS, 2006; Sneider & Burke, 2011), examples of longer term STEM learning programs managed by museums include the following:

- afterschool programs that occur during the week after school hours or on weekends that serve a consistent group of enrolled participants and have a particular focus or set of learning goals;
- camps that occur over summer and during school breaks that are focused on science, math, engineering, and/or technology activities, and enroll youth for one-week (or longer) in a sequence of activities;
- youth explainer or docent programs that provided intensive, multi-year engagement for youth in the life of the institution, including opportunities for STEM teaching, learning, and mentoring;
- research experiences in which youth assist with ongoing research or create their own investigations through longer-term opportunities over the course of a school year;
- making, tinkering, or innovating spaces offered through on-going programs during afterschool hours or weekends to promote youth-driven making or tinkering experiences.

In addition, there are recent examples of longer-term programs that continue to expand the influence of museums in supporting STEM learning, blurring the lines between formal and informal education. These programs offer examples of instances in which informal institutions partner with schools to provide STEM learning opportunities for youth that often incorporate elements of informal education such inquiry, hands-on experiences, and participant-centered instruction. The following represent a small sample of these types of programs:

- *East Bay Academy of Young Scientists* at the Lawrence Hall of Science in Berkeley, CA, facilitates afterschool science programs, working with teachers, science center staff, and undergraduates to collect water and air quality data and then analyze and present their findings to their community (http://www.lawrencehallofscience.org/ays/enroll.php);

- *Urban Advantage* in New York City is a consortium of eight STEM-rich institutions that provides both students and teachers with opportunities to engage in year-long science investigations with the culmination of an eighth-grade science exit project (Weinstein, Whitesell, & Schwartz, 2013).
- *BioSITE (Students Investigating Their Environment)* at the Children's Discovery Museum in San Jose, CA, engages museum staff in co-teaching high school environmental science classes in which high school students lead field science activities for fourth grade students (Chi, Reisman, & Chung, 2014);
- *Watsonville Area Teens Conserving Habitats (WATCH)* is a program coordinated by the Monterey Bay Aquarium in three local high schools, providing high school students with a two-week summer program and a class offered during the school year to develop their own environmental projects (Parsons, Bell, & Swan-Sosky, 2011).

Clearly, there are many more configurations of partnerships and examples of museum-managed STEM learning programs that are beyond the scope of this paper and deserve more careful examination. As will be discussed in more detail in the following section, the practices of museums to support STEM learning on their own and through partnerships with other institutions has outpaced the research to examine their implementation and impact.

Evidence

The most recent comprehensive examination of evidence regarding STEM learning in informal settings is the National Research Council's publication, *Learning Science in Informal Environments* (2009). Chapter 6 of that publication summarizes the research related to youth STEM out-of-school time programs: though evaluation studies suggest that out-of-school programs can have "positive effects on participants' attitudes toward science, grades, test scores, graduation rates, and specific science knowledge and skills … there is little evidence of a synthesized literature on out-of-school-time science programs" (p. 175). Further, this report explains:

> *While still relatively new, the study of out-of-school science programs holds great potential. To realize this potential, it will be necessary not only to greatly expand the body of literature regarding out-of-school science programs, but also to define the hoped-for outcomes* (p. 187).

While some progress has been made in expanding the literature regarding out-of-school science youth programs since 2009 (e.g., Bevan & Michalchik, 2013), little progress has been made regarding those that are specifically museum-managed. The vast majority of studies since 2009 that provide evidence of youth outcomes of museum-managed STEM learning experiences are focused on short-term programming, such as individual or family visits to exhibitions (Arcand & Watzke, 2010; Falk & Storksdieck, 2010; Gutwill & Allen, 2010; Haden, 2010; Kim & Crowley, 2010; Luebke & Matiasek, 2013; Speigel et al., 2011; Szechter & Carey, 2009; Van Schijndel et al., 2010) and field trips organized by schools (Gutwill & Allen, 2012; Holmes, 2011; Meissner & Bogner, 2011; Stavrova & Urhahne, 2010; Sturm & Bogner, 2010; Yoon et al., 2012; Zaharias & Chrysanthou, 2013). Some of these studies provide evidence of a range of outcomes of these STEM learning experiences. For example, many studies focus on evidence of learning as an outcome, including content knowledge (Falk & Storksdieck, 2010; Kim & Crowley, 2010); content knowledge and attitudes (Stavrova & Urhanne, 2010); content knowledge and affect (Meissner & Bogner, 2011); knowledge, attitudes, and behaviors (Falk & Gillespie, 2009); and others. Studies also focus on the development of scientific skills (Speigel et al., 2011) and during-visit behaviors (Kim & Crowley, 2010).

A majority of these studies focus on learning in the short-term, while only a few focus on long-term learning (for example, Bamberger & Tal, 2008; Falk, Needham, Dierking, & Predergast, 2014). Of 37 peer-reviewed research articles reviewed within the informal education and museum studies literature for this paper, only five studies pertained to longer-term museum-based STEM learning experiences and focused on outcomes for youth.[1]

- Rahm (2008) conducted a qualitative study of two informal science programs: (1) a partnership between museums, scientists, and schools in which students completed projects that were often exhibited in museums; and (2) an afterschool program for girls only. She investigated youths' hybrid identity development within these programs and underscored the pluralism of spaces in which youth can come to own science. She concluded with the suggestion that by "creating opportunity spaces and places that build on youths' funds of knowledge and allow for the co-option of science between youth and adults, we could possibly turn youths' interest in science into genuine science literacy for many of them, irrespective of who they are or want to become" (p. 120).
- Rahm and Ash (2008) also conducted a multi-site, ethnographic reporting on four participant cases and explored "how two informal educational contexts—an aquarium and an after-school science program—enabled disenfranchised learners to adopt an identity as insiders to the world of science" (p. 49).
- MacDonald and Bean (2011) conducted a preliminary evaluation of a physics education program that involved a website, animated videos, and educational programs at a museum. The evaluation focused on student engagement and teacher perceptions of the program's relevancy. Findings suggested that the program engaged students and was perceived by teachers to be relevant to their instruction.
- Regarding camp experiences, Bexell, Jarrett, and Xu (2013) evaluated the impact of a zoo-based, environmental conservation-focused summer camp program located in China

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[1] The list of identified studies is available upon request. We used search terms such as the following: museum, science center, zoo, aquarium, program, youth, science, technology, engineering, mathematics, after school, out of school, informal, and STEM. We searched for articles both through google scholar as well as through citation searches for relevant authors for published research, and on the internet to identify program evaluations that may be relevant for the topic.

on youth knowledge, attitudes, and behavior towards animals. Results suggested increases in student “knowledge, care, and propensity for action” toward animals as well as increased empathy.

- Gillespie and Melber (2014) investigated a collaboration program between an American zoo and a Nigerian museum where students designed their own research projects, collected data, and presented their results to peers in both locations. Results indicate that participants increased their knowledge about wildlife native to their own country, the wildlife and culture of their partner community, and the scientific process. They also improved their attitudes related to cultural understanding.

Interestingly, two studies on this short list focus on longer-term programs that cross settings—those that combined museum experiences with school-based or online experiences (MacDonald & Bean, 2011; Rahm, 2008).[2] The existence of studies of such cross-setting programs in the sparse literature on longer-term programs is worthy of note. Additional attention may be necessary regarding the power and growth of experiences that cross-contextual boundaries and partner with participating youth as they navigate in and between types of learning environments.

Another source of evidence for the impact of such programs are evaluation studies that are documented in evaluation reports developed for program leaders and funders. Given that this literature is more complex to access and quite diverse in scope and rigor, we only draw on it selectively as illustrative of what can be learned through some of these studies. One such illustration emerges from a particular type of youth-focused, museum-based, multi-year program. YouthALIVE! programs were initiated in 1991 through the Association of Science-Technology Centers to enable museums and science centers to establish programs to engage disadvantaged and underserved youth in the life of museums and science/technology centers (Shelnut, 1994;

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[2] Examples of some of these cross-setting programs were provided in section 1

Sneider & Burke, 2011). Over 160 youth programs similar to YouthALIVE! continue to currently exist, engaging high school and middle school students in workshops to promote learning STEM concepts and practices, and eventually engaging these youth in serving as exhibit explainers, docents, teaching assistants, or in animal care.

According to a review of YouthALIVE! programs and their evaluations, Sneider & Burke (2011) suggest that youth involved in these programs have relatively high rates of high school graduation, college enrollment, and pursuit of STEM careers, though the evaluation studies that were reviewed did not include control or comparison groups to examine the effects of program participation. One evaluation study cited in this review did conduct a ten-year retrospective study of Chicago-based Project Exploration alumni to document longer-term influences of program participation (Chi & Snow, 2010). Researchers interviewed or surveyed approximately 30% of the former participants of the program and found that 95% of alumni respondents graduated high school or were on track to graduate. In addition, 60% of Project Exploration alumni enrolled in a four-year college pursuing degrees in STEM-related fields; and 60% of students who graduated college reported earning a degree in a STEM-related field.

Another recent international evaluation of the effects of youth and adult participation in science centers suggest that the amount of engagement and participation in science centers was generally correlated with the following outcomes: 1) improved science and technology knowledge and understanding; 2) science and technology interest and curiosity; 3) engagement with out-of-school science and technology-related activities; 4) engagement with and interest in science as a school subject (youth); and 5) personal identity and confidence in science and technology (Falk et al., 2014). For example: “for adults in general and youth relative to interest and curiosity, there appeared to be a threshold effect with greatest incremental change in correlation seen when individuals visited (science centers) between two and four times a year, but not more. Similarly, relationships were relatively flat for visits lasting up to four hours, but then increased markedly after five or more hours (of engagement with science center programming)" (p. 40). In addition, the study found that those adults who reported that their typical science experience was of the prolonged participation nature (e.g., attending a camp, volunteering at the science center, or attending a long-term special program) showed no long-term correlation with science interest and curiosity. The study acknowledges its limitations regarding the effects of self-selection bias of participants and the inability to explain the correlations; however the findings of this study suggest empirical hypotheses that can help museums and science-centers identify a "sweet spot" of how much exposure can be provided to youth that could potentially lead to positive outcomes (i.e., how much is enough?).

Evidence of learning through making, tinkering, or innovating experiences is emerging as the practice of making/tinkering spaces has clearly outpaced research and evaluation about the potential influence of these experiences for youth (e.g., Gutwill et al., in review; Brahms & Crowley, in submission; Dorph & Cannady, 2014; Martinez & Stager, 2013; Honey & Kanter, 2013). We understand Shirin Vossoughi is writing a paper summarizing the research in this area for the NRC Committee; thus we have not included further review of that literature in this paper. Instead, we refer Committee members to (1) Vossoughi's paper and (2) a website (https://makingandlearning.squarespace.com/resources) recently updated as a result of a Making and Learning Conference convened by the Children's Museum of Pittsburgh in July 2014. We also advise the committee to "stay tuned" to emerging research in this area as a significant number of making programs are museum managed.

The small number of peer-reviewed journal articles identified through this literature review of research on programs managed by museums, science centers, aquaria, etc., coupled with the disparate nature of the evaluation literature, suggests a lack of a unified body of research regarding longer-term types of museum-managed STEM programs. Existing research is scarce; that which exists is scattered throughout various sub-fields and is identified using disparate terms and descriptors. The small number of studies and reports that were reviewed do, however, suggest that longer-term museum programs have the potential to influence youth knowledge, attitudes, and behaviors related to STEM and the many specific disciplines within it. Additional research is needed to investigate these impacts.

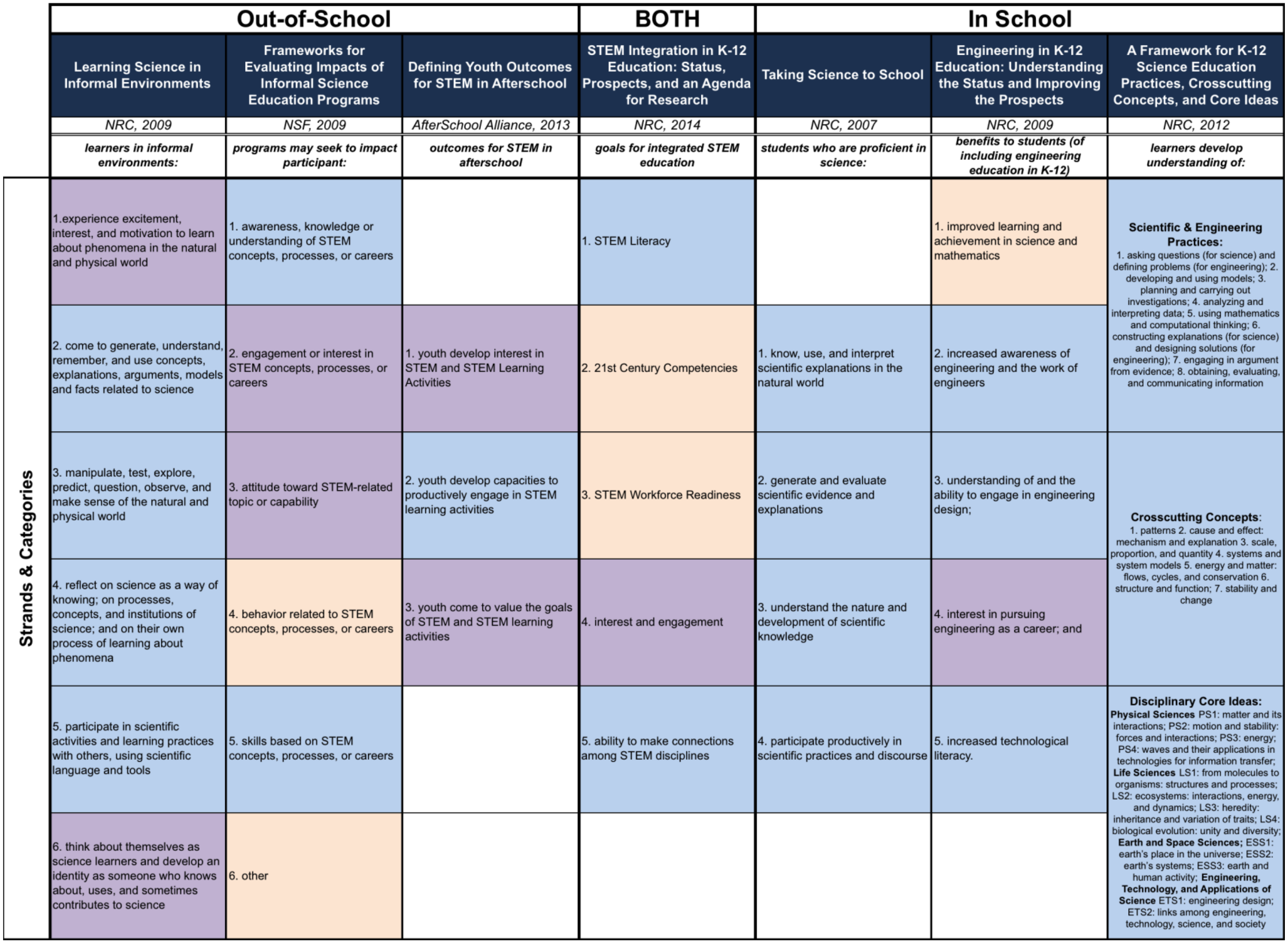
The limitations of the evidence reviewed above raise several questions that warrant further attention. *What do we mean by success in museum-managed youth programs? Are there data that provide compelling evidence of success? What do we know about the particular features of "successful" learning experiences that are associated with compelling evidence of success in out-of-school environments?* We now turn our attention to these questions.

Impact

One of the issues with the body of literature described above is its collective incoherence regarding what impact we seek through longer-term, museum-managed STEM programs for youth. It quickly becomes evident that the field is working with multiple visions of what "success" for STEM learning in out-of school settings might look like, as well as varying standards of what evidence of success should look like. These varying visions and standards are part of the landscape that must be addressed if we are to move research and practice forward.

In order to support understanding the variety and overlap across various visions, we summarize multiple synthesis frameworks in Table 1 that each delineate outcomes that could be fostered through STEM education—both formal and informal experiences. Within this table we have color-coded the articulated goals and outcomes within and across framework to indicate those that are related to one another. More specifically, those shaded in green indicate that they are related to STEM content knowledge (including understanding of the nature of science and scientific skills and practices); those shaded in blue indicate that they are related to affective and motivational outcomes (e.g., interest in STEM, positive attitudes towards STEM, etc.); those shaded in peach are related to other outcomes (behaviors, career, achievement). Please note that this categorization system is not absolute as some of the elements in some of the frameworks could have fit in more than one category.

Table 1. Summary of Various Goal/Outcome Frameworks for STEM Education



	Out-of-School			BOTH	In School		
	Learning Science in Informal Environments	**Frameworks for Evaluating Impacts of Informal Science Education Programs**	**Defining Youth Outcomes for STEM in Afterschool**	**STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research**	**Taking Science to School**	**Engineering in K-12 Education: Understanding the Status and Improving the Prospects**	**A Framework for K-12 Science Education Practices, Crosscutting Concepts, and Core Ideas**
	NRC, 2009	*NSF, 2009*	*AfterSchool Alliance, 2013*	*NRC, 2014*	*NRC, 2007*	*NRC, 2009*	*NRC, 2012*
	learners in informal environments:	***programs may seek to impact participant:***	***outcomes for STEM in afterschool***	***goals for integrated STEM education***	***students who are proficient in science:***	***benefits to students (of including engineering education in K-12)***	***learners develop understanding of:***
Strands & Categories	1.experience excitement, interest, and motivation to learn about phenomena in the natural and physical world	1. awareness, knowledge or understanding of STEM concepts, processes, or careers		1. STEM Literacy		1. improved learning and achievement in science and mathematics	**Scientific & Engineering Practices:** 1. asking questions (for science) and defining problems (for engineering); 2. developing and using models; 3. planning and carrying out investigations; 4. analyzing and interpreting data; 5. using mathematics and computational thinking; 6. constructing explanations (for science) and designing solutions (for engineering); 7. engaging in argument from evidence; 8. obtaining, evaluating, and communicating information
	2. come to generate, understand, remember, and use concepts, explanations, arguments, models and facts related to science	2. engagement or interest in STEM concepts, processes, or careers	1. youth develop interest in STEM and STEM Learning Activities	2. 21st Century Competencies	1. know, use, and interpret scientific explanations in the natural world	2. increased awareness of engineering and the work of engineers	
	3. manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world	3. attitude toward STEM-related topic or capability	2. youth develop capacities to productively engage in STEM learning activities	3. STEM Workforce Readiness	2. generate and evaluate scientific evidence and explanations	3. understanding of and the ability to engage in engineering design;	**Crosscutting Concepts**: 1. patterns 2. cause and effect: mechanism and explanation 3. scale, proportion, and quantity 4. systems and system models 5. energy and matter: flows, cycles, and conservation 6. structure and function; 7. stability and change
	4. reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena	4. behavior related to STEM concepts, processes, or careers	3. youth come to value the goals of STEM and STEM learning activities	4. interest and engagement	3. understand the nature and development of scientific knowledge	4. interest in pursuing engineering as a career; and	
	5. participate in scientific activities and learning practices with others, using scientific language and tools	5. skills based on STEM concepts, processes, or careers		5. ability to make connections among STEM disciplines	4. participate productively in scientific practices and discourse	5. increased technological literacy.	**Disciplinary Core Ideas:** **Physical Sciences** PS1: matter and its interactions; PS2: motion and stability: forces and interactions; PS3: energy; PS4: waves and their applications in technologies for information transfer; **Life Sciences** LS1: from molecules to organisms: structures and processes; LS2: ecosystems: interactions, energy, and dynamics; LS3: heredity: inheritance and variation of traits; LS4: biological evolution: unity and diversity; **Earth and Space Sciences;** ESS1: earth's place in the universe; ESS2: earth's systems; ESS3: earth and human activity; **Engineering, Technology, and Applications of Science** ETS1: engineering design; ETS2: links among engineering, technology, science, and society
	6. think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science	6. other					

Review of the table above quickly can make one's head spin. As we looked across these multiple frameworks and the literature reviewed above we saw the following general outcome clusters (color coded to match Table 1):

- ***STEM Conceptual Understanding*** including awareness, knowledge, understanding, or use of STEM concepts, facts, phenomena, theory, explanations, and models
- ***Skills*** including use of techniques/tools, development and implementation of investigations, etc.
- ***Practices*** related to STEM as a way of knowing (e.g. manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world).
- ***Engagement*** in STEM activities, learning practices, tools and language, topics, concepts, phenomena, theories, or careers
- ***Interest/Excitement/Motivation*** to learn about STEM topics, phenomena, concepts, and theories or to pursue STEM careers
- ***Identity/Dispositions*** as learners who know about, use, and contribute to science, or who think/act like a STEM professional
- ***Workforce Readiness*** for 21st Century and STEM-related jobs
- ***Other***—behavior related to STEM concepts, processes, or careers, Math/Science achievement, etc.

It also is relevant to note that since the publication of *Learning Science in Informal Environments*, additional research studies on out-of-school programs to support other strands of STEM learning have emerged, only a few of which are based on research on museum-managed programs. We include them here to illustrate the emerging literature in these areas, highlight the importance of looking beyond studies of particular museum-managed programs, and suggest that future research could focus on how the following outcomes may be specifically supported by museum-managed programs:

- **Engaging in scientific reasoning/reflecting on science/practices of science & engineering** (e.g., Chi, Reisman, & Chung, 2014; Cuff, Corazza, & Liang, 2007; Wang, 2014)
- **Science content/concepts** not measured by standardized measures (e.g., Chi, Wierman, & Stuart, 2013; Cuff, Corazza, & Liang, 2007)
- **Identity formation** (e.g., Barron, 2006; Bell et al., 2012; Calabrese Barton, & Tan, 2009; Chi & Snow, 2010; Hsu, Roth, Marshall, & Guenette, 2009; Nasir, 2002)

Given that many of the museum-managed programs that we are aware of include "developing a positive STEM identity" among their participant outcomes and that two of the five peer-reviewed studies reviewed in Section 1 related to identity development, we briefly review insight from related relevant literature (albeit not related to museum-managed programs) as an example of how the bodies of literature listed above might warrant further investigation. STEM identity development remains a compelling, yet very difficult to define (and measure), outcome for STEM programs. For example, in the LSIE report, Strand 6 addresses "how learners view themselves with respect to science (and) the process by which individuals become comfortable with, knowledgeable about, or interested in science" (National Research Council, 2009, p. 4). Others have conceptualized identity as "authoring" different possibilities of self (Holland, Lachicotte, Skinner, & Cain, 1998). Other aspects of identity include "a sense of belonging in a community, a sense of competence, the development of interest, and the desire to participate in additional learning activities" (Barron, 2004, p. 6). Evoking Wenger (1998), Nasir and Hand (2008) define "practice-linked identities … that people come to take on, construct, and embrace that are linked to participation in particular social and cultural practices" (p. 147).

Beyond these studies, there has been significant attention to the concept of identity formation and development in recent literature within both formal and informal education that suggests definitions, methodologies, and theoretical frameworks that would be relevant to consider if and when examining how these processes may unfold through museum-managed programs (e.g., Archer et al., 2010; Bell et al., 2012; Chi & Snow, 2010; Hsu, Roth, Marshall & Guenette, 2009; Marshall et al., 2011; Nasir & Hand, 2008). For example, two other studies explored identity formation within the context of afterschool/out of school programs that were not managed by museums. First, Ahn et al., (2012) examined a case study of urban middle school participants in an after school program focused on science storytelling. The research project created an online community for these youth to share, remix, and publish stories about science that help them to develop identities as scientists and engineers (sci-dentity.org). Findings suggest that youth developed certain concepts, including "(a) imagination as a requirement for remix, (b) methods for credit, (c) ways of giving and receiving permission, and (d) the role of social and personal identity" (Ahn, et al., 2012). In the second relevant study, Calabrese Barton & Tan (2010) studied youth, aged 10-14, who were participating in a year-round after school program to learn about green technologies. They found that:

> *in producing and critiquing science through the process of making a science documentary, the youth were able to negotiate, within the affordances and constraints of the Get City figured world, to momentarily transform their engagement with science. They problematized established symbols of science, authored alternative identities, and displayed agency in their transforming acts that challenged how science should be presented, contemplated, and understood not just among their peers but among the general public, because the youth were clear in their intentions that their movies were "not just for kids, but for everybody" (p. 224).*

Another element of this landscape that introduces complexity is that several of these outcome constructs, like identity, have been defined differently across the field and are currently in use in multiple ways. This issue was recently illustrated in report entitled *Game-Changers and the Assessment Predicament in Afterschool Science* (Noam & Shah, 2013) that was inspired by a *2012 Summit on Assessment of Informal and Afterschool Science Learning*, organized by the *Board on Science Education* at the National Research Council and the *Program in Educational, Afterschool, and Resiliency (PEAR)* at Harvard University and McLean Hospital. In this report Noam and Shah state the following:

> *In her white paper, Ann Renninger argues that while the terms engagement, interest, curiosity, and motivation all have their own literature bases, you cannot define them without referring to the others (2012, WP, p.1-2). She offers the following simple definitions:*
>
> - ***Engagement** refers to connecting for some period of time to any of a variety of tasks or activities.*
> - ***Interest** refers to both the state of being engaged with and also the predisposition to return to engagement with particular content (e.g., science).*
> - ***Curiosity** describes a disposition to explore and question.*
> - ***Motivation** in its most general usage refers to the will to engage.*
>
> *For the sake of this report, when we discuss "engagement," we are referring to a combination of these terms* (Noam & Shah, 2013, p. 32).

Note that although many researchers (e.g., Renninger, 2012; Dorph et al., 2013) have paid careful attention to delineate the differences among these constructs, this Noam & Shah report still uses the term "engagement" to refer to a combination of constructs with various meanings. This is not unique to this report; we often find that researchers and practitioners use words like "engagement" and "identity" with different and various intended meanings.

Another complication in this “desperately seeking impact” story emerges as researchers try to operationalize the myriad outcomes into their measurement instruments and research agenda. Each of the frameworks depicted in Table 1 was developed through a consensus process. This type of process often results in loosely coupled lists that emerge from multiple theoretical and conceptual traditions and may lack internal coherence. Accordingly, in each framework the outcomes/goals are underspecified—exacerbating the issue of multiple meanings highlighted above—as are the relationships among them. The list(s) that have emerged do not necessarily easily lend themselves to developing robust measures or building research hypotheses and theories. For these reasons, among others, many research teams have developed various ways of defining these terms and their own ideas about outcomes that are important to pay attention to within particular theoretical and empirical traditions. As a result, there are even more specific ways of framing and characterizing goals/outcomes for youth than those depicted in Table 1. These are formulated in different ways relative to the particular theoretical underpinnings and goals of a given research effort; several will be discussed further in Section 5 of this paper.

Features of Successful Programs

Given the limited scope and quantity of literature regarding longer-term, museum-managed programs, there is still much to be done to understand which features of these types of learning experiences lead to one or more of the outcomes discussed in the previous section. Findings from studies related to shorter-term, museum-managed experiences suggest that a variety of elements influence the degree, type, and impact of learning that occurs in museums. Elements range from youth’s pre-visit motivations, knowledge, and/or dispositions (Falk & Storksdieck, 2010; Meissner & Bogner, 2011) to the features of the learning experiences like display types

(Meissner & Bogner, 2011; Yoon et al., 2012), learning goals (Kim & Crowley, 2010), discussion prompts (Gutwill & Allen, 2010, 2012), and others (Dorph et al., 2012).

While there is little research on museum-managed youth research experiences, evidence drawn from other educational settings can offer insight into the features of STEM learning opportunities that support changes in a variety of outcomes like those listed in Table 1. For example, research and evaluation of research experiences including camps organized by national laboratories or universities may offer relevant lessons for museum-managed STEM research experiences and camps, particularly for those museums that have professional researchers on staff and have access to laboratory settings. This area of research suggests that partnering youth with professional scientists in their labs provides participants with positive peer relationships, increased personal autonomy, increased interest in science, positive relationships with staff, and deepened science knowledge (Bell, Blair, Crawford, & Lederman, 2003; Richmond & Kurth, 1999; Barab, 2001; Fields, 2009; Hay & Barab, 2001).

Another example emerges from empirical studies that demonstrate the value of "authentic" science experiences, linking exposure to such experiences to outcomes like improved standardized test scores and learning (Johnson, Zhang, and & Kahle, 2012; Murphy, Lunn, & Jones, 2006; Tyler-Wood, Ellison, Lim, & Periathiruvadi, 2011) and more positive affective relationships with science (e.g., more positive attitudes, increased confidence, increased interest in pursuing further scientific research) (Brownell et al., 2012; Murphy, Lunn, & Jones, 2006; Tyler-Wood, Ellison, Lim, & Periathiruvadi, 2011). While these studies utilized divergent definitions of "authentic" science, they nevertheless demonstrate the promise such experiences hold in impacting student outcomes.

Synthesizing across these studies as well as a wide range of other literature about science learning within both informal and formal settings as well as input from researcher and practitioners, researchers at the *Science Learning Activation Lab* (*www.activationlab.org*) have compiled a list of such features which synthesizes across a wide range of research efforts situated both in and out of school settings. Elements on this list are drawn from multiple research efforts (e.g., Anderson et al., 2007; Barron & Darling-Hammond, 2008; Bevan & Michalchik, 2013; Falk & Storksdieck, 2005; Nasir & Cooks, 2009, 2014; PEAR, 2013; Reeve, 2006; Shouse et al., 2010; and White & Pea, 2011), as well as from the wisdom of practice (Liston et. al., 2007; E^3 Convening, 2011[3]).

- **The learning environment:** *goals, materials, accessibility, intellectual richness, expertise*
- **The social affordances:** *positive social relationships with adults and peers, development & demonstration of expertise, sense of belonging, supportive culture, opportunities for engagement in collaborative scientific sensemaking*
- **The learning experiences:** *relevant, authentic, includes engagement in fundamental practices of science, offers choice/control, promotes stimulation and/or enjoyment, offers increasing complexity*

As one considers this list, there are a couple points worthy of consideration. First, research and practice have highlighted a key, and possibly obvious, point: the same activity may not yield the same experience for each individual who participates in it (e.g., Fisher & Frasier, 1983; Dorph et al., 2012). One person's relevant may be another person's irrelevant, depending on who they are and their prior experiences, etc. Second, it is difficult to find examples of studies that make causal links between individual or combinations of these features and specific STEM

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[3] In February 2011, the *Science Learning Activation Lab* convened a small workshop entitled *E^3: Environments, Experiences & Engagement* in which researchers and practitioners worked together to identify and articulate the features of STEM learning experiences that support the development of science learning activation.

outcomes within informal learning settings. So, while the field has been able to identify such lists of features that exist within "successful" STEM programs, we do not have compelling evidence that helps us sort through for whom and under what conditions do which of these features support which outcomes. A small number of research efforts identified in the next section are taking on some of these challenges.

The Way Forward

The majority of studies of out-of-school STEM learning programs managed by museums focus on the impact of individual programs on program-specific outcomes. The diversity of program offerings, contexts, outcomes, and measures are documented by research studies and evaluation reports that focus on small-scale qualitative studies or particular program outcomes rather than the development of generalizable knowledge. Thus, these studies do not offer much systematic, generalizable evidence for the field regarding the impact of these programs on youth. In this final section of this paper, we consider the way forward. First, we describe a small number of research efforts that offer promise for future production of generalizable knowledge. Each of the selected projects has the potential of enabling correlational or causal links to be made between features/types of learning experiences and consequential proximal and distal outcomes for youth. Second, we offer some concluding considerations for the Committee that commissioned this paper.

Promising Projects

As we seek a way forward that will support the gathering of systematic and generalizable evidence for the field, we find promising possibilities in several research efforts currently underway. We have chosen to highlight four projects currently engaged in systematic research and assessment development that define and measure the quality of STEM learning environments and a variety of overlapping learner outcomes. While none of them are particular to museum-managed settings, two are focused on OST and two are engaged in efforts that are applicable across settings. Some of these programs are also working at tying program features to learning outcomes in either correlational or causal studies. In December 2013, these groups participated in a convening with a few others to consider the commonalities and differences across their efforts. The following descriptions are summarized based on the information compiled within a synthesis report developed by SRI (Shields, 2014).

Framework for Observing and Categorizing Instructional Strategies (FOCIS),

Robert Tai, University of Virginia.

An examination of STEM curriculum and programs led to the development of FOCIS, which is a learning activity typology. The typology includes seven activities: *collaborating, creating/making, caretaking, teaching, performing, discovering, and competing*. The project administers a survey to youth in grades 3-12 that is designed to measure their preferences for engaging in these seven types of activities and collects some background, career interest, and prior experience information about respondents. A core research question the project asks is whether youth who have preferences for particular types of learning activities are more likely to select STEM-related career choices than youth who have different preferences (accounting for demographic characteristics). For example, the project reported the finding that students who prefer to do discovery activities and making activities, but who do not like to be in collaborative activities, are more likely to say they would choose a STEM career.[4] The project reported this was true for students in elementary, middle, and high school. Implications of this finding for

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[4] An important consideration here is that several of the participants in the 2013 convening raised concerns about the measures and methods utilized in this project, with particular concerns raised about the response choices offered in the question used to measure career interest.

program development might be in designing activities that could shift students' attitudes from neutral to positive levels around collaborating, creating/making, caretaking, teaching, performing, discovering, competing, and collaborating.

Program in Education Afterschool and Resiliency (PEAR)

Gil Noam, McClean Hospital/Harvard University; http://www.pearweb.org/

As referenced earlier in this paper, Noam, his team at PEAR, and their collaborators have defined 12 "dimensions of success" that can be used to rate the quality of OST STEM programs. Further they have developed two instruments to support evaluation and research of OST STEM programs.

Dimensions of Success (DoS) is an observation tool designed to help measure STEM program quality in out-of-school time (e.g., afterschool, summer camps, etc.). DoS is developed based on the National Science Foundation's evaluation framework (Friedman, 2008) which assesses informal STEM program quality in out-of-school time settings such as afterschool programs, summer programs, museums, field trips, community centers. DoS is made up of 12 dimensions that address different quality indicators of a STEM program. These dimensions are split into four categories with three dimensions per categories: *Features of the Learning Environment* (1. Organization; 2. Materials; 3. Space Utilization); *Activity Engagement* (4. Participation; 5. Purposeful Activities; 6. Engagement with STEM); *STEM Knowledge & Practices* (7. STEM Content Learning; 8. Inquiry; 9. Reflection); *Youth Development in STEM* (10. Relationships; 11. Relevance; 12. Youth Voice). DoS was developed collaboratively by PEAR and partners; PEAR conducts observations and trains observers in the use of the tool to conduct additional observations. DoS can be used as a quality improvement tool or an evaluation tool. They are engaged in ongoing study of the psychometric properties of the tool.

The ***Common Instrument*** is a survey for youth 10 years or older that includes 20 self-report items to assess youth interest and engagement in science. There are also abbreviated 10-item forms. The Common Instrument is simple and quick to administer, easy to receive feedback on, and useable for pre-post analysis. The Common Instrument has been administered in programs across 18 different states, with more than 11,000 respondents. A validation study was conducted (n=1200) which found that the survey measured one unidimensional factor with a high internal reliability (α =0.91) and a moderately high test/retest reliability of 0.82.

The team is currently working on studies that investigate associations between scores on the instrument and measures of program quality. The goal of the studies is to identify whether higher quality programs are more likely to produce changes in student scores on the assessment. Preliminary findings indicate that program quality as measured by the 12 dimensions of DoS is significantly related to science interest and engagement as measured by the Common Instrument. These studies address several questions posed by the committee, albeit not necessarily in museum-managed programs.

The Science Learning Activation Lab

Rena Dorph & Matthew Cannady, The Lawrence Hall of Science, University of California, Berkeley; Christian Schunn & Kevin Crowley, The Learning Research and Development Center, University of Pittsburgh; Patrick Shields, SRI; http://www.activationlab.org.

The Lab expands on recent advances in science education, cognitive psychology, social psychology, and educational psychology, by investigating a new construct called *science learning activation* (Dorph et al., 2011) and a conceptual framework of how it supports science learning. The Lab defines *science learning activation* as a composition of dispositions, practices, and knowledge that enables success in proximal science learning experiences. *Lab* researchers have identified four dimensions of science learning activation that are predictive *and* can be shaped by designed interventions: fascination with natural and physical phenomenon, valuing science, competency belief in science, and engaging in scientific sensemaking. By success they mean: 1) making choices towards science learning opportunities (often informal in nature); 2) positive cognitive, behavioral, and affective engagement during science learning opportunities; and 3) greater learning. Lab researchers hypothesize that successive iterations of proximal successes in science learning, often experienced in out-of-school learning contexts, generate a feedback loop that propels youth on pathways towards consequential distal outcomes such as: persistent participation in STEM, pursuit of science degrees and careers, and scientific literacy.

In order to test the hypotheses embedded in the above framework the *Lab* has developed a set of measures that are psychometrically sound (in terms of reliability, validity, and fit), continually improving, and functioning well in the context of research efforts. Included among these instruments:

- *The Science Learning Activation Survey*: The assessment of *science learning activation* includes four scales, each of which demonstrate a high degree of internal reliability (Cronbach's α >.7) —fascination (α=.88), values (α =.70), competency belief (α =.84), and scientific sensemaking (α =.75)—that parallel the dimensions of *science learning activation*. The assessment takes about 25 minutes to complete.
- *Background Survey:* This instrument enables researchers to collect data related to demographic variables and family resources. It also measures two factors related to prior science learning experiences: (1) prior participation in structured science activities and (2) prior participation in unstructured science activities. Each scale has an internal reliability of 0.80 or greater.
- The self-report *Engagement Survey* asks subjects about their level of affective, behavioral, and cognitive engagement in a particular science learning experience or lesson. It takes subjects about 5 minutes to complete and has an internal reliability of

0.87.

Other measures developed by the *Lab* that are available and relevant to this study include: choice preference survey, student engagement observation protocols, science learning experience observation protocol, and a learning environment inventory/survey. The *Lab* has continued to refine the surveys and protocols listed above and has completed multiple studies (Dorph et al., 2012, 2013, in submission). So far, the dimensions of activation have been shown to be predictive of *choice preferences* (choosing to participate, attend, and engage in the next opportunity for science learning), *engagement* (including emotional, behavioral, and cognitive components), and *learning* (the student has achieved the learning goals for that particular science experience). The *Lab* is now engaged in two NSF-funded projects: *The Activation Approach: A Comprehensive Method and Toolkit for Evaluating the Impact of Science Learning Experiences Across Environments* and *Collaborative Research: Studying the Malleability and Impact of Science Learning Activation.* In addition, Lab researchers are involved in numerous smaller-scale evaluation and design studies that utilize the Lab's framework and measurement instruments and investigate the features of STEM learning experience that support youth to increase their activation towards STEM learning and experience success in science learning experiences.

Synergies—Understanding and Connecting STEM Learning in the Community

John Falk & Lynn Dierking, University of Oregon; Bill Penuel, University of Colorado, Boulder; *http://education.oregonstate.edu/book/synergies-parkrose-community*.

This is a four-year longitudinal project designed to study "how, when, where, why, and with whom children access and use STEM resources in their daily lives." The premise of this project:

> *…if one better understands how children become interested and engaged with STEM (or not) across settings, time and space, it will be possible to use that information to support a more coordinated network of educational opportunities, involving many partners in and out of school, and in the process, create a community-wide, research-based educational system that is more effective and synergistic (http://education.oregonstate.edu/book/synergies-parkrose-community).*

The project aims to establish links between activities and interest. The data collection is wide-ranging and the focus in this project is on STEM interest. Synergies has developed and uses a 10-page instrument that asks participants about their interests, participation in activities, who encourages participants to do activities, self-efficacy in science, and participants' future aspirations. They developed items by drawing from existing instruments and through focus testing with the youth researchers with whom they are working. At its inception, the Synergies project identified the need to deconstruct and parse what was meant by STEM interest. They broke the construct down into four content domain categories: earth and space science, human biology, tech and engineering, and mathematics. Each participant in the study receives an index score in each of the four areas. From fifth to sixth grade, project researchers found an increase in interest in those indexed areas. These data serve as a baseline for an upcoming intervention product from the project. So far they have identified four clusters of students: (1) those who dislike mathematics, but like all other dimensions; (2) those who dislike human biology, but like all other dimensions; (3) those who like all dimensions; and (4) those who dislike all dimensions. Preliminary analysis indicates that most out-of-school activities decrease from fifth to sixth grade; however, individuals in these four clusters different patterns from one another in terms of interest over time. In addition, in general, participants appear to be doing fewer out of school activities as they transition into middle school. Research approaches combine surveys, in-depth interviews, innovative participatory research tools, agent-based modeling, video documentation, high school-aged youth research, and mapping activities.

Considerations for the Committee

The field is interested in research that systematically investigates the features of learning experiences that yield meaningful outcomes for youth in OST STEM programs. The review presented above highlights that most of the peer-reviewed literature related to museum-managed STEM learning experiences in museums are about short duration interactions or museum visits. The literature related to systematic, rigorous investigations of museum-managed youth OST STEM programs of longer duration is quite thin. While many evaluation studies exist, there are few focused research efforts that examine larger questions designed to produce generalizable results. As the field sets out to engage in such studies, we must be prepared to handle the diversity of programs along multiple dimensions: focus, goals, duration, location of activities, source/impetus for activity (museum initiated, or school initiated), outcomes, pedagogic philosophy, approach, student centeredness, quality of facilitation, who is in charge, etc. Further, the field should continue to explore and support cross-setting spaces leveraged by museums to bring features of informal learning into a variety of settings to foster rich diversity of STEM learning outcomes. Cross-setting programs can be valuable in that they can intersect with both in-school and out-of-school learning opportunities and offer fertile ground for learning more about the features of learning experiences that lead to positive outcomes for diverse learners.

Finally, continued dialogue is needed regarding a few critical questions that this paper raises:

- What are outcomes that museums are particularly well suited to impact?

- What is the potential utility of common outcomes and measures to understand impact across programs and contexts given the diversity of existing programs?
- How can we best study which combinations and permutations of programmatic features yield which outcomes, under what conditions, in what settings, and for whom?
- The authors of this paper did not have the capacity to review all the “grey literature” and evaluation studies related to museum-managed youth STEM programs. Is it worth investing in this task? Would it yield anything we do not know already? Would we glean generalizable knowledge given the particular nature of each of those evaluation methods, questions, etc.? Or, might we be better off investing in research and evaluation studies that are designed to contribute generalizable information for the field? Or, do we need both?
- Do we need/want to invest in a category of museum-managed STEM learning programs for youth as an area of study in and of itself, or do we just want to look at causal links between features of learning experiences and the outcomes we care about—regardless of setting/management?
- Can the Committee help the field make sense of the “framework soup” that is already out there rather than introducing yet another synthesis framework related to goals/outcomes for program participants?

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