Making Science Matter: Collaborations Between Informal Science Education Organizations and Schools

A CAISE Inquiry Group Report

March 2010

About CAISE

The Center for Advancement of Informal Science Education (CAISE) works to strengthen and connect the informal science education community by catalyzing conversation and collaboration across the entire field—including film and broadcast media, science centers and museums, zoos and aquariums, botanical gardens and nature centers, digital media and gaming, science journalism, and youth, community, and after-school programs. CAISE focuses on improving practice, documenting evidence of impact, and communicating the contributions of informal science education.

Founded in 2007 with support from the National Science Foundation (NSF), CAISE is a partnership among the Association of Science-Technology Centers (ASTC), Oregon State University (OSU), the University of Pittsburgh Center for Learning in Out-of-School Environments (UPCLOSE), and the Visitor Studies Association (VSA). Inverness Research Associates serves as evaluator. CAISE is housed at ASTC's Washington, D.C. offices.

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CAISE Formal-Informal Partnerships Inquiry Group Participants

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Foreword

This report is the result of work by the Center for Advancement of Informal Science Education (CAISE) Formal/Informal Inquiry Group which was constituted in 2008 to explore relationships between science education in formal and informal settings.

We are grateful to all of the members of the group for their contributions, and particularly to Bronwyn Bevan, who led the group and drafted this report. Each of the group's members brought a depth of experience to their exploration of this topic. In addition, the group solicited input during a session at the July 2008 Informal Science Education Summit in Washington, D.C., organized by CAISE; through reviews of published literature and case studies; and through consultations with their extensive networks.

The report offers an alternative to the traditional view of informal education as secondary or supplementary to schools, instead examining what the authors call "the hybrid nature of formal-informal collaborations." Drawing on both theoretical perspectives and case studies, the authors suggest that, "in fact, formal-informal collaborations fall *exactly within the core activities* of both schools and informal learning organizations, including museums, youth programs, and libraries." By taking advantage of "the particular affordances and strengths of different institutional types," formal-informal collaborations, they say, can "meet shared goals of making science learning more accessible and compelling to young people in our communities."

With its concise summary of relevant theory, its case studies of effective programs, and its delineation of the affordances of each, this report will be of value to all who are dedicated to this goal.

The discussions that began among the members of the Formal-Informal Collaborations Inquiry Group are intended to inform and spark further study, discussion, and reflection among colleagues from across the field. We look forward to continuing the conversation. To find out about online discussions and conference sessions, visit the CAISE website (www.insci.org), join the CAISE Forum (at www.connect.astc.org), or subscribe to the CAISE Newsletter.

We are grateful to the National Science Foundation for its support of CAISE Inquiry Groups and informal science education field.

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CAISE Formal-Informal Partnerships Inquiry Group Participants

Bronwyn Bevan is the director of the Exploratorium's Center for Informal Learning and Schools, an NSF-funded CLT that develops professional practices and knowledge related to strengthening connections between learning in- and out-of-school. Bevan has worked at the Exploratorium since 1991. She currently serves as a Principal or Co-Principal Investigator on several projects, including the NSFAYS Research & Evaluation Center, the Museums After-school: Principles, Data, and Design project, DRL-Net, and the Learning about Out-of-School-Time (LOST) Learning Opportunities project. Bevan's work in both research and professional development focuses on strengthening partnerships between cultural institutions and schools, and building understanding about the ways that different educational settings shape opportunities for learning.

Justin Dillon is Professor of Science and Environmental Education and Head of the Science and Technology Group at King's College London. After teaching in London schools for 10 years, Prof. Dillon joined the staff at King's in 1989. He has researched and published widely in both science and environmental education and directs King's contribution to the European Commission-funded project, Towards Women in Science and Technology. Prof. Dillon's BSc is in Chemistry (University of Birmingham) and his MA (Science Education) and Ph.D. were both awarded by King's College London, University of London. Prof. Dillon was elected President of the European Science Education Research Association (ESERA) in 2007. He is a trustee of Sustainability and Environmental Education, Past Chair of both the London Wildlife Trust and the London Environmental Education Forum and Secretary of Bankside Open Spaces Trust. As well as being an editor of the International Journal of Science Education, he is on the editorial board of Environmental Education Research, the Journal of Environmental Education and many other science and environmental education journals. He is a member of both the Society of Biology and the Royal Society of Chemistry and is a Fellow of the Linnaen Society of London.

George E. Hein, Professor Emeritus at Lesley University, is active in visitor studies and museum education as a researcher and teacher. Originally trained as a chemist (Ph.D. University of Michigan, and faculty positions at U. of Michigan, California Institute of Technology, Boston University and Harvard Medical School) he turned to science education and then museum education, joining Lesley University in 1975. He was a Fulbright Research Fellow in Science Education at King's College, London (1990), visiting faculty member at the University of Leicester Museum Studies Program (1996), Visiting Scholar at the California Institute of Technology (1998), Osher Fellow at The Exploratorium in San Francisco (1999) and Visiting Professor at University of Technology, Sydney (2000). He serves on the advisory boards for several museum exhibition development teams, and as a consultant for numerous museums. He is the author, with Mary Alexander, of *Museums, Places of Learning* (AAM, 1998) and of *Learning in the Museum* (Routledge, 1998) as well as numerous articles on visitor studies, museum education and museology. He has lectured widely, including cultural tours in Brazil, Finland, Greece, Mexico, Norway, Spain, and Taiwan. He has been active in ICOM/CECA serving as both secretary and president of CECA in the 1990's. His primary current interest is the significance of John Dewey's work for museums.

Maritza Macdonald is Senior Director of Education and Policy for the American Museum of Natural History (AMNH) since 1997. Dr. Macdonald's major responsibilities include research, evaluation, policy, higher education partnerships teaching courses and managing internships from higher education partners, and international partnerships. Dr. Macdonald was a member of the National Commission on 21st Century STEM Education, National Science Board, Washington, D.C. (2007) and the Regents Work Group on Urban Education. She has been Co-PI on grants from the National Science Foundation (NSF) to prepare Earth Science Teachers in collaboration with graduate schools of education (TRUST); and from the National Oceanic and Atmospheric Administration (NOAA), to develop science museum education supports for English Language Learners (ELL) middle school students. Dr. Macdonald also works closely with exhibitions for conducting in-house evaluations and managing external evaluations of education impact. Graduate courses focus on teaching and learning in museums, informal science, and evaluation and research and international work with museums and science research institutions interns from South Africa, Europe, Vietnam, China, Japan, and South America. Prior to working at AMNH, Macdonald worked at Columbia University Teachers College in Urban Education Research, and directed teacher education program at Bank Street College of Education. In all these contexts she focuses on issues of equity and the policies that affect learning and access to learning for underserved groups.

Vera Michalchik is a Senior Social Scientist at SRI International's Center for Technology in Learning where she leads the informal learning practice. Her work includes helping lead the NSFAYS Research and Evaluation Center, studying technology-focused youth development programs, researching models for building partnerships between informal science institutions and schools, coordinating worldwide evaluation for education programs funded by the Intel Foundation, and developing assessments for informal learning settings. Vera also conducts research in the areas of teacher professional development and visualizations for learning science and math. From 2006-2008, she served on the NSF-sponsored Committee on Learning Science in Informal Environments at the National Research Council. Vera holds a Ph.D. from Stanford University.

Diane Miller is the Senior Vice President of School and Community Programs and Partnerships at the Saint Louis Science Center. Her overall responsibilities include initiating, developing, coordinating, and implementing STEM programs and collaborative projects with schools, community-based organizations, underserved audiences, interns, and youth. Working with schools and community-based organizations, she is responsible to develop strategies that increase the involvement of audiences not usually reached by the Saint Louis Science Center. Miller was the project director and program developer for two YouthALIVE! grants, one for the California Science Center (formerly the California Museum of Science and Industry) and one for the Saint Louis Science Center. She was a member of the YouthALIVE! steering committee and responsible for co-planning and co-facilitating national network meetings. Currently she is PI on an NSF grant and Co-PI on two additional NSF grants. A main focus of her job is to design and manage programs that utilize the environment and galleries of the Saint Louis Science Center, and to develop comprehensive, inviting curriculum that nurtures and interest in science, technology, engineering, and math.

Dolores Root has a Ph.D. in anthropology and over 30 years experience in public programming in the arts, science and humanities. Dolores has held leadership positions in museums, a public humanities council and education. She has taught and lectured on museums and public interpretation, published articles and reviews in professional journals and organized and participated in national and international conferences and symposia. She was the Director for Exhibits and Programs at the

EcoTarium in Worcester, MA, where she transformed a venerable natural history museum into an environmental science museum focused on the urban ecosystem. Currently, she works for New Visions for Public Schools, an education reform organization, and is involved in a partnership with the American Museum of Natural History working to improve the teaching and learning of science in New York City public schools.

Lorna Rudder-Kilkenny is the Director of the Central Library Department at the Queens Public Library in Jamaica, New York. She directs all public service operations, activities and staff of the Central Library and oversees a 1.5 million item collection that includes: a book collection which supports up to graduate level programs in some subjects; a multi-media center with 80k+ CDs, DVDs and audio books; and books in more than 50 languages. Ms. Rudder-Kilkenny is the Principal Investigator for the NSF funded Science in the Stacks program. This novel project seeks to create a new model for children's public library services in urban settings by integrating interactive museum type STEM exhibits with the traditional print and electronic library resources. The Science in the Stacks Program will be an integral part of the Central Library's new Children's Library Discovery Center (CLDC) scheduled to be opened in Fall 2009. Ms. Kilkenny holds a Master's degree in Library Science from Pratt Institute in New York.

Maria Xanthoudaki is Director of Education and of International Relations at the National Museum of Science and Technology Leonardo da Vinci of Milan, Italy. Dr. Xanthoudaki's major responsibilities as Director of Education include the development of policy and strategy for education addressing different audiences and the management of the education staff and programmes. She is also coordinator of trans-national cooperation projects for science education, informal learning or museum education and involved in professional development courses for museum educators and teachers as trainer. As Director of International Relations, she is in charge of the Museum's joint programmes with foreign institutions. Dr Xanthoudaki holds a B.A. in Education from the University of Crete (GR), a Master in Art Education and a Ph.D. in Museum Education from the University of Sussex (UK). Before entering the National Museum of Science and Technology, she was Senior Research Associate at the Department of Education and Professional Development at the University of East Anglia (UK) where she worked also with the Sainsbury Centre for Visual Arts. She has taught B.A. and postgraduate courses at the University of Siena, the University of Padoa, the Scuola Normale Superiore di Pisa, and professional development courses for museums across the country. Since 2001, Dr Xanthoudaki is also Expert Fellow at the Bocconi University, Department of Management, for the Workshop in Museums and Art Markets. She is member of the Annual Conference Programme Committee of Ecsite, the European Network of Science Centres and Museums; member of the Editorial Board of the Journal of Science Communication, member of the Regional Committee for the Dissemination of Scientific Culture (Region of Lombardy, Italy) and member for the steering committee of THE Group (the thematic group of Ecsite focusing on explainers' professional development).

Susan Yoon is Assistant Professor in the Graduate School of Education at the University of Pennsylvania. Her research and teaching span the disciplinary fields of Science, Technology, and Learning Sciences Education where she works with both teachers in professional development activities and students in classroom and informal learning environments. Her core interests include applying complex systems and social networking theories and methods to curricula, group interactions, and larger educational social systems. She is the PI of two NSF projects aimed at increasing participation in the STEM education and career pipeline for underserved youth in the Philadelphia region. The first is an out-of-school time project for youth in grades 4–8: SPARK—Igniting Interest and Achievement in STEM through Engineering Design (2006–2009). The second is a high school project: Nanotechnology and Bioengineering in Philadelphia Public Schools, under the NSF-ITEST program (2008–2011). She is also Co-PI with the Franklin Institute Science Museum on an NSF-ISE project: ARIEL—Augmented Reality for Interpretive and Experiential Learning (2008–2012).

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Special thanks to Catherine Eberbach for her work reviewing the field to identify programs to spotlight in this report, and also for her review of and reactions to early drafts of the report.

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Executive Summary

Introduction

Throughout the world, and for many decades, science-rich cultural institutions, such as zoos, aquaria, museums, and others, have collaborated with schools to provide students, teachers and families with opportunities to expand their experiences and understanding of science. A recent study (Phillips, Finkelstein, & Wever-Frerichs, 2007) found that more than 70% of science-rich cultural institutions in the United States have programs specifically designed for school audiences. These programs include supplementary classroom experiences; integrated core academic curricula; student science learning communities located in afterschool, summer, and weekend programs; teacher professional development programs and communities; and even district infrastructure efforts around issues such as standards and assessment development or teacher preparation.

These collaborations have allowed students, and also teachers, to explore, understand, and care about a wide range of natural settings, phenomena, and cultural and historical objects. They have helped students to notice, consider, and investigate relationships between human social behavior and environmental consequences. They have provided contexts, materials, rationales, and support for students and teachers to engage deeply in scientific inquiry processes of learning. These experiences—with an array of real-life settings, animals, professional science communities, objects, scientific instrumentation, and current research and data—have been shown to spark curiosity, generate questions, and lead to a depth of understanding and commitment in ways that are often less possible when the same material is encountered in books or on screens.

But despite scores of such examples, these collaborations have generally failed to institutionalize: in many communities they come and go with changes in funding or leadership. There are many reasons for this pattern, both global and local. Global reasons relate to the hybrid nature of formal-informal collaborations which make them fall outside of obvious funding categories, render standard assessment tools inadequate to document their effects, and challenge priorities for both formal and informal institutions, since this work appears to fall outside of the core activities of each institutional type. Local reasons include changes in leadership or immediate priorities.

This report begins with the premise that it is important for us to move beyond these challenges. We draw on theoretical perspectives as well as practical examples to show that, in fact, formal-informal collaborations fall *exactly within the core activities* of both schools and informal learning organizations, including museums, youth programs, and libraries. But we do not argue, simply, for *more* collaborations. Rather, we argue for more intentional and strategic deployments of resources, leading to collaborations that build on the particular affordances and strengths of different institutional types to meet shared goals of making science learning more accessible and compelling to young people in our communities.

This Report

This report does three things that we hope will advance discussion about the value and nature of formal-informal collaborations:

1) Provides a rationale and theoretical basis for why the ISE and K–12 fields should care about and pursue such collaborations.

2) Reviews examples of such collaborations, noting their documented outcomes, and identifying emergent themes or characteristics.
3) Identifies existing trends, gaps, and questions that would benefit from further experiments in both research and practice.

Formal-informal collaborations are defined in this report as taking place among **K–12 schools** (and the supportive infrastructure including schools of education or district and state education offices), and informal learning organizations which include (a) **informal education organizations** (such as libraries, afterschool and youth programs) and/or (b) **science-rich cultural institutions** (such as museums, zoos, nature centers, and aquaria).

Rationale

Over the past decade, consensus in research, policy, and education communities has begun to emerge around three crucial understandings that pertain directly to the value and importance of formal-informal collaborations as well as to informal science education itself. These are:

1) Scientific literacy is more than factual recall; it involves a rich array of conceptual understanding, ways of thinking, capacities to use scientific knowledge for personal and social purposes, and an understanding of the meaning and relevance of science to everyday life (American Association for the Advancement of Science, 1993; National Academies of Sciences Committee on Science Learning K–8, 2007).
2) Learning, and the development of a sustained commitment to a discipline, develops over multiple settings and timeframes (Bransford et al., 2006; National Research Council, 2000, 2009).
3) Science education, as it is traditionally constituted, fails to engage and include a significant portion of society; most notably, women and people from high-poverty and non-dominant communities are underrepresented in science professional, academic, and organized leisure-time activities (Barton & Yang, 2000; Eisenhart, Finkel, & Marion, 1996; Nasir, Rosebery, Warren, & Lee, 2006).

These consensus understandings have direct implications for formal-informal collaborations. First, because the emerging vision of scientific literacy is complex, no single institution, such as schools, afterschool or youth organizations, or science-rich cultural institutions, can achieve this vision acting alone. It will take a combination of resources, expertise, timeframes, and learning designs to support and expand science literacy in today's world. Second, if we understand that children learn through multiple, varied, independent, and inter-dependent experiences across time and settings, it is incumbent upon educational designers and leaders (both formal and informal) to provide experiences that leverage prior and future experiences, and help to build coherence and meaning, across settings, around critical ideas and understandings in science. Third, schools serve diverse socioeconomic and cultural populations. But schools that serve high-poverty communities tend to be under-resourced, text-based, and test-driven (Harvard Civil Rights Project, 2006; Nasir et al., 2006); as such, despite dedicated teaching, these schools have limited capacity to support the development of rich science literacies. At the same time, science-rich cultural institutions, while excelling in ways to make science compelling, are less likely to work with children from under-represented communities. Formal-informal collaborations bring both the audiences and the opportunities together.

Theoretical Perspectives

The recent NRC volume *Learning Science in Informal Environments* (2009) stresses the utility of sociocultural theories of learning for guiding program designs and evaluations in informal as well as formal settings. Sociocultural perspectives suggest the importance of establishing authentic goals or purposes that provide students a meaningful context in which they can build on their skills, strengths, and interests to participate in and contribute to valued activities (Bronfenbrenner, 1979; Eisenhart et al., 1996; Rogoff, 2003; Stetsenko & Arievitch, 2004). Learning activities are organized such that they require participants to take up and use the cultural tools of science in order to achieve their goals. In this view, people learn to use the tools of science (such as thermometers, telescopes, formulae, scientific argumentation, modeling, and others) because they are the best available means for answering questions or achieving purposes that matter to them. In this sense, powerful learning activities are designed to be "authentic" both in terms of establishing real purposes for undertaking them, and in introducing the tools of science as the best available means for successfully achieving one's purpose (which is also why they were developed historically: to achieve real purposes such as building bridges or navigating under the night skies).

Sociocultural perspectives also stress the critical role of the adult (or more capable peer or supportive community) in helping learners to create or find purpose. As such, they underscore the importance of designing and facilitating activities that can both inspire *and* sustain participation by welcoming in, supporting, and gradually increasing the complexity or sophistication (the "conceptual depth") of the goals, tool-use, and activities with which participants engage (Bronfenbrenner, 1979; Lave & Wenger, 1991). People forge their developing selves (or identities) through active participation in such authentic, accessible, and conceptually rich activities (Holland, Lachicotte Jr., Skinner, & Cain, 1998; Lemke, 2001).

While such perspectives help to build a vision of powerful learning designs, understanding why and how collaborations among formal and informal organizations can achieve such a vision requires an analysis of the particular properties and affordances of the different learning environments. Our report details both the structural and the social properties of formal and informal settings, and later applies this analytical lens to exemplary collaborations.

For example, **structural properties** of K–12 schools afford the time, sequencing, and consistency necessary for learners to systematically develop the foundations for deep conceptual understanding. Such foundations may be necessary for learners to become seriously engaged in the subject matter, including pursuing advanced coursework and science careers. At the same time, schools are structured around primarily verbal or textual engagement with subject matter, and often present concepts in ways disconnected from everyday concerns of students. The structural properties of science-rich cultural organizations, on the other hand, include tactile, kinesthetic, and three-dimensional exhibits, objects and experiences that may afford different kinds of engagement and even understanding than can be developed in schools. Because most informal settings must design for general audiences, they may also be more accessible to greater ranges of prior knowledge and experience. At the same time, such settings are usually not accessed in systematic or regular ways; the episodic nature of their use may be a barrier to developing systematic understanding of specific concepts and how they relate to one another.

The **social properties** of informal settings include low-stakes environments, group or collaborative learning, and levels of flexibility that may afford learners' greater use of imagination and taking of risks. They allow learners to work at their own pace, following and developing their own interests. In schools, social properties include year-long relationships between teachers and students that may be critical to teaching and learning, including expectations for engagement, and instruction that can take into account knowledge of the individual learner that is come to be understood over time.

Thus an affordance analysis suggests that it is more than objects or collections that formal-informal collaborations bring to K–12 science education, but rather potentially a more accessible, contextualized, and meaningful *approach* to the material. Such collaborations can be designed to draw upon

- The ways in which informal learning environments support direct, multi-modal experiences with multi-faceted portrayals of science, presented within their cultural context, and using authentic objects and phenomena.
- The ways in which school contexts can provide the sustained time, and developmental and pedagogical expertise, to build increasingly complex understandings of science phenomena and processes.

Program Examples

Our report identifies a wide range of formal-informal collaborations in five general areas: supplementary classroom experiences; integrated core academic curricula; student science learning communities; teacher professional development programs and communities; and district infrastructure efforts. The actual nature of these collaborations differs, based on the local needs and resources.

Most obviously, collaborations can differ in terms of the content area, reflecting the particular collections or resources of the science rich cultural institution, and particular content foci of the schools. Some programs are designed primarily for students, others for teachers. Formal-informal collaborations also differ along the dimensions of *time* (including both frequency and duration) and *structure* (meaning the extent to which activities are scripted, sequenced, and assessed). The less time and structure, the more the collaboration may resemble typical audience patterns at informal learning institutions: the drop-in visitor who arrives with their own agenda and spends as much time as they wish on whichever materials, exhibits, or activities that they choose. At the other extreme, at the time-intensive, highly-structured collaboration, programs may begin to resemble school-like patterns of activity, often in the tradition of learner-centered, constructivist classroom teaching and learning.

Our report spotlights three programs in each of the five collaboration types. All of these examples had collected evidence of their impact on participants. These programs may represent just the tip of the iceberg in terms of the number and types of formal-informal collaborations one finds around the globe. However, they represent virtually the entirety of the collaborative programs that we located with documented impacts on participants (and we defined impacts quite broadly, as readers will find). Despite their small number, the data collected by these exemplary programs suggest that formal-informal collaborations can be designed to contribute towards:

- Advancing students' conceptual understanding in science.
- Improving students' school achievement and attainment.
- Strengthening students' positive dispositions towards science.
- Advancing teachers' conceptual understanding in science.
- Supporting teachers' integration of inquiry and new materials in the classroom.

Emergent Themes

Our analysis of the properties and structural and social affordances of collaborations found five recurrent themes running through the programs:

1) Formal-informal collaborations can lead to conceptually rich and compelling science learning programs that build on the structural and social affordances of informal settings and objects.
2) Formal-informal collaborations can lead to the creation of learning communities that develop practices, dispositions, and understandings that valued across multiple institutional settings and boundaries.
3) Formal-informal collaborations can create more equity and access for children, and teachers of children, from high-poverty communities.
4) There is a lack of strong, valid, and meaningful evidence of the impacts of formal-informal collaborations, largely due to the lack of a well-theorized methodology that captures and describes impacts that have valence with both formal and informal stakeholders.
5) Formal-informal collaborations take significant time and energy, often unacknowledged by sponsors of the work, and are a continuing but valuable process of evolution for individuals and institutions.

These themes are not conclusive findings, but preliminary observations, all of which need to be subjected to more rigorous experimentation and research.

Recommendations

The Inquiry Group's review of the material, informed by both theory and impact data, led us to close the report with five recommendations to the field:

1) Expanding the research base. There is a need for more studies of existing and robust programs, including studies that address the different issues raised in the report, and studies that take a systems perspective to understand how learning in formal or informal settings affects the other.
2) Addressing funding barriers. There is a need for more funding for formal-informal collaborations. Many current funding agencies have difficulty knowing how to classify these hybrid programs, and as a consequence they oftentimes fall between the cracks of funding categories. Funders need to look to the goals of the projects (enhanced teenage understanding of science, or improved teaching practices, for example) rather than the mode. The mode of work is what needs expansion and experimentation. In peer review panels, this means that panelists must be selected who have an understanding of both formal and informal environments.
3) Expanding professional development for informal educators who work with formal audiences. There is a need for more professional development for informal educators that addresses the nature of work with schools and teachers, including school policies, assessment policies and trends, theories of learning, program design and evaluation. More teacher preparation programs should include introductions to informal learning institutions, resources, pedagogies, and people.
4) Expanding systems perspectives and programs. There is a need for more program experiments that test models of systems integration, for example, testing how afterschool settings can serve as teacher development sites, or for graduate training for future behavioral scientists, or for science-rich cultural institutions providing science pedagogical leadership in afterschool or youth settings, or for the co-development of K–12 science curriculum and activities.

5) Institutionally valuing formal-informal collaborations, and the expertise required to advance them. In the end, there is a need for greater understanding and support within science-rich cultural institutions for work with schools. Too often schools and teachers are seen as a "market" for field trips or other paid programs, rather than as a stakeholder audience. The extent to which science-rich cultural institutions conceptualize themselves as educative rather than entertainment organizations will be reflected in the depth of their collaborations with K–12 schools. A part of being deeply committed to science education must involve working with the more diverse populations of science learners that exist in local public schools and engaging their families in the life of cultural institutions.

In conclusion, our report finds that there is a great deal of work already happening in formal-informal collaborations. Many people and places are pioneering new ideas and approaches, some of which were included in this report. Many are increasingly concerned with documenting the results of these collaborations in meaningful and useful ways. We argue in this report that so long as public opinion polls continue to find that the public, especially the public from communities underrepresented in the sciences, characterizes science as alien, boring, overly difficult, or not directly relevant to their lives, we must increase our efforts in formal-informal collaborations to reach the greatest number of people, in the most compelling ways, for the most sustained amounts of time, in ways that can be achieved at scale.

Part 1: Introduction

Throughout the world, and for many decades, science-rich cultural institutions, such as zoos, aquaria, museums, and others, have collaborated with schools to provide students, teachers, and families with opportunities to expand their experiences and understanding of science. A recent study (Phillips, Finkelstein, & Wever-Frerichs, 2007) found that more than 70 percent of science-rich cultural institutions in the United States have programs specifically designed for school audiences. These programs include supplementary classroom experiences; integrated core academic curricula; student science learning communities located in after-school, summer, and weekend programs; teacher professional development programs and communities; and even district infrastructure efforts around issues such as standards and assessment development or teacher preparation.

Programs falling into these five categories have allowed students and also teachers to explore, understand, and care about a wide range of natural settings, phenomena, and cultural and historical objects. They have helped students to notice, consider, and investigate relationships between human social behavior and environmental consequences. They have provided contexts, materials, rationales, and support for students and teachers to engage deeply in scientific inquiry processes of learning. These experiences—with an array of real-life settings, animals, professional science communities, objects, scientific instrumentation, and current research and data—have been shown to spark curiosity, generate questions, and lead to a depth of understanding and commitment in ways that are often less possible when the same material is encountered in books or on screens. These formal-informal collaborations have rejuvenated the curriculum, the school week, teachers' passions and commitments to their work, and in many cases have contributed to students' development of lifelong interests and even pursuit of particular academic or career pathways.

But despite scores of examples, these collaborations have generally failed to institutionalize: in many communities they come and go with changes in funding or leadership. There are many reasons for this pattern, both global and local. Local reasons include changes in leadership or immediate priorities. Global reasons relate to the hybrid nature of formal-informal collaborations which make them fall outside of obvious funding categories, render standard assessment tools inadequate to document their effects, and challenge priorities for both formal and informal institutions, since this work appears to fall outside of the core activities of each institutional type.

This report argues that it is important for us to move beyond these challenges. We draw on theoretical perspectives as well as practical examples to show that, in fact, formal-informal collaborations fall exactly within the core activities of both schools and informal learning organizations, including museums, youth programs, and libraries. But we do not argue, simply, for more collaborations. Rather, we argue for more intentional and strategic deployments of resources, leading to collaborations that build on the particular affordances and strengths of different institutional types to meet shared goals of making science learning more accessible and compelling to young people in our communities. The result will be science learning opportunities that are conceptually richer and more coherent for both children and the teachers responsible for their science education (Jolly, Campbell, and Perlman, 2004).

Over the past decade, consensus in the research, policy, and education communities has begun to emerge around three crucial understandings that pertain directly to the value and importance of formal-informal collaborations as well as to informal science education (ISE) itself. These are:

1) Scientific literacy is more than factual recall. It involves a rich array of conceptual understanding, ways of thinking, capacities to use scientific knowledge for personal and social purposes, and an understanding of the meaning and relevance of science to everyday life (American Association for the Advancement of Science, 1993; National Academies of Sciences Committee on Science Learning K–8, 2007).
2) Learning, and the development of a sustained commitment to a discipline, develops over multiple settings and timeframes (Bransford et al., 2006; National Research Council, 2000, 2009).
3) Science education, as it is traditionally constituted, fails to engage and include a significant portion of society; most notably women and people from high-poverty and non-dominant communities are underrepresented in science professional, academic, and organized leisure-time activities (Barton & Yang, 2000; Eisenhart, Finkel, & Marion, 1996; Nasir, Rosebery, Warren, & Lee, 2006).

These consensus understandings have direct implications for formal-informal collaborations.

First, because the emerging vision of scientific literacy is complex, no single institution—whether schools, after-school or youth organizations, or science-rich cultural institutions—can achieve this vision acting alone. It will take a combination of resources, expertise, timeframes, and learning designs to support and expand science literacy in today's world.

Second, if we understand that children learn through multiple, varied, independent, and inter-dependent experiences across time and settings, it is incumbent upon educational designers and leaders (both formal and informal) to provide experiences that leverage prior and future experiences, and help to build coherence and meaning, across settings, around critical ideas and understandings in science.

Third, schools serve diverse socioeconomic and cultural populations. But schools that serve high-poverty communities tend to be under-resourced, text-based, and test-driven (Harvard Civil Rights Project, 2006; Nasir et al., 2006). As such, despite dedicated teaching, these schools have limited capacity to support the development of rich science literacies. At the same time, science-rich cultural institutions, while excelling in ways to make science compelling, are less likely to work with children from underrepresented communities. Formal-informal collaborations bring both the audiences and the opportunities together (Phillips et al., 2007).

We contend that different educational resources, formal and informal, can and must be intentionally deployed in ways that enrich and expand a range of science experiences for more children. A wide variety of institutional settings and opportunities are necessary to support opportunities for such engagement, including schools, youth programs, science-rich cultural organizations, online environments, books, and films. We do not advocate strict alignment or lock-step agreement, or for carving up the universe of science learning ("you do engagement and we'll do learning"). Rather, we propose that the best way forward is to intentionally establish systemic relationships between formal and informal institutions, with the goal of creating greater coherence and access.

In the following sections of this report we do three things that we hope will advance discussion about the value and nature of formal-informal collaborations:

1) Provide a rationale and theoretical basis for why the ISE and K-12 fields should care about and pursue such collaborations.

2) Review examples of such collaborations, noting their documented outcomes, and identifying emergent themes and characteristics.
3) Identify existing trends, gaps, and questions that would benefit from further experiments in both research and practice.

A primary goal of this report is to update past reports (ASTC, 1996; IMLS, 1996) that explored the potential for formal-informal collaborations, by providing, in today's *No Child Left Behind* accountability environment, the rationale and evidence base that will encourage educators in both formal and informal settings to design increasingly strategic and robust collaborations to strengthen science learning opportunities for children and the teachers who serve them.

Terms and Limitations

In this report, we define formal-informal collaborations as taking place among

- K–12 schools (and the supportive infrastructure including schools of education or district and state education offices), and
- Informal education organizations (such as libraries, after-school and youth programs) and/or
- Science-rich cultural institutions (such as museums, zoos, nature centers, and aquaria).

This report does not address the many different media and curricular resources that are developed by a range of educational organizations, formal and informal, for use in schools. We focus primarily on what happens *outside* of schools, but in purposeful collaboration with schools, and towards ends that are valued by both formal and informal institutions. We hope that a future CAISE report will specifically address how different web, print, and other media tools and products can be integrated into the classroom, identifying specific features that science-rich cultural institutions and other informal education organizations may bring to the creation and implementation of such tools.

This report also does not include or address the many other ways that ISE organizations support communities' and children's interest, readiness, and capacities to engage in STEM learning. For most ISE organizations the main purpose and vast majority of their work does not directly involve formal K-12 institutions. A comprehensive overview of the ways in which ISE supports STEM learning beyond connections with schools is provided in the NRC (2009) consensus volume, *Learning Science in Informal Environments*.

Program Spotlights and Analyses

Section Two of the report spotlights fifteen different formal-informal collaborations. To identify these programs, in Fall 2008–Spring2009, Catherine Eberbach, then a graduate student with UPCLOSE at the University of Pittsburgh, conducted a literature review in informalscience.org and sent requests for information about relevant programs to several professional listservs including those of the National Association of Researchers in Science Teaching Informal Learning Special Interest Group, Association of Science Technology Centers, Center for Informal Learning and Schools, and American Public Gardens Association. She and Inquiry Group members also contacted a variety of individuals, identified by the Inquiry Group as people knowledgeable about programs in the field, including the director of the Coalition for Science After-School, leaders of professional associations such as ECSITE in Europe, the Asia Pacific Network of Science & Technology Centres, the Southern African Association of Science and Technology Centres in South

Africa, the Institute for Museum and Library Services, the American Association of Museums, and informal education leaders in countries such as India, Mexico, Cyprus, Israel, the UK, Singapore, and Malaysia, as well as around the United States.

The inquiry group leader contacted programs identified through these methods that

1) were co-developed by both K–12 and informal education personnel,
2) were formally evaluated in terms of student or teacher outcomes, and
3) included activities taking place in informal settings.

A series of email exchanges or phone calls ensued. Program leaders sent additional descriptive material, evaluation reports, and promotional materials, many of which served as the basis for the program descriptions included here. The inquiry group reviewed these program examples written in draft form, identifying salient themes and asking questions which were then pursued with the program leaders.

Part 2: Rationale and Theory

Our central premise is that the combination of an evolving vision of what constitutes scientific literacy, a developing understanding of how people learn across settings and timeframes, and the need to expand access and opportunities for participation to more students from a more diverse set of communities argue for

- more collaborative work between different educational institutions and settings;
- a better understanding of how the particular resources, expertise, and affordances of each institutional setting shape, and make connections between and among, different learning experiences; and,
- a more coherent strategy for utilizing all of the resources in a community to create rich, compelling, and accessible science education for all children.

Emerging Views of Science Literacy and Learning

For decades, research has found that classroom science is too often presented and experienced as a static and disconnected body of facts and lock-step procedures (DeBoer, 1991; Nasir et al., 2006). Science-rich cultural institutions have not been subjected to quite the same critique; however, the ongoing movement in the field to expand interactivity, address social relevance, provide more cultural context, and expand an interdisciplinary view of current science suggests that perhaps cultural institutions, too, have struggled with how to present and represent science (Garrett, 1987; MacDonald, 1998).

Creativity, uncertainty, collaboration, the driving desire to know the unknown, the inherent inter-disciplinarity of compelling questions about the material and social world--these things are only rarely associated with science in the minds of children (and the general public). The fixed version of science presented in much science teaching and learning not only fails to capture the interest and imagination of most children, it also fails to resemble the actual nature of science or practices of scientists.

For over a hundred years, many scientists and science educators have argued for the need to place scientific inquiry at the heart of school science. The NSF-funded science curricular reforms of the 1960s (e.g., curricula such as SCIS, ESS, and BSCS[1]) were driven by this vision. These curricula were also the inspiration for public exhibits at some of the world's first interactive science museums, such as the Lawrence Hall of Science, the Ontario Science Centre, and the Exploratorium. This reform movement, largely inspired by scholars such as Dewey and Piaget, emphasized the ways in which students learned scientific concepts through questions and first-hand investigations. This constructivist view of science learning remains a strong undercurrent in science reform efforts today (e.g., Fosnot, 2005; Minstrell, 2000).

More recent constructivist reform efforts continue this emphasis on inquiry as an organizing principle of science, but, increasingly, they stress designs that require students to weigh evidence and develop explanations about observed phenomena (National Academies of Sciences Committee on Science Learning K-8, 2007). Many of these efforts also have children use and come to understand scientific modeling as a tool for scientific thinking and understanding (see. e.g., Lehrer, Schauble, Strom, & Pligge, 2001). These and related efforts also seek to tie the children's science learning activities to real-world issues of concern to children, such as endangered species and global warming, air and water quality in local communities, or the statistical relationships between income and health problems (Roth & Barton, 2004; Roth, 2009; Tobin, Elmesky & Seiler, 2005).

1 Science Curriculum Improvement Study, Elementary Science Studies, Biological Sciences Curriculum Study

The rationale for providing science education rooted in authentic problems, questions, and objects derives from sociocultural theories of learning that stress the relationship between purposeful participation, the cultural tools of science, and learning.

Sociocultural perspectives suggest the importance of establishing authentic goals or purposes that provide students a meaningful context in which they can build on their skills, strengths, and interests to participate in and contribute to valued activities (Bronfenbrenner, 1979; Eisenhart et al., 1996; Rogoff, 2003; Stetsenko & Arievitch, 2004). Activities are organized such that they require participants to take up and use the cultural tools of science in order to achieve their goals. In this view, people learn to use the tools of science (such as thermometers, telescopes, formulae, scientific argumentation, modeling, and others) because they are the best available means for answering questions or achieving purposes that matter to them. In this sense, powerful learning activities are designed to be "authentic" both in terms of establishing real purposes for undertaking them, and in introducing the tools of science as the best available means for successfully achieving one's purpose. (This is also why they were developed historically: to achieve real purposes such as building bridges or navigating under the night skies.)

Sociocultural perspectives

Sociocultural perspectives include several different schools of thought including:

Social constructivism
Social constructionism
Ecological systems theory
Cultural-historical activity theory
Symbolic interactionism

Such perspectives on learning are increasingly used in the design of materials and research in classrooms. The National Research Council's recent (2009) volume on informal learning stresses the value of using sociocultural, and especially ecological, perspectives in designing and researching learning in informal environments as well.

Sociocultural perspectives also stress the critical role of the adult (or more capable peer or supportive community) in helping learners to create or find purpose. As such, they underscore the importance of designing and facilitating activities that can both inspire *and* sustain participation by welcoming in, supporting, and gradually increasing the complexity or sophistication (the "conceptual depth") of the goals, tool-use, and activities with which participants engage (Bronfenbrenner, 1979; Lave & Wenger, 1991). People forge their developing selves (or identities) through active participation in such authentic, accessible, and conceptually rich activities--particularly when they are grounded in, and developed by, communities of peers engaged in similar goals (Holland, Lachicotte Jr., Skinner, & Cain, 1998; Lemke, 2001). Sociocultural perspectives do not separate identity from activity, or the skills and knowledge inherent to activity, but see the self as emerging *through* concrete and valued practices (Brown, 2004; Nasir, 2002). In this view, engaging children in accessible, authentic, conceptually rich, and coherent science activities by definition contributes to their emergent identities as science learners.

These views on the nature of how people learn suggest that to more effectively engage diverse bodies of students in conceptually rich science learning, science educators need to understand how their community resources and expertise can be brought to bear to make science more authentic, accessible, and coherent.

Working across boundaries

The 2009 National Research Council report, *Learning Science in Informal Environments*, draws upon the growing body of research in informal settings to note that informal environments, as a type, engage participants in multiple ways; encourage direct interactions with phenomena; provide multifaceted and dynamic portrayals of science; and build on learners' prior knowledge and interests. This characterization provides important guidance in thinking about how and why formal-informal collaborations might be designed. In this section we consider the particular *structural* and *social* features of each setting, and how their combination may lead to more powerful affordances for science learning than either one might have working in isolation.

Structural Features and Affordances for Science Learning

Schools have specific structural properties that afford science learning. For example, schools are structured around the sequencing of experiences and materials over time, in a linear or spiraling process. It is understood that children are expected to attend school each day, over a period of years, building sustained engagement with different subject matter and approaches. Mandated testing and evaluation reflect the social contract schools have to ensure that children's learning is progressing. Because most schooling occurs in dedicated classroom spaces, teachers and students have the opportunity to work on projects spanning multiple days,

What is an affordance?

"Affordances" are the opportunities for acting, thinking, or feeling that are provided by a given environment (Gibson, 1977). As settings vary according to their environmental features (for example, consider the contrast between a classroom, a museum floor, a web browser, and a local city park), the affordances for learning and engagement may also vary for a given person at a given time.

Ideas about affordances build on ecological perspectives on learning developed by scholars including James and Eleanor Gibson and Roger Barker and Herbert Wright. The majority of the literature focuses on how *physical* features of different environments afford activity (Barker & Wright, 1971; Gibson, 1977). For instance, analyzing the equipment and landscape of a playground for its affordances for jumping, climbing, individual or group activity, etc. (Heft, 1988). Some scholars have also considered how the social or relational features of different settings afford various actions or affective states, such as peer interactions, inter-generational activity, or contemplative activity (Kytta, 2002; Loveland, 1991; Valenti & Good, 1991). The physical features of informal settings vary so widely (e.g., from libraries, to botanical gardens, to science museums) that we do not consider them in this report. Instead we consider the *structural* features that underpin and cut across many informal settings—that is, the ways in which the settings are organized and positioned within society—along with the *social* features that characterize relationships within the settings.

Understanding, designing, and assessing for these environmental features and affordances can help efforts to intentionally build coherence across learning settings.

leaving out materials or notes until they are no longer required. Schools are able to provide training and professional development processes that can support the development of teacher expertise within a given subject matter and for specific age levels. All of these properties can create conditions of stability and coherence that may be necessary for sustaining learning.

However, some of the structural properties and affordances of schools may work against the potential for rich science learning. For example, schools, which are primarily text-based and teacher-directed, and sometimes test-driven, can tend to be more focused on transmitting scientific facts than on developing understanding of science as a way of knowing. Epistemological understanding is more likely to emerge through using scientific processes to engage with the material world rather than through reading about it. Such school-based approaches may lead to science being understood as static truths, rather than as a tentative, evidence-based body of knowledge and a process of inquiry. Schools may not have the resources or the institutional practices—the real-world settings, questions, objects, and phenomena—to spark and sustain student interest in authentic and compelling experiences with STEM. Even schools that are rich in resources and committed to inquiry-based science programs, have limits to what they can offer students.

Science-rich cultural institutions are routinely able to mount major three-dimensional exhibits, provide immersive experiences, offer complex technological displays, and generate science narratives in ways beyond the capacities of most other types of educational organizations. Such tactile, visual, and kinesthetic representations of ideas may afford different kinds of engagement and even understanding. Through on-site or internet-based media, many science-rich cultural organizations have access to different kinds of data, instrumentation, and representations of current science that can support the goals of engaging children with current research. Because they design for general audiences, they may be more able to design experiences that allow for varying levels of prior knowledge, interest, and experience. They often provide an historical and cultural context for understanding how and why science has developed, been used, and might be developed and used in the future; thus affording a more cultural understanding of science than a fact-based one.

Nonetheless, because they design for general audiences, science-rich cultural institutions may vary in their ability to make science and science exhibits relevant to students' everyday lives. Additionally, their non-sequenced nature does not afford, necessarily, coherent understanding of processes and relationships across phenomena. The more sporadic and fleeting experiences in museums, for example, can be powerful but may or may not be pursued further after the visit. Youth development programs, have structural properties that include more consistent participation rates (less than schools but greater than most science-rich cultural organizations) that can lead to knowledge of children's personal experiences and communities. This understanding can help programs personalize learning opportunities and help children make connections between phenomena and their personal interests and concerns, including how such experiences can support their engagement in school. While many youth programs, particularly in afteschool settings, face structural constraints related to funding, staff preparation, and borrowed spaces, among others, their location between school and home affords particular opportunities to bridge academic and personal understandings and meaning. In some cases, bringing together youth programs, science-rich cultural institutions and/or schools has been shown to substantially support children to come to see that science matters in their lives, and that they can engage in science to contribute to their communities (e.g., Fusco, 2001; Rahm, 2007; Roth & Barton, 2004).

Informal learning settings, which are not subject to the same time and testing pressures as formal learning settings, are generally organized to allow learner-centered decision making or direction, such that individual children or groups of children may participate in the activities that resonate most strongly with their interests and abilities. They allow for flexible uses of time, with children following their own pace; they are low-stakes, non-judgmental spaces, where children's work or interactions are not formally judged against standardized measures (Honig & McDonald, 2005; Mahoney, Larson, Eccles, & Lord, 2005). They thus can feel more inviting, welcoming, and supportive of children, encouraging them to try new things, to take intellectual risks. In this way, they may be well positioned to support the development of positive dispositions, linguistic practices, and conceptual understandings and skills that are essential for and contribute to science literacy.

In comparison, the social properties of schooling, where students spend up to a full year with a teacher, can allow for the development of ongoing and consistent relationships between adults and children. Over extended periods of time, these relationships among teachers and students can be leveraged to facilitate the complexification or transformation of students' initial engagement with scientific phenomena, objects, or questions into deeper engagement with scientific structures of knowledge.

Sustained relationships, resources, and learning in ISE settings

In some cases science-rich cultural institutions build structures that can support sustained and sequential learning, using informal resources and pedagogies. For example, the Youth Exploring Science (YES) program at the Saint Louis Science Center requires high school youth to participate in the program on a weekly basis for four years, thereby creating the time and relationships that can allow for serious and sustained scaffolding of learning. The American Museum of Natural History offers a Ph.D. program based at the museum. The Exploratorium Teacher Institute works with teachers for an average of six years.

But most educational programs at science-rich cultural organizations are subject to more fleeting or fluctuating rates of participation. Therefore, most cannot *alone* develop the kinds of systematic understanding (of scientific inquiry, evidence, and reasoning, for example) necessary for students to succeed in STEM-based academic and career pathways. Instead, they support a different—perhaps essential—level of interest, capacity building, and readiness that may or may not have opportunities to flourish beyond the ISE experience.

Informal education settings that host youth development programs (whether in libraries, community centers, or museums) can also allow for the sustained development of relationships. The social affordances of youth programs have been found to include physical and psychological safety; appropriate structure; supportive relationships; opportunities to belong; positive social norms; support for efficacy and mentoring; opportunities for skill building; and integration of family, school, and community efforts (National Academies of Sciences, 2002). A growing number of science educators who seek to expand science in youth-centered after-school programs posit that these features create conditions where science learning through direct interactions, multi-modal learning, and building on prior experiences has the potential to flourish (Coalition, 2007, LSIE, 2009).

Finally, because informal education settings such as youth programs, libraries, or science-rich cultural institutions are more learner-directed and learner-paced than in formal settings, they offer a wider array of participation structures for learners. That is, they allow for multiple forms of participation, with individual children taking on roles and responsibilities that resonate with their interests and developing capacities. Another significant social property of these settings is that these varied participation structures can lead to greater rates of involvement and engagement. Research is needed to understand whether these social features of informal settings can afford expanded opportunities for meaning-making and growing commitments to science engagement.

Figure A. Features Affording and Shaping Science Learning and Committment

	Formal Settings	Informal Science Education Settings	
	K–12	Informal Education Organizations	Science-Rich Cultural Institutions
Structural Features	Abstract/textual Scoped and sequenced curriculum Mandated entry points and modalities Regular and required participation Dedicated children's spaces Professional structures and supports Formal assessments	Concrete/object-based and textual Sequenced curriculum Optional entry points and modalities Less regular and more volitional participation Borrowed learning spaces Little professional structure and support Few formal assessments; links to school scores	Concrete/object-based, little text Linked curriculum Multiple entry points and modalities Sporadic and volitional participation Public learning spaces Little professional structure and support No formal assessments
Social Features	Extended (year-long) relationships Individual learning Teacher-directed activities Teacher-paced activities High-stakes (evaluative)	Sustained relationships Collaborative learning Group-directed activities Group-paced activities Low-stakes (non-evaluative)	Short-term, sporadic relationships Collaborative learning Learner-directed activities Learner-paced activities Low-stakes (non-evaluative)
Physical Features	Classrooms in school buildings	Variety of spaces in the community	Variety of cultural institutions and natural settings

Summary

Identifying the particular properties and affordances of the informal learning environment reveals the ways in which the low-stakes context and flexible uses of time create conditions (as in youth programs) where children feel welcomed and supported to engage at their own pace with the multiple representations of science. Such settings also can provide children with the historical contexts and cultural meaning and values of science that are sometimes difficult to convey in classrooms. In settings such as zoos, natural history museums, or nature centers, practicing scientists are available to engage directly with children, revealing both the practical relevance of the concepts as well as possible pathways for children to pursue in school and careers. Thus, it is more than objects or collections that formal-informal collaborations bring to K–12 science education, but rather potentially a more accessible, contextualized, and meaningful *approach* to the material.

The particular properties and affordances of school settings provide the time and sequencing that most informal settings lack, structures that are necessary for students to more systematically develop the foundations for deep conceptual understanding, which is necessary for them to become seriously engaged in the subject matter, including pursuing advanced coursework and science careers. Schools also work with all children within a community, including those who may not otherwise attend museums, zoos, or youth programs.

To provide more authentic, accessible, and coherent science learning experiences for children, formal-informal collaborations can be designed to draw upon

- The ways in which informal learning environments support direct, multi-modal experiences with multi-faceted portrayals of science, presented within their cultural context, and using authentic objects and phenomena.
- The ways in which school contexts can provide the sustained time, and developmental and pedagogical expertise, to build increasingly complex understandings of science phenomena and processes.

Despite this rationale for collaboration, we contend, along with others (Carnegie Corporation of New York & Institute for Advanced Study, 2009; Institute for Museum and Library Services, 2002; National Research Council, 2009) that the potential of formal-informal collaborations is not currently being capitalized on in ways that can advance goals of developing a more STEM-engaged populace. It might be argued that neither the K–12 nor the ISE field pays sufficient attention to the ways in which they can design facilitated experiences that bridge students' and teachers' formal and informal experiences.

To encourage consideration of the need for, possibilities for, and outcomes of such collaborations, in the next section we examine collaborations that have built on the social and structural features and affordances of both formal and informal learning institutions to provide authentic and accessible science learning opportunities to both students and teachers.

Part 3: Formal-Informal Collaborations

This section of the report contains descriptive examples of formal-informal collaborations and their documented impacts on children and teachers. This is not intended to be a scientific review of programs, but rather meant to illustrate possibilities and raise questions for future work, in both research and practice.

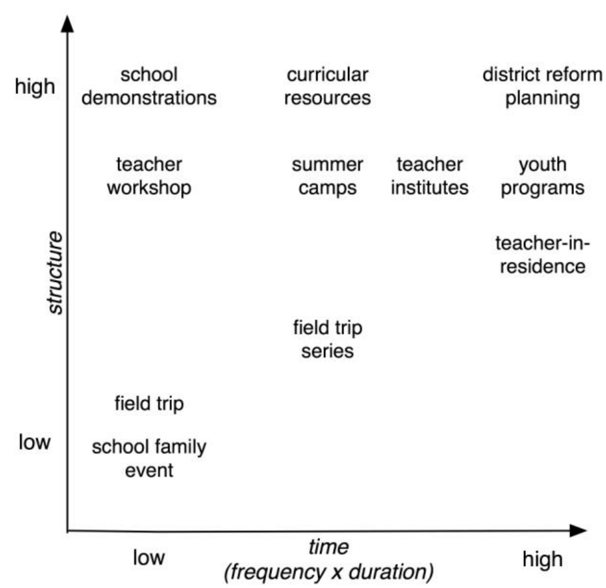
There is a wide range of ways in which formal and informal organizations collaborate. These include collaborations around core curriculum, particular learning activities or events, teacher practice and professional development, family and community events, after-school/summer enrichment programs, and even support of district infrastructure and improvement efforts. The actual nature of these collaborations differs widely, based on local needs and resources.

Most obviously, collaborations can differ in terms of content area, reflecting the particular collections or resources of the science-rich cultural institution or informal learning organization, and particular content foci of the schools. Some programs are designed primarily for students, others for teachers.

Formal-informal collaborations also differ along the dimensions of *time* (including both frequency and duration) and *structure* (meaning the extent to which activities are scripted, sequenced, and assessed). The less time and structure, the more the collaboration may resemble typical audience patterns at informal learning institutions: drop-in visitors who arrive with their own agendas and spend as much time as they wish on whichever materials, exhibits, or activities they choose. At the other extreme, at the time-intensive, highly structured collaboration, programs may begin to resemble school-like patterns of activity, often in the tradition of learner-centered, constructivist classroom teaching and learning.

Figure B roughly approximates the ways in which a range of formal-informal collaborations may fall into a time-structure matrix. The *time* axis represents a multiple of frequency and duration. That is, programs can differ in the frequency of interactions (such as a one-time field trip versus a semester-long series of field trips) and the duration of interactions (such as a 2-hour field trip versus a whole-day field trip, or a 3-hour teacher workshop versus a 3-week teacher institute). The *structure* axis represents the level to which activities are designed and delivered in a planned sequence, with explicit inclusion of specific concepts or experiences, and are monitored (or assessed) to some degree such that the program leaders can make adjustments if certain understandings or capacities are not evidenced by participants.

Figure B



Many other local variables must be considered to make this calculus meaningful (see below). Nevertheless, it is our conjecture that the programs at the higher ends of the scales would be more likely to show measured or documented impacts than activities on the lower ends; activities in the top right quadrant would be more likely to show lasting or transformational effects. This conjecture is based on the theories of human development and learning we referenced earlier in the report, but to date this has not been systematically tested in the context of formal-informal collaborations. It is another conjecture that the experiences at the lower ends of the scales may be critical for engaging interest, stimulating ideas and questions, and introducing or reinforcing science concepts and skills, which translates to a readiness or capacity to engage productively in activities at the higher ends of the scale, or in science learning activities at home, on the Internet, in school, or elsewhere. Again, this is a conjecture that needs to be tested. Current theories of learning suggest that all of these activities are important, but taken in isolation they yield different types of results, with more structure yielding more measurable results. (The relationship between *measurable* and *meaningful* results is a highly contested issue that this report will not address.) The chances of isolated experiences leading to lasting change are low. Yet, we all have had such experiences—they are not impossible. The question is whether as educational designers we are content leaving this issue to chance.

Although we call out frequency and duration as essential dimensions of collaborations, we also argue that time has to be thought of broadly—as the time before, during, and after the collaboration. For example, in 2002, a K–12 school in Poughkeepsie, New York, designed an entire grade 1 and 2 Science and Humanities curriculum around the study and use of local informal science and other cultural resources. Initial funding from the National Park Service, through a project called Teaching the Hudson Valley, allowed the teachers to design a series of 12 field trips to local nature centers, natural settings, and cultural institutions for students to experience and learn about the natural and social history of the Mohonk Ridge and Hudson River. But in addition to these site visits and interactions with museum and park educators, students spent intensive classroom time conducting further research, activities, and experiments related to the geological and ecological systems of the Ridge and River. They built a clay model of the river bed and ridge. They tracked and recorded weather patterns in the region. They wrote and illustrated poems and short stories about the native Lenape culture. They learned songs about the composition of the conglomerate rock that ran through the ridge. They thus developed, over time and multiple settings, deep relationships with understandings of the scientific, cultural, and historical developments in the area. Building on just 12 4-hour field trips per year, this 2-year long unit now serves as the foundational curriculum for all first and second graders at Poughkeepsie Day School. These are the types of local conditions, contingencies, and variables (including the dedication of the teachers and the vision of the school leaders) that must be taken into account when conceptualizing and evaluating the impacts of formal-informal collaborations.

The types of programs we describe above can be grouped into five general categories:

Figure C

Supplementary classroom enrichment Time: low-medium Structure: low-high	These programs build on the goals for classroom STEM. For example, field trips to augment student understanding of science concepts, school visits and demonstrations, or drop-in afterschool science programs at a range of settings. They may also include teacher workshops that provide orientation and pre and post materials for teachers to plan their field trips.
Integrated classroom resources Time: medium-high Structure: medium-high	These programs include materials, activities, regular or sequenced field trips and field research projects, kits and collections, and other resources that are developed by informal institutions and integrated into the core academic curriculum. They may include teacher workshops that help teachers to integrate the resources into the classroom curriculum.

Sustained student learning communities Time: medium-high Structure: high	These programs work directly with K–12 students, for example in afterschool, weekend and summer programs that develop specific skills, capacities, and understandings, including understanding of possible academic and career pathways that may be available to students. These programs may or may not directly reference state standards, and aim to build student capacities to engage in STEM.
Sustained teacher learning communities Time: medium-high Structure: high	These programs provide teachers with sustained or ongoing professional development support that focuses on science content and/or science pedagogies. They use the resources of the science-rich cultural institution (which may include exhibits, natural settings, staff teaching expertise, staff scientific research activities) to engage teachers as science learners (and not necessarily for direct use with their students).
District infrastructure development Time: high Structure: high	These programs are designed in collaboration with districts as part of long-term improvement strategies. They include novice teacher training, district-mandated teacher development, curriculum planning projects, etc.

In the next part of this section we provide examples of these types of programs that have collected evidence of their impact on participants.

Documented Results

Through multiple inquiries, we identified a modest number of formal-informal collaborations in the United States and the European Union that had collected participant impact data. Many programs had evaluations that attended to the features and designs of the programs, including participant satisfaction levels; but few addressed the ways that the programs contributed to changes in attitudes, understanding, or practices among program participants. Some, like the Florida Museum of Natural History's Project Butterfly WINGS or St. Louis's Forest part Forever, had impact data but had not been designed in collaboration with schools. We did not seek to establish causal relationships between program designs and documented impacts. (In fact, we conjecture that dynamic models that identify multiple variables and feedback loops may be more appropriate than linear causal models for assessing impacts of formal-informal collaborations.)

Type 1: Supplementary Classroom Enrichment

Although they are perhaps the most common formal-informal collaborative programs, and there is a robust research literature that examines the nature of field trips and field trip design (see National Research Council, 2009, pp. 131–135), our search did not locate any typical (3-hour) field trip programs that were designed in collaboration with schools and that had student impact data. This is not surprising, given our learning model described above, which links *measurable* causal impacts to more sustained and systematic experiences. We did however locate several programs where formal and informal educators co-designed programs that provided students with STEM learning experiences that intentionally connected with, and potentially enriched, their classroom studies. These programs built on the affordances of school STEM in that they approached STEM through sequenced curricular units. They built on informal affordances by situating the units in low-stakes, multi-modal, and hands-on approaches to the activities.

LEAP (Learn, Explore, And Play): Science is Fun!, Belcamp, Maryland

LEAP: Science is Fun! is a program based at the Harford County Public Library (HCPL) in the northeast corner of Maryland. It is supported by federal Institute for Museum and Library Services funds through the Maryland State Department of Education. LEAP provides children aged 8 to 13 with science programs that focus on conceptual learning and how science connects with their everyday lives and communities. The program, which has worked with more than 1,000 children since 2007, has documented the participants' and parents' perceptions of how the LEAP Programs and materials have affected their attitudes and beliefs about science, their performance in science at school and on science projects at home, and the possibility of science as a future career choice.

LEAP library educators worked with science teachers from the Harford County Public Schools, and representatives from local STEM industries, to design and develop a series of after-school science programs as well as a set of 50 science kits on 18 different topics. Topics included *Roots, Droids, and Transformers; Medical Manhunt; Voyage to the Planets; Legends and Lore of the Night Sky*, and others.

LEAP: Science is Fun!

Structural Features	Social Features
Sequenced activity units	Learner-directed
3-D or hands-on objects	Learner-paced
Multiple access points	Low stakes context
Multi-modal activities	Connections to everyday STEM
Documented Outcomes	
Attitudes	
Interest	
School performance/practices	

The kits are used as the centerpiece of inquiry-based science programs in the library. The concepts that children explore through the kits and programs relate to the elementary and middle school curriculum in the district, which are aligned with the state science standards. They also represent the interests of the local children. For example, when children had questions about microscopic life they heard lived in a local stream, the program held a program about plankton, and created both a Microscope Kit and a Microscopic Aquatic Life Kit. Topics for programs and kits include Chemistry, Microscopy, Robotics, Biology, Engineering, Astronomy, Environment, Forensics, and Entomology.

LEAP programs meet twice a month throughout the school year and once a month during the summer. Program topics often coincide with national science celebrations such as National Chemistry Week, Inventors Day, or Archeology Month. LEAP is housed at the Edgewood branch of the HCPL system. Edgewood is a low-income area and many library users do not possess library cards. The LEAP kits can be used within the library as well as at home. Sometimes a group of four to five middle schoolers can be found building electric circuits or erecting bridge models all at one time.

Making the science kits accessible for children to check out and take home has proven to be an immensely popular aspect of the program. For most of the first summer, for which the program has data, about 75 percent of kits were checked out at any given time. LEAP kits are available for children to check out and use at home. One of the most popular kits has been the Microscope Kit. This kit includes a microscope that magnifies 20X–200X; a set of prepared slides of insects, textiles, plants, and more; along with an explanation of each slide; blank slides and cover slips; lens paper; and a book detailing how to make your own slides. By taking the kit home, children can explore the microscopic world found in their own house. Rather than just reading about science, they are able to use the tools of science to explore scientific aspects of their everyday lives.

The evaluation of LEAP used a descriptive research design to test the hypothesis that participation in Project LEAP would produce an increased interest in science and awareness of science in the participants' lives, a desire to consider a career in a science-related field, and a positive perception in the community of the project and of the public library. Data was collected using a combination of surveys, interviews, and a focus group of participating children who had attended three or more LEAP programs. The evaluation suggests that parents of children participating in Project LEAP highly value the programs and materials. Children participating in the program report that LEAP programs

- have made science more interesting for them
- have caused them to consider a career in science
- have helped them pay more attention to science in the world around them
- have helped them want to read more about science.

The LEAP program is a good example of a semi-structured program—carefully chosen curricular topics that connect to the school curriculum—offered in ways that allow students to engage with the materials and kits that interest them, during timeframes that work for them (at home, at the library, repeatedly, or not at all), within a safe and supportive community setting. The program thus has the potential to advance students' science interest, capacities, and commitment, which they bring with them to school and other everyday settings.

A key question LEAP raises is the ways in which schools can become aware of, and build on, the kinds of questions, capacities, and interests students are developing in after-school hours. It also raises questions about how intermediary spaces such as libraries—learning environments that are equally associated with home and school life—may provide unique niches for supporting student comfort with trying new subject matter and activities.

Minds-on-Math, Shreveport, Louisiana

Sci-Port, a science center in Shreveport, in partnership with the Caddo Parish Schools, has developed a K–8 after-school program that has documented statistically significant improvements in state math scores. Since 2007, the program, funded by the state Department of Education, has worked with 73 students.

Minds-On-Math is a two-and-a-half-hour after-school program that meets twice a week at the museum for a seven-week period. The program, which serves roughly 20 students at a time, is designed to use the exhibit collection to support students' development of mathematics concepts. Designed as a state-funded State Education Standards (SES) program, Minds-On-Math consists of math activities; guided and directed time with exhibits; and other activities. Examples of exhibit experiences include:

> *Bed of Nails*—Students explore the concept of inverse proportionality, discovering that the greater the area over which their weight is spread, the less pressure is exerted.
>
> *Standards of Measurement*—Students are challenged to determine how many exact units of dried noodles are needed to fill up a range of different vessels shaped as pyramids, cylinders, spheres, and cubes. The different shapes require careful use of standard units of measurement in order to get to exact results.

Students take diagnostic tests, which closely mimic the Louisiana state achievement tests, and then are assigned to different elementary or middle school groups of about 10 children per adult. Each session focuses on a specific area in which the child's diagnostic tests show that the child could benefit from remediation and enrichment; each consecutive session reviews concepts from the last session before introducing new content. Exhibits are used as tactile and 3-D teaching tools. For example, one child who was working on area and perimeter experienced an "aha" moment at an exhibit consisting of a square grid and different flat shapes. By working with the shapes at the exhibit, the child came to see that she could find the area by counting the number of physical one-inch diameter squares that completed the grid. What "a square inch was" suddenly became clear to her. This exhibit experience was followed by an activity called *Three Units* where participants were given string, paper, scissors and clay and challenged to make a centimeter, a square centimeter, and a cubic centimeter.

A tutor works with students on volume concepts. *Photo by Al Bohl, Sci-Port: Louisiana's Science Center*

Teaching staff include certified teachers from local schools and museum education staff who participate in trainings at the museum on how to use the exhibits as teaching tools, as well as training in the state SES program audit requirements. Family nights are scheduled so that siblings can experience the museum while parents meet with the adult leaders. All students receive a year-long Sci-Port Family Membership.

Evaluations show that, as a whole, the children who attended Sci-Port's SES math program showed a noticeable increase in math scores in the Louisiana LEAP/iLEAP test. More than 80 percent of participants who completed the 2008–2009 year of Minds-On-Math and took both the Sci-Port-administered pre- and post-tests increased their scores. Sci-Port and the school district have comparison data to show that the students in the program show greater math score gains than non-participating students.

Minds-On Math

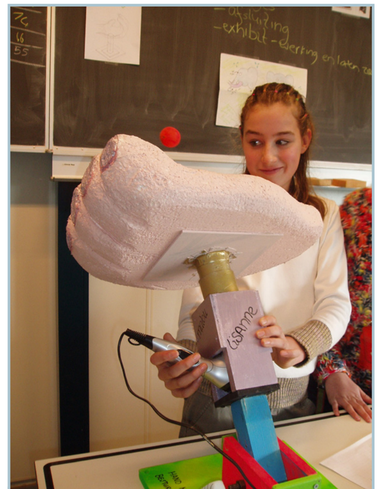
Structural Features	Social Features
Sequenced activity units	Sustained relationships
Diagnostic assessments	Learner-paced
3-D or hands-on objects	Connections to school STEM
Multiple access points	
Multi-modal activities	
Professional training/support	
Documented Outcomes	
School performance/practices	

This program is a highly structured, 7-week intensive that strictly follows the state standardized test curriculum, but which builds on the inquiry and tactile modalities and affordances of a science center to create new opportunities for children to experience and come to understand subject matter that they are struggling with. It is thus an example of how the resources of science-rich cultural institutions can be intentionally deployed to make school science more accessible, possibly more enjoyable, and thus more inclusive.

A key question that Mind-on-Math raises is how three-dimensional, and often life-sized, exhibits can be used to help children grasp and understand concepts that may be more difficult to comprehend using verbal approaches. How can school systems more seamlessly collaborate with institutions that house such collections before students find themselves in need of remediation?

Science Centre at School, Amsterdam, Netherlands[2]

The NEMO Science Center's *Science Center at School* project challenges 11- and 12-year-old students to design and create their own exhibits, culminating in the creation and installation of a science center in their school. The program involves 8 day-long sessions, over a 5-week period, at both NEMO and at the participating school.



Students of Baken Park High School in Almere, the Netherlands, have designed this Bernoulli Blower exhibit, called the Magic Hand. Photo by Amito Haarhuis

At the Science Center, students view and play with exhibits. They are then introduced to a set of exhibits selected to be both conceptually rich and easily constructed using low-cost materials. Students select one of these exhibits and make a technical drawing that they will take back to school. Later, in their classrooms, the students are supported by their teachers to build a tabletop version of the exhibit using a booklet of recipes for building the exhibits. The booklet contains the description of 20 well-known, easy to build exhibits (featuring for example, soap bubbles, an electrical cell, an electrical motor, leaf recognition, the Bernoulli effect, mirrors, sounds from straws, and so on). NEMO also provides a teacher's guide to the project. Students explore, research, and draft written explanations of the science behind the exhibits which they incorporate into a poster that accompanies their exhibit. At the school, students make oral presentations of their exhibits and the science behind them before opening up the science center to the school and family audiences.

The Science Centre in a School project was developed by NEMO staff working with the Institute for Mathematics and Science Education of the University of Amsterdam (Amstel). It emphasizes processes of inquiry over the exhibit product. Therefore, teachers are asked to focus primarily on students' use of inquiry and other technical skills that can help them to isolate issues that require investigation. NEMO provides a full day of staff development to prepare teachers for the project. This session includes an overview of the project goals and schedule, introduction to the range of exhibits the children will choose to replicate, having teachers build a number of the exhibits themselves, and assistance in supervising the process of research- and design-based learning.

NEMO was funded through the PENCIL project, a collaboration between ECSITE (the European science center professional organization) and the European Union Ministry of Education. NEMO designed the project to address specific Dutch Ministry of Education learning objectives, including:

- Key objective 42 : The pupils learn to research materials and physical phenomena such as light, sound, electricity, force, magnetism and temperature.
- Key objective 44: The pupils learn to see relationships between the operation, form, and use of materials in products from their own environment.
- Key objective 45: The pupils learn to design solutions for technical problems and to implement and evaluate them.

2 Portions of this description were provided by the authors of Permanent European Centre for Informal Learning (PENCIL). (2009). *Science centres and museums working with schools: New ways of cooperating*. Brussels: ECSITE.

Interesting findings relating to gender emerged from the evaluation of the data. First, boys and girls had different preferences with regard to the exhibits they chose to build. For the boys, the most popular exhibits were those about batteries and electric circuitry; girls liked exhibits involving human interaction such as the magic mirrors and the exhibit involving a quiz about the names of leaves. Second, pre and post questions asking students "how technical" they would say they were showed changes, with girls becoming 50 percent less likely to describe themselves as "not very technical" (moving from 60 percent to 30 percent describing themselves in this way); self-estimations of the boys remained high both before and after the experience.

NEMO's project is an example of a way that science centers can provide a context for students and teachers to take on targeted activities that expand the nature of the school science curriculum. The strategic use of the science center, as a place to inspire the school activities (instead of as a "reward" at the end of the unit), suggests an important way that collaborations can be designed to advance student engagement.

Science Center at School

Structural Features	Social Features
Sequenced activity units	Extended relationships
Performance assessments	Learner-directed activities
3-D or hands-on objects	Connections to school STEM
Professional training/support	
Documented Outcomes	
Attitudes Interest	

Type 2: Integrated Classroom Resources

The programs we highlight here have designed semester- or year-long experiences that serve as the centerpiece of students' school science curriculum. Combining site-based programs for students, classroom resources, and teacher professional development, these programs have developed hybrid or blended curricula that span both informal and formal settings, resources, and pedagogies.

Calumet Environmental Education Program, Chicago, Illinois

The Calumet Environmental Education Program (CEEP)[3] was developed by the Field Museum of Natural History in collaboration with Washington High School and its eight feeder elementary schools in the Calumet region of southeast Chicago. The Calumet region, which has been environmentally challenged by industrial pollution from former steel mills and municipal and industrial garbage dumps, is home to several hundred acres of forest preserves and recreational areas, a large lake, and waterway system and is endowed with rich ecosystems.

CEEP focuses on expanding teachers' knowledge of local biodiversity and basic ecological concepts in order to support the adoption of an integrated multi-year environmental studies curriculum for students in grades 4–12. Evaluation results showed that teachers participating in CEEP significantly increased their knowledge of local environmental issues and content, increased their inclusion of local biodiversity into their teaching objectives, and reported higher confidence levels when teaching about environmental subject matter. Student results, using pre and post tests addressing subject-matter understanding, also showed increases in knowledge about local ecologies. Moreover, principals and teachers remarked that the project required students to use problem-solving, collaboration, and higher order thinking skills. Questionnaires were also administered to

3 Significant portions of this description were provided by a report prepared by Laurel Ross and KirkAnne Taylor, of the Conservation Education Department at the Field Museum, using evaluation data collected by Terrie Nolinske.

students at the beginning and end of the academic year, each of the three years, to detect changes in attitudes and behaviors towards the environment.

Subject matter that students learn in their regular earth science, chemistry, and biology classes is integrated into CEEP activities along with frequent field trips and hands-on experiences in local natural areas. For example, students in 4–6 grades, participate in Mighty Acorns, a field-based program that introduces young people to nature through exploration and stewardship. Stewardship activities can include anything from removing invasive plant species and collecting seeds to reintroducing native plants. By participating in stewardship activities, students become part of a larger land management effort which includes private citizens, public agencies and community organizations. Students learn basic ecological concepts such as adaptation, interdependence, communities, competition and biodiversity as they move through a series of integrated classroom lessons and field experiences. Students take three field trips each year to a local natural area such as a park, a prairie, or a woodland. They explore the area in order to become familiar with its flora and fauna, to understand its history and to observe its ecological relationships. Teachers build on these experiences throughout the school year.

Summer Institutes and Inquiry Group workshops enhance teachers' environmental content knowledge, while giving them time to plan and integrate that content. During these workshops teachers practice upcoming segments of CEEP curricula and network with teachers from other grades and disciplines to coordinate activities across years. Together, teachers have constructed strand maps depicting concepts to be learned in each grade and how these concepts link to each other through the curriculum. They also help to define learning goals, highlight areas of curricular overlap, identify strengths and weaknesses in lesson plans, and suggest assessment measurements.

Questionnaires were administered to teachers at the beginning and end of the school year to measure changes in attitudes towards the environment and gains in environmental and ecological knowledge. In addition, teachers were surveyed at the end of each year on their teaching style preferences and how they incorporated CEEP into their daily curricula. According to the questionnaires, which were independently validated by a statistical consultant, teachers made sometimes dramatic gains in science concepts, understanding of the local ecological systems, and awareness of stewardship issues. Teachers also reported integrating teaching about the environment across their curriculum. This increased from 25 percent in the year one pre-test to 56 percent in the year three post-test. At the end of the three years there was a 96 percent increase in agreement with the statement: "I am comfortable answering student questions about environmental issues in Calumet." There was a 79 percent decrease in the number of teachers who agreed with the statement: "Lack of knowledge makes it difficult to include content about nature or the environment in my teaching."

The CEEP program is a time-intensive and structured program that fundamentally changes the nature of the STEM curriculum for students, and simultaneously builds long-term capacity of teachers. It thus exemplifies the ways in which formal-informal collaborations

CEEP

Structural Features	Social Features
Sequenced activity units	Extended relationships
Assessments	Connections to everyday STEM
3-D or hands-on objects	Connections to school STEM
Place/site-based	Collaborative learning
Multi-modal activities	
Professional training/support	
Documented Outcomes	
Student conceptual understanding Teacher practices	

can change the experience of science learning, by rooting it in the real world environment, by building professional networks grounded in disciplinary material and environmental settings, and by getting students out of the classroom and into the local ecology.

The CEEP project raises questions about how place-based professional development may support teacher professional development in ways different than traditional approaches, and whether such programs are more likely to lead to changes in classroom practice and student learning.

WATCH, Monterey, California[4]

In 2006, the Monterey Bay Aquarium, in partnership with Pajaro Valley High School, launched the Watsonville Area Teens Conserving Habitats (WATCH) program. The program includes a three-week summer session where students work in teams to visit, study, and restore three main habitats of the Pajaro River Watershed (riparian, wetlands, and dunes), and a school-year project-based environmental science class involving more extensive research projects in the watershed. The program serves about 30 students annually, of whom over 90 percent self-report as Latino, and almost 70 percent as female. Using pre/post surveys and concept maps, a study of the program found statistically significant changes in students' relationships to local ecologies, including their awareness of various environmental issues, and their import and impact for local communities.

As he tends the Community Garden at Pajaro Valley High School, a WATCH student attempts to identify the impacts that conventional agricultural methods have on the local environment. *Photographed by Monterey Bay Aquarium Staff*

During the summer, WATCH students learn key scientific skills—observation, exploration, data collection, communication—and apply them as they explore and work to restore the Pajaro River Watershed. During the school year, the students transform their summer experiences into community leadership. With the support of aquarium staff and high school faculty, students identify an environmental issue that's of personal interest and design and implement a project to address it. In the past, projects have included studying the impact of watershed education classes at local elementary schools, comparing the levels of nutrients in wetlands surrounded by agriculture and urban development, sampling beaches to quantify common types of marine debris, and developing restoration plans for local dune habitats, among others.

During their year-long projects, students are paired with mentors from the local scientific community, including scientists and educators from the Monterey Bay Aquarium Research Institute, Moss Landing Marine Laboratories, the University of California, Santa Cruz, the City of Watsonville, and Watsonville Wetlands Watch. The students work with these mentors along with high school teachers to create projects that are both scientifically rigorous and relevant to their community.

In the process of developing and implementing their projects, the students also learn environmental science content through a class co-taught by a Pajaro Valley High School Science teacher and aquarium staff. The 2009–2010 school year marked the first year that the WATCH school-year program was integrated into the regular school day as an elective science course. The school year culminates in two formal presentations of the students' work: a poster presentation at the Monterey Bay National Marine Sanctuary Currents

4 Significant portions of this description were provided by MBA employee Angela Haines

Symposium, alongside local scientists and graduate students, and a final presentation for the students' families and other community members at the Monterey Bay Aquarium Research Institute.

Upon completion of their projects, students are eligible to apply for a scholarship of up to $1,000 to be used at the college or university of their choice. The amount awarded to each student is based on participation as well as the community impact and longevity of their project. After students have participated in the WATCH program, the aquarium also offers opportunities to continue engaging in leadership opportunities through an Alumni Action Committee. The alumni meet during the school year to plan local conservation events, such as hosting a site for the California Coastal Commission's Coastal Cleanup Day and implementing restoration events in the Pajaro River Watershed. Students can also continue participating in the WATCH program as summer interns and as teaching assistants for the WATCH class.

WATCH

Structural Features	Social Features
3-D or hands-on objects	Extended relationships
Multi-modal activities	Learner-directed
MBA staff scientists	Connections to everyday STEM
Place/site-based	Connections to school STEM
	Collaborative learning
Documented Outcomes	
Attitudes Interest	

In the future, the program will add an economics component so that students engage not only directly within their sphere of influence, like authoring a brochure on environmental debris, but also on coming to understand issues that drive change within community. The program is also scheduled to expand to a second school, Watsonville High School, during the 2010–2011 school year, with plans to continue expanding to other Watsonville area schools.

The WATCH program is a strong example of a year-long, integrated program that builds on the expertise of staff at the aquarium to engage students with research questions that matter to them, their communities, and to the professional fields of the scientists who work at the aquarium. It effectively expands the resources of the local school system to incorporate these perspectives into the academic curriculum.

WATCH programs may provide foundational experiences for students to develop identities as active science, environmental, or community participants and leaders. How these experiences play out in the students' lifetime is a critical question for understanding the importance of providing students such experiences. Considering how such locally engaged, science-rich experiences can be scaled up to be available to more students (offered in a variety of local sites organized around a range of science-based issues or resources) is a challenge to both formal and informal institutions.

Urban Advantage, New York City

Urban Advantage has documented the ways in which participation in their program has impacted students' understanding of both inquiry-based investigations and of specific science subject-matter.

Led by the American Museum of Natural History, the Urban Advantage (UA) program is a collaboration that includes the Brooklyn Botanic Garden, New York Botanical Garden, New York Hall of Science, Queens Botanical Garden, Staten Island Zoological Society, the Wildlife Conservation Society's Bronx Zoo and New York Aquarium, and the New York City Department of Education. The project is funded by the New York

City Council and several private foundations. In 2008, the program served 30 percent of the city's 8th grade population—24,000 students from 147 schools—as well as 257 of their teachers.

The centerpiece of the UA program consists of student investigations that also serve as the students' required "exit projects" for middle school in New York City. The investigations are designed as controlled experiments, field studies, secondary research, and design projects—giving opportunities to teachers and the UA partners to use the best of their content and processes. Investigations are usually conducted by groups of three to four students, mentored by teachers and staff at the partnering science-rich cultural institutions, and carried out over the course of several weeks after initial visits to the institutions. In addition the initiative includes 48 hours of professional development for teachers, resources for students and their families, and inquiry instructional tools for participating classrooms.

Examples of model projects developed by institutions to prepare students and teachers include :

- a study of the effects of composting on seed germination and plant growth, inspired by a student noting enormous sunflower plants during a trip to the Brooklyn Botanic Garden;
- a study to understand how feeding schedules affect sea lion activity, inspired by visits to the Bronx Zoo;
- a study of earthquakes at different types of plate boundaries based on content and resources from the Hall of Planet Earth at the American Museum of Natural History;
- a study of how a waterfall affects water oxygen levels, inspired by a trip to the New York Botanical Garden.

The UA project builds on the affordances of both schools and cultural institutions. It uses the authentic and multi-modal objects, collections, visualizations, and sites of science-rich cultural institutions to motivate and inspire student questions and interest. Teachers, supported by UA professional development offered by partnering organizations, work with children over a period of weeks to design and develop their studies. Families participate in UA family day programs and receive vouchers for visiting for future visits. Resources for families are available in the nine different languages spoken in participating schools. Science experts at the cultural institutions are available to coach and mentor students, directing them to resources or providing them access to information, tools, or locations that schools may not have. The investigations are grounded in real questions, real settings, and the real purpose of completing the required middle school exit projects. During the course of the projects, students work with a range of science concepts through learning about and conducting controlled experiments. Completed projects are shared at school-wide poster sessions. Each school selects a single project to be highlighted at a city-wide poster session event, hosted by the American Museum of Natural History and attended by families and the community.

Urban Advantage

Structural Features	Social Features
Sequenced activity units	Extended relationships
Assessed	Learner-directed
3-D or hands-on objects	Connections to everyday STEM
Multi-modal activities	Connections to school STEM
Professional scientists	Collaborative learning
Place/site-based	
Professional training	
Documented Outcomes	
Student conceptual understanding	

Preliminary evaluations found that 83 percent of UA teachers observed evidence of improvement in the quality of UA students' science content knowledge. Additionally, 80 percent of UA teachers reported students' increased understanding of the process of scientific investigations. In the past several years, the rubric developed for exit projects has improved the pacing and quality of the projects. These evaluations relied on five forms of evidence: observations in classrooms, observations in field trips, observation and interviews with students at the time of exhibitions at the end of the year, interviews with teachers, and multiple surveys to teachers, families, and partners. Currently, UA evaluators are also looking into the items in the 8th grade New York State exam that specifically test for knowledge of investigations, and preliminary findings suggest that students in UA do better in those parts of the exam. The program is on its sixth year, reflecting sustainability and growth. It began with 35 schools and 60 teachers and now serves 168 schools, 383 teachers, and 37,510 students in every borough of New York City and in every city council district.

Key questions that this program raises are whether, how, and the degree to which rooting science experiments in children's authentic questions can lead to enhanced learning outcomes. Furthermore, if authentic questions can serve as powerful motivators for science engagement, how can formal-informal partnerships be developed at scale, such that all school children have access to such settings not at the close of curricular units, as a capstone field trip experience, but at the beginning, as a starting point for in-depth studies?

Type 3: Sustained Student Learning Communities

These programs provide sustained, multi-year science learning programs for students spanning all grade levels. Although they have different levels of direct connection to the school curriculum, they each provide a social learning space in which students can build their science capacities, understandings, commitments, and identities. Schools do not generally play a strong role in the design and implementation of these programs, but they participate in the partnerships—by providing space, recruiting participants, or communicating with parents because of shared formal and informal goals of supporting students' identities of achievement, as well as their development of specific STEM skills and understandings.

Science Club for Girls, Cambridge, Massachusetts

Science Club for Girls (SCFG) has documented changes in girls' attitudes towards science and science careers. SCFG partners with several schools and community centers in the greater Boston area, which provide space for the program during after-school hours, and disseminate information about the program to support recruitment of students.

Fifth grade Science Club participants dissect a perch. *Photo courtesy Science Club for Girls*

SCFG engages girls in grades K–12 in weekly hands-on science programs led by a volunteer staff of women scientists. The program is designed around establishing relationships among the participating youth (in both age cohorts) and the women scientists, graduate students, or undergraduate science majors. The goal of these relationships is to make science more accessible and science careers more imaginable to participating girls. The women scientists, who volunteer to lead the programs at local sites, bring passion for their work and deep familiarity with processes of scientific inquiry. They mentor high school students who, in turn, serve as peer mentors to the K–7 girls. The women scientists serve as three-dimensional role models who challenge the stereotypes that girls might have about who scientists are.

Girls in grades K–7 participate in after-school clubs led by the women mentor-scientists. High school girls participate in a Junior Mentor (JM) program, which involves engaging in science learning activities, learning about local science resources, professions, and industries, and serving as peer mentors to the K–7 girls. In weekly workshops, JMs reflect on work and learn leadership and life skills. For example, a group of 6th and 7th graders spent a semester performing biochemical assays on food and fluids, performed a mock angioplasty, and discussed their family experiences with diabetes, heart disease, and hypertension with their two mentor-scientists (a Wellesley College student majoring in biochemistry and a Ph.D. cell biologist). At the end, they impressed their parents and friends with a skit called "Fat Cinderella," which, they named, wrote, and performed to humorously explore the correlations between diet and disease.

Science Clubs for Girls

Structural Features	Social Features
3-D or hands-on objects	Sustained relationships
Multi-modal activities	Learner-directed
Professional scientists	Low-stakes
	Collaborative learning
	Connections to everyday STEM
Documented Outcomes	
Attitudes Interests Career awareness	

SCFG credits some of their success in recruiting girls from low-income families to their ability to provide programs at familiar locations (local schools) and at no cost, thus removing major barriers to access for children from low-income families. Teachers at collaborating schools have repeatedly reported that for some girls, including some who may be in a homeless situation, SCFG is the only after-school program that they attend. Similarly, the program's field trips to museums, special STEM-related events, and introduction to a wide range of STEM professionals and industries expose girls to science experiences and environments that they may not otherwise be able to access.

SCFG seeks to build girls' confidence. As one graduate explains, "Being with a small group of girls, there's more freedom to be wrong, it's easier to open up. We developed really good friendships because the program emphasized working together so much." In 2006, SCFG completed its first outcomes-based evaluation, which examined how the program affected the confidence and attitude of participating middle school and high school girls. The evaluation suggests that, as compared to peers from the same schools, girls in the programs:

- retained their interest in science throughout high school
- had higher confidence in themselves as science students
- were more favorably disposed towards science
- were more likely to select a career in STEM, and
- had a greater desire to attend college.

Key questions raised by SCFG are how participation in such multi-leveled communities of practice affects children's lifelong trajectories with science, and how schools can tap into these communities to strengthen both their programs and student experiences.

SPARK!, Philadelphia, Pennsylvania

SPARK! works with children in grades 4–8 to engage in real-world science and engineering activities. Children are recruited through the schools to participate for up to 100 hours through after-school, Saturday, and summertime programs offered at the partner institutions. SPARK! has found that students' interest in science and engineering has increased, along with their conceptual understanding of the design-engineering process. The project has achieved these outcomes through contextualizing science and engineering activities in their social use and relevance. SPARK! is an NSF–funded collaboration between the Graduate School of Education at the University of Pennsylvania, the School of Engineering and Applied Sciences, the Philadelphia Zoo, and the School District of Philadelphia.

SPARK! students built biodomes and used STEM skills to record their weekly observations. *Photo courtesy SPARK!*

The program focuses on how engineering design is premised on human, societal, and environmental interdependence. For example, during the summer and weekend hours, one group of children works with zoologists at the Philadelphia Zoo to understand design considerations for animal habitat construction. This activity involves observing and learning about animal behavior and needs, and coming to understand how zoologists design and engineer appropriate habitats. During the school year, participating teachers from Philadelphia schools work with students in after-school programs to build similar inquiry and engineering design capacities to solve problems that are relevant to their daily lives such as designing and constructing a shoe with a particular purpose, or designing a variety of devices to support people with disabilities. Students are challenged in both settings to work with partners to solve a design problem by first identifying important parameters, planning the solution, constructing a prototype, evaluating purpose and impact, and redesigning to improve results.

SPARK!

Structural Features	Social Features
3-D or hands-on objects	Sustained relationships
Multi-modal activities	Learner-directed
Professional scientists	Low-stakes
Professional training	Collaborative learning
	Connections to everyday STEM
Documented Outcomes Interest Student conceptual understanding	

The partnership is supported through joint professional development sessions in which engineering and zoo instructors collaborate with the school of education and district teachers to build understanding of both learning and pedagogical strategies and content knowledge needs. This program element was developed in the face of perceived institutional cultural gaps affecting both communication and program implementation. The sessions focus, for example, on engaging engineering students in student-centered social constructivist approaches while teachers learn about cutting-edge scientific research. This capacity building has provided contiguous programming where students experience the same concepts and teaching approaches from their teachers and at sites where real-world science takes place.

A central goal of SPARK! has been to raise student engagement levels in STEM. Two aspects of the SPARK! program evaluation focused on what students learned about the engineering design process and whether their interest in science increased as a result of participation in the program. In post-intervention concept maps 57 percent were able to accurately demonstrate understanding of the engineering design cycle and processes compared to just 26 percent at the beginning of the study. In short answer responses, 73 percent of students also showed increased understanding of engineering design and associated applications. Similarly, in individual interviews, students overwhelmingly signaled their interest in science and identified SPARK! as having a major influence on their opinions about science and science learning.

A key question raised by SPARK! is the degree to which helping children understand science and engineering as a tool to solve real-life challenges or problems can be leveraged to engage them in increasingly complex and sophisticated studies in science. It also suggests that schools might look to informal learning institutions not just to provide resources as illustrations but also as professional settings where science is used to pursue practical purposes.

Youth Exploring Science, St Louis, Missouri

Youth Exploring Science (YES) is a year-round youth development program based at the Saint Louis Science Center which was developed with funding from NSF (DRL-0423178). Participants enroll in 9th grade and are expected to continue through 12th grade. It is a collaboration between the Saint Louis Science Center, the St. Louis Public School District, and 15 after-school and youth programs that work with high-poverty communities. Examples include shelters, group homes, faith-based youth programs, and traditional after-school programs in the city of St. Louis, county of St. Louis, and East St. Louis, Illinois. The program is funded through private donations as well as through the science center's general operating fund. The YES program has shown significant impacts on student high school graduation and college enrollment rates.

Youth Exploring Science

Structural Features	Social Features
3-D or hands-on objects	Extended relationships
Multi-modal activities	Learner-directed
Authentic employment	Low-stakes
	Collaborative learning
	Connections to everyday STEM
Documented Outcomes	
School performance/graduation	

The program recruits students from high schools around the city. Youth attend classes at the science center that focus on science concepts, facilitating hands-on science activities, and inquiry pedagogies. They then lead the same science activities for elementary and middle school youth at local after-school programs. Students' participation is seen as a commitment and a job, and students are paid for their time in the program. YES provides participating students opportunities for increasing leadership, including mentoring of younger participants, as they progress through the program.

The community partner venues where YES students lead elementary and middle school science activities provide a sense of purpose and achievement to the students' activities that add authenticity to their studies at the science center and allow them to actively contribute to their communities. The program positions science as a way of understanding the world which can be used to engage learning and to address real social and community issues. For example, through their work at one after-school program, students in the YES program learned that a food pantry located in the same building had limited access to fresh produce and instead mostly distributed canned and boxed food to families in need. In response to what they perceived as a community need for more fresh produce, the YES students decided to design and build a greenhouse and garden at a museum-owned green space. Science center staff were called upon to help the YES students learn about and accomplish their goals.

The project involved research, measurement, engineering, and ongoing work to plant and harvest the produce, which they presented to the food pantry throughout the summer. The partnerships between community groups thus provided a real-world application of science and math skills, as well as a way in which students could become more connected with each other and their community.

YES provides participating students with a community of peers that is dedicated to both supporting the local community and also to developing their own individual trajectories through high school graduation and into college. The program has documented a 95 percent high school graduation and college admissions rate against a city average of less than 60 percent.

The YES program raises questions about how science-rich cultural organizations can not only provide rich science experiences, but also leverage these programs to connect with other community venues, both to develop participants' understanding of science as a tool that can be used to support people and places in local communities, and also as a mechanism to strengthen ties between science-rich cultural institutions and local audiences who may not otherwise come to use or know them.

Type 4: Sustained Teacher Learning Communities

These programs have been co-designed to address teacher classroom practices through sustained, multi-week professional development programs. Programs address different combinations of conceptual understanding, classroom strategies, and STEM lessons/activities for the classroom. They are not tied to teachers' use of the informal setting or to specific mandated curricula for students, but rather to the teachers' own professional development and capacity. Equally important seems to be the development or strengthening of teachers' identities as capable and committed STEM teacher leaders and participants.

Da Vinci Science and Discovery Center, Allentown, Pennsylvania

The Da Vinci Teacher Leader Institute is a partnership between the Allentown School District, Cedar Crest College, and the Da Vinci Science Center. Teachers from several other regional districts have also been involved. The goals of the partnership are to increase teachers' content knowledge, ability to use inquiry in the classroom, and leadership activities, with the ultimate goal of increasing student science achievement. The project, funded through a USDOE Math Science Partnership, has shown positive impacts in all of these areas.

A group of Da Vinci Fellows Meet in the Da Vinci Science Center to read and comment on science notebooks from each other's students as part of an investigation of how students express understanding in their notebooks. *Photograph by David Smith*

The project is organized around collegial networks, involving Da Vinci *Fellows* and Da Vinci *Peers*. Fellows participate in content training at the science center, and then provide ongoing professional development to their colleagues, who become Peers, at their various school sites. Since 2004, the project has served more than 300 teachers.

Each year, Fellows participate in 85 hours of professional development workshops, mostly during an intensive two-week summer institute at the science center. The subject matter changes each year and includes physical science, life science, or earth science. Most workshop activities or inquiries begin with the Allentown elementary science curriculum FOSS kits, but the goal is to move beyond the curriculum to engage teachers in learning the science content themselves at an adult-appropriate level.

Back at their school, Fellows recruit their colleagues to participate as Peers in a science teaching professional learning community (PLC) led by the Fellow. Each PLC identifies and focuses on a question or issue related to the needs of their school—for example, through learning how to use science notebooks to advance literacy goals on a school-wide basis. Peers and Fellows attend two workshops at the science center. These workshops feature activities that can be more directly applied to the classroom, but are still oriented toward supporting teachers' abilities to deeply implement their existing science curriculum. Teachers who participate in the program also receive free field trips and outreach programs from the Da Vinci Science Center, thus reaching many students from Allentown, a poor urban district, with new experiences and opportunities to engage with science in informal settings.

The summer institute and school year workshops are taught by a team consisting of science content faculty from Cedar Crest College, exemplary elementary teachers from the Allentown School District, and professional development experts from the Da Vinci Science Center. The faculty keep the content rich and current, the teachers keep the team focused on what teachers need to perform better in their classrooms, and the professional developers from the science center keep the team focused on the adult learning needs and styles of the participants. Project leaders report that this sometimes contentious triangulation of perspectives has contributed significantly to the rigor and quality of the project.

MSP, Da Vinci

Structural Features	Social Features
Sequenced activity units	Sustained relationships
Assessed	Learner-directed
3-D or hands-on objects	Collaborative learning
Multi-modal activities	Connections to school STEM
Professional scientists	
Professional training	
Documented Outcomes	
School performance	

For example, in 2005, the university life sciences faculty led an experimental activity involving seed germination observed that teachers' investigations were simplistic and often mixed multiple variables. When the workshop was repeated three years later, the Da Vinci Center professional developer integrated the use of "inquiry boards,"[5] which allowed teachers to significantly deepen and improve their questions. The school faculty worked with teachers to consider how they might integrate this tool into their classrooms.

Each year, Fellows have shown a statistically significant gain in content knowledge on nationally-normed conceptual inventories (such as DTAMS and MOSART)[6]. Peers have also shown statistically significant gains in most years. Often the gains are small, however, and the project reports struggling to balance the time to do deeper inquiry with the desire to support teachers across the breadth of the curriculum. There is tentative evidence that portions of the Da Vinci workshops that are rated higher on the RTOP assessment of inquiry-based teaching practices may result in greater gains on the corresponding portions of the content tests.

5 Inquiry boards are graphic organizers that use post-it notes to isolate questions, hypotheses, variables, and other elements of investigations. They allow students or teachers to review the different steps and dimensions of their investigations before deciding whether designs are appropriate.

6 Diagnostic Teacher Assessment for Math and Science, Misconception Oriented Standards-based Assessment Resource for Teachers

One of the major efforts of the science center's professional developers in the last few years has been to explicitly try to help content faculty shape their content lessons to include more and better inquiry practice. They have seen this effort pay off in improved evaluations of workshop sessions by the project's external evaluator.

In addition to content gains, both Peers and Fellows show statistically significantly higher practices of inquiry (based on RTOP observations of science lessons) than comparison teachers in similar schools (average RTOP for Fellows and Peers =80/100, average comparison = 40/100). This is the most dramatic effect and it shows up most dramatically in the second year of a teacher's participation.

A question this project raises is how informal science institutions bring specific, and replicable, value-added to work traditionally led by universities and school districts, and whether a national network of such efforts could support school systems across the country.

CLUSTER, New York, NY

CLUSTER is an NSF–funded teacher preparation program led by the New York Hall of Science (NYSCI), the City College of City University of New York, and City University of New York's Center for Advanced Study in Education. CLUSTER responds to a city-wide need by focusing on both the recruitment of cultural minority teacher candidates and the incorporation of inquiry practices into the classroom. In addition to completing state-mandated courses, preservice teachers enrolled in the program at City College participate in a paid internship at NYSCI. At the museum, they work as Explainers for 150+ hours, interact with public and school group visitors, and participate in weekly training sessions. CLUSTER, which involves preservice secondary teacher training in both formal and informal environments, has documented ways in which it has supported expanded use of inquiry methods in the classroom by new teachers.

Training at the museum focuses on the science content of the exhibits, different approaches for engaging visitors, various presentation styles and strategies for relating the content to the visitors' daily life, and reflective practices. The rigorous training and associated opportunities to interact with visitors builds participants' capacities to experiment with and refine their teaching practices. For example, one of the preservice teachers, when conducting a cow's eye dissection for a group of 11th grade students, was directly confronted by a student who yelled out, "Miss, you think we are so smart, but we don't know what you are talking about." The low-stakes context both gave the student "permission" to speak out, and also allowed the teacher to "hear" the complaint without putting her authority at risk. The program has documented how this reflective moment led the preservice teacher to become more aware of when and how to introduce science words into her demonstration, which she was then able to test through multiple opportunities to conduct the same demonstration with different audiences over time.

CLUSTER

Structural Features	Social Features
Sequenced activity units	Sustained relationships
Assessed	Low-stakes
3-D or hands-on objects	Collaborative learning
Multi-modal activities	Connections to school STEM
Professional training	Connections to everyday STEM
Documented Outcomes	
School performance	

Although the number of CLUSTER participants is small (n=43), early results suggest that CLUSTER graduates improve in their understanding of inquiry pedagogy, although not in their understanding of science content. In a comparison study of student teaching observations, CLUSTER students were found to engage student interest more successfully than students in another teacher preparation program at the same college. As of Fall 2008, a majority of CLUSTER students were from populations that are underrepresented in science (e.g., 59 percent female; 87 percent from minority groups, including Black, Hispanic, Asian/Pacific Island, West Indian, Other).

A question this project raises is whether alternative and low-stakes teaching environments, where science is more broadly defined and portrayed than in many classroom curricula, can help to "inoculate" new teachers against narrow conceptions of science, and how this would play out over their teaching careers. Additionally, we wonder how preservice programs might more consistently make use of such environments, while at the same time building connections to school science.

CREI, National Museum of Science and Technology Leonardo Da Vinci, Milano, Italy

In 2009, the National Museum of Science and Technology Leonardo da Vinci in Italy launched CREI, the Centre for Research in Informal Education. Building on the museum's history of working with teachers, CREI is designed specifically to support the integration of inquiry methods into the science classroom. CREI provides teachers' workshops, institutes, classroom resources, activity designs, and regular after-school discussion groups. Among the several long-standing projects that contributed to the creation of CREI were Open Schools (Scuole Aperte) and Educate in Science and Technology (EST).

Teachers participate in a CREI training course in the Genetics Interactive Lab of the National Museum of Science and Technology Leonardo da Vinci, Italy. *Photo courtesy National Museum of Science and Technology*

Open Schools is a project developed in response to the Ministry of Education's plans to institute more community after-school programs at school sites. Open Schools works with teachers from about 100 schools to support the inclusion of inquiry-based science in their new school-based after-school programs. The museum provides professional development courses, education kits, and support in integrating a learner-centered hands-on and inquiry-based approach to science programs. Open Schools stresses teachers' direct experimentation, encouraging them to learn through personal experience and critical reflection on the content and methodology of the activities.

Open Schools is the first program at the National Museum that does not include students' field trips to the museum, but rather works directly for the development of an inquiry "culture" in the school itself. As such, it invests in building structural and social properties in the programs that can be sustained over time. In addition to professional development courses and resources, the program has engendered relationships among the school teachers and museum staff that have spilled over the bounds of the project, leading to the establishment of a set of scheduled meetings where formal and informal educators can discuss and test activities that will be used both in the after-school and sometimes the classroom setting.

EST, a partnership with another project of the National Museum of Science and Technology Leonardo da Vinci, the Museum of Natural History of Milano, the Regional Office for Schools, and the Regional Authority for Lombardy, is funded by the Cariplo Foundation. Between 2004 and 2009, EST worked with 3,000 teachers in 1,000 schools of the region, involving many more museums in the same territory. The challenge was to reach an ambitious number of schools and teachers and at the same time establish personal, long-term, and personalized collaborations with each one of them.

EST consists of four interrelated elements: a) teacher training; b) work in the classroom using museum resources; c) visits to museums; d) project-based learning as the teaching and learning framework in which the other activities of the project are integrated (Xanthoudaki, Tirelli, Cerutti, & Calcagnini, 2007). The principal aim of the project has been to improve the quality of, and approach to, science education at school by building on teachers' professional development, inquiry-learning methodologies, and museum- and classroom-based resources.

CREI

Structural Features	Social Features
3-D or hands-on objects	Sustained relationships
Multi-modal activities	Low-stakes
Professional training	Collaborative learning
	Connections to school STEM
Documented Outcomes	
Teacher attitudes Teacher interests	

Each of the involved museums developed activities and resources focusing on one or more science and technology topics. The National Museum of Science and Technology Leonardo da Vinci built three new interactive labs on telecommunications, robotics, and biotechnologies. The labs offered an experimental context in which teachers (in training) and students (in field trips) were able to follow inquiry-base learning activities and run experiments. Experience in the labs was also considered as the base for, and related to, additional resources for work at school. Educational kits focusing on the same topics were given for free to each teacher with tools and materials for activities in the classroom. Museum staff also visited students at school in order to run more activities with them.

The central element of EST has been the teacher as an agent of change. Although the principal objective of the project addresses students and their relationship with science, the program works with teachers as the focal and pivot point for reaching young people. Teacher training workshops have been centered on first-hand experiences. Hands-on and cooperative learning, observation, and evaluation of outcomes are some of the methods used, encouraging teachers to learn through personal experience and practice. Using a train-the-trainer model, participating teachers worked in small groups focusing on one topic, and later engaged their school colleagues in the same or similar efforts.

The project included documentation of the joint work of teachers and museum staff both in museums and schools, focusing in particular on teachers' and museum educators' perceptions of change. Data, collected through observations, interviews, and questionnaires, documented how EST changed practice and attitudes towards science as well as how teachers themselves changed their approach to teaching science, especially through the use of museums. The final evaluation report is expected in 2010. Some of the main outcomes of the documentation argue that:

- addressing teachers as learners and as reflective practitioners offers substantial support to their professional development as educators and facilitators of students' learning, with long-term sustainable effects;
- teacher-training courses based on inquiry and action research have been decisive in helping teachers overcome feelings of self-limitation or skepticism towards experimental approaches to science teaching, away from the consolidated book-based approach;

- using objects (including museum or everyday objects) and tools of science for creating authentic questions and problems strongly contributes to the use of an inquiry-based approach in science education;
- the museum is a powerful teaching and learning resource, the benefits of which go beyond the one-off field trip to a "science wonder-full" setting. If seen within a long-standing collaboration that helps setting goals and methods, the museum becomes a permanent tool for the delivery of the curriculum and the development of science-related knowledge, skills, and attitudes for young people.

This project exemplifies how museums can provide external supportive structures for teachers and school systems that are highly centralized, including as professional development nodes connecting schools and after-school programs. Better understanding which teachers elect to participate in the programs and how their participation may change their teaching would help the field to generalize from the successes of this program.

Type 5: District Infrastructure Development

These programs represent joint district-informal efforts to address infrastructural elements of the local school systems. Museum schools, of which there are over two dozen in the United States (Phillips, 2006), are one significant example of such efforts. Building district capacity to design and lead inquiry-based professional development, or training and supporting lead teachers, is another approach. Additionally, some science-rich cultural institutions participate in district or state-wide standards or assessment committees. These intensive collaborations may be the places where the most compromise is needed, where the two cultures come face to face, and where significant changes in practice in both cultures have the potential to result in a hybrid culture.

Alexander Science Center School, Los Angeles, California

In 2004, the California Science Center (CSC) partnered with the Los Angeles Unified School District to open the Dr. Theodore J. Alexander, Jr. Science Center School. This K-5 affiliated charter school uses a lottery process to ensure that at least 70 percent of students are from the underserved neighborhood surrounding Exposition Park, where the science center is located. The population of 620 students is roughly two-thirds Latino and one-third African-American. More than three-quarters of students participate in the free or reduced price lunch program. School performance data show that students in the Science Center School outperform demographically matched peers on state tests.

Students build sailboats at the water works experimental platform at the Science Center's Big Lab. *Photo courtesy Alexander Science Center*

The school's approach is to integrate science, mathematics, and technology into a language arts, social studies, and fine arts curriculum. The partnership allows teachers and students regular access to the resources of the science center—exhibits, programs, materials, and professional staff. Curriculum and programs are developed and implemented collaboratively between the school's teachers and CSC staff, who meet on a monthly basis.

The collaboration builds on the strengths and affordances of both partners. The science center draws on its collections, inquiry pedagogies, and facility with forming partnerships to co-develop a K–5 curriculum that engages students in multiple modes of learning. Teachers in the school incorporate activities, materials, and field trips into their curriculum to engage students in standards-based district-mandated studies. The school stresses the everyday relevance of science and the natural world, drawing on formal and informal experiences. For example, fifth graders take an annual 4-day trip to nearby Catalina Island, chaperoned by teachers, science center staff, and parents, where they explore local ecologies. The trip is a culmination of a year-long course of study that builds on science center exhibits, investigations in its Big Lab, text-based studies in the classroom, and local field trips where students experiment with water activities involving swimming, kayaking, and other experiences they will be encountering in Catalina, sometimes for the first time.

Ongoing professional development for teachers includes science content and teaching methods that integrate inquiry and learner-driven teaching strategies. In recognition of the role that families play in student academic achievement, parents receive mentoring, special workshops, and free family membership in the science center so that new opportunities for science learning may go beyond the school day.

Alexander Science Center

Structural Features	Social Features
Sequenced activity units	Extended relationships
Assessed	Collaborative learning
3-D or hands-on objects	Connections to school STEM
Multi-modal activities	Connections to everyday STEM
Professional training	
Documented Outcomes	
School performance	

Leaders discuss the challenges to developing a hybrid institutional culture, including reliance on vision setting and flexibility through the district office as well as from the science center staff. To date, outcomes have focused on student academic performance as demonstrated by standardized, criterion-referenced and performance-based tests. For example, recent findings from the Academic Performance Index suggest that Science Center School students scored significantly higher for proficiency in English language arts, math, and science than students in comparable schools with similar demographics. An extensive multi-year evaluation of both student and teacher performance is forthcoming.

The work and collaboration of the Alexander Science Center School make us wonder about the development of different kinds of hybrid practices among both the school and the science center staff. How is this collaboration changing expectations, practices, and decision-making at the level of both staff and administration? What can such schools teach us about schooling?

The Exploratorium Teacher Programs, San Francisco, California

The Exploratorium has two distinct teacher programs, both of which have documented the ways in they have impacted teacher practices. The Exploratorium Institute for Inquiry, which works with district elementary staff developers, has been shown in a triple blind study to have led to greater inquiry practices in the classroom. The Exploratorium Teacher Induction Program (TIP), for middle and high school teachers, has dramatically affected teacher retention rates for new teachers in the San Francisco Bay Area and has contributed to teachers' growth in content understanding and classroom practices.

The Institute for Inquiry, a national professional development program, was initially funded by NSF in 1995. The program built on its prior two decades of work with regional elementary teachers, to begin to support teams of elementary school science professional developers from state and urban systemic school change projects from around the country. Since its inception, over 4,000 curriculum and professional development leaders and lead teachers, representing over 500 school districts, museums, and universities from 42 states have attended workshops at the Institute for Inquiry. Week-long workshops include: Fundamentals of Inquiry, Assessing for Learning, and Classroom Strategies for Teaching Hands-On, Inquiry-Based Science.

Novice teachers building fancarts during a summer workshop on Newton's Laws. *Photo by Linda Shore*

Institute for Inquiry participants engage in a number of inquiry activities that can be replicated in professional development workshops back in their home districts. Special attention is paid to the facilitation of inquiry workshops for adults, with a focus on the materials, pacing, and pedagogical strategies that can not only engage adults in learning inquiry, but can prompt reflection and discussion about how such activities could be integrated into the elementary classroom as part of district-wide shifts to make science more inquiry-oriented. External evaluation found that professional development leaders from districts that had participated in the Institute for Inquiry program revealed greater depth of understanding of inquiry, had more sophisticated professional development designs, and were "clearly and statistically distinguishable" from their comparable counterparts.

Exploratorium Teacher Programs

Structural Features	Social Features
Sequenced activity units	Sustained relationships
3-D or hands-on objects	Learner-paced
Multi-modal activities	Low-stakes
Professional scientists	Collaborative learning
Professional training	Connections to school STEM
	Connections to everyday STEM
Documented Outcomes	
School performance	

In 1999, the Exploratorium started a middle and high school science teacher induction program (TIP) in collaboration with the San Francisco Unified School Dustrict and San Mateo County Offices of Education. TIP, which has served 375 teachers to date, provides novice science teachers with a two-year professional development program consisting of a menu of supports. The program is funded by NSF and several private foundations.

TIP is the first part of a developmental, staged, multi-year program that begins with teacher induction, progresses through mid-career support, and concludes with teacher leadership training. Some program components (such as classroom management or working with parents) specifically support TIP novice teachers, but many components are integrated so that novices are working alongside experienced and veteran teachers. Over two years, the TIP program provides 400 hours of supports including intensive summer institutes, weekend content workshops, peer support groups, classroom coaching, and mentoring led by veteran teachers who have graduated from the Teacher Institute's Leadership Program. TIP was developed in response to changing demographics in California's classrooms, with increasingly young and out-of-field teachers being placed in science classrooms, due to massive retirements and a "revolving door" which saw more than half of teachers leaving the field within their first three years in the classroom. The theory behind TIP is that new teachers need not only content, pedagogical strategies, and classroom coaching, but they also need a community of like-minded teachers committed to high-quality science teaching that can help to sustain their vision and commitment to the practice.

A five-year evaluation of TIP found that after completing the two-year induction program, over 90 percent of the novice science teachers remain in the teaching profession (compared to 50 percent retention rate typically reported in participating Bay Area school districts). In addition, novice science teachers reported higher levels of confidence in their ability to plan and create science lessons and more frequent use of investigative teaching practices than a control group of novice science teachers. They also reported that their knowledge of science concepts, modes of scientific inquiry, and the richness of their instructional repertoires increased over the course of the program.

Both of these programs illustrate ways that science-rich cultural organizations can become embedded components in systemic efforts to make changes in districts, at multiple levels throughout the district. The informal educational environments, which are dedicated to and animated by inquiry-based learning, may help to create a grounded vision of what districts are aiming for (science-engaged children), and a belief that the vision is realizable. It would be important to understand how locating these professional communities outside of the district infrastructure, in science-rich settings, affects participants' vision and commitment.

LASER, Seattle, Washington

For nearly a decade, the Pacific Science Center (PSC) has demonstrated that informal education institutions can play key roles in K–12 statewide science education reform. Though its leadership of the Leadership and Assistance for Science Education Reform (LASER) program, PSC identified 10 LASER Alliances that provided professional development to 20,000 teachers, often providing each teacher with at least 54 hours of professional development over the course of three years. In addition, PSC staff has vetted new science curriculum and developed science education materials for use across the state of Washington. Evaluation of state test scores has shown that student gains correlated with teacher participation in LASER.

School district leadership teams at a Washington State LASER Strategic Planning Institute. *Photo by Dennis Schatz.*

LASER is one of eight regional sites across the country that has disseminated and implemented the adoption of NSF funded inquiry-based science curriculum materials through an Implementation and Dissemination grant to the National Science Resource Center (NSRC). PSC has collaborated with statewide education officials to help establish and support a state infrastructure to sustain the adoption of curriculum funded by NSF (e.g., STC, FOSS, SEPUP)[7]. PSC leads the LASER program in Washington by coordinating the participation of a network of LASER Alliances across the state that provide regional support to teachers and school systems. PSC brings to the collaboration a statewide reputation as a site for engaging and inquiry-based learning. PSC thus appeals to teachers through leveraging the experience and perception that PSC, as a longstanding institution dedicated to firsthand learning in science, is neutral territory in school system politics. The longstanding relationship with the education system, and close understanding of state standards and policies, also means that PSC is seen as a statewide resource to the LASER Alliances, and as such works to support their capacity to be productive contributors to the statewide project.

7 Science and Technology Concepts, Full Option Science System, and Science Education for Public Understanding Program

LASER's teacher workshops stress 1) the content in the elementary curriculum, 2) inquiry-based teaching strategies, 3) the adoption and incorporation of NSF–funded curriculum materials into the classroom, and 4) how to integrate the science curriculum with other subject matter into the elementary classroom.

At the district leadership level, workshops focus on national and statewide trends in science education and science curriculum and assessment. Through attending a LASER Strategic Planning Institute, school-district teams review their resources and assets, develop a mission and vision statement, map to the state standards, discuss standards for collaboration, and identify needs for engaging stakeholders. External evaluation of LASER is generally focused on teacher professional development, teacher classroom practice, and the relationship of these to student academic performance. Findings from the 2007–2008 school year evaluation studies suggested that students with the highest gains were instructed by teachers with a minimum of 18 hours of professional development. Furthermore, student gains were also more closely associated with those teachers who participated in professional learning communities and took time during the day to work on professional development. In future, PSC plans to implement school-embedded professional learning communities where the teachers examine student work and modify their instructional practices based on student outcomes.

LASER is a strong example of how science centers can help to leverage networks to support school systems state-wide. We wonder what particular features of informal science institutions make them effective partners, and how such a system might be replicated in other parts of the country.

LASER

Structural Features	Social Features
Sequenced activity units	Sustained relationships
Assessed	Collaborative learning
3-D or hands-on objects	Connections to school STEM
Multi-modal activities	
Professional training	
Documented Outcomes	
School performance	

Summary

The programs highlighted above represent just the tip of the iceberg in terms of the number and types of formal-informal collaborations one finds around the globe. Furthermore, it is important to note that most informal education organizations provide programs either directly or indirectly to students and teachers, outside of the framework of formal collaborations. The programs we included here, however, represent virtually the entirety of the collaborative programs that we located that have documented participant outcomes. Despite their small number, they provide the science education field with a window into the fact that formal-informal collaborations can be designed to contribute towards

- Advancing students' conceptual understanding in science
- Improving students' school achievement and attainment
- Strengthening students' positive dispositions towards science
- Advancing teachers' conceptual understanding in science
- Supporting teachers' integration of inquiry and new materials in the classroom.

In the next section we discuss the ways in which these collaborations build on the affordances of both formal and informal settings to achieve results that perhaps neither of the partnering institutions could achieve alone.

Part 4: Emergent Themes

A central premise of this report is that both K–12 schools and informal education and science-rich cultural institutions have a vested interest in supporting student and teacher engagement with science, and that their efforts can be enhanced through collaboration with one another.

Schools are concerned with many different subject areas, with the social and emotional development of children, and with community and district policies and needs. Science-rich cultural institutions are concerned with learners of all ages, with stewardship of science resources and collections, and with public engagement with science. Youth and after-school programs are concerned with children's emotional, intellectual, physical, and social well-being. But enabling and enhancing student and teacher engagement with science is the common ground; and the programs we highlighted provide evidence that collaboration can advance the goals and enhance the respective work and impacts of each institutional type in strengthening student and teacher engagement with science.

Part One of this report provided a rationale for the ways in which formal and informal institutions can collaborate. It provided a theoretical perspective that positions purposeful and meaningful social activity as the driver of learning and development. It showed how formal and informal institutions, combining their respective pedagogies and institutional affordances, can provide more authentic, rich, compelling, and sustained science learning activities than they might be able to do acting alone. Part Two of this report highlighted five different types of formal-informal collaborations that build on these institutional affordances to support and sustain participant engagement with science. The programs we highlighted have documented their impacts on participants in terms of conceptual understanding, inquiry skills, dispositions, career awareness and interest, school achievement, and classroom teaching practices.

Five central themes emerge from our review of the programs described in Part Two. We discuss these themes in this section of the report.

Theme 1: Conceptually rich and compelling science learning experiences

The nature of formal-informal collaborations, sustained over time, seems to consistently produce science learning programs, curricula, and experiences that are conceptually rich and compelling to participants. They build on interests, communities, and local resources to capture the imagination, stimulate questions, and drive participants to take up the tools of science to address their concerns or curiosities.

A significant part of this conceptual richness and engagement appears to be the physicality of place, phenomena, life forms, and objects that are deployed to engage attention and imagination on the part of the participants. Whether conducting flora and fauna counts to better know the Calumet region of Illinois, or working with pin-screen exhibits in Shreveport, to explore the meaning of cubic units, the physicality of informal settings can help learners care about and make meaning of abstract concepts otherwise usually encountered in books on screens.

Deeply implicated in the programs we highlighted is the way in which the scientific processes of inquiry emerge naturally as modes of engagement in object-based or place-based programs. Indeed, informal learning environments seem to be places where inquiry can flourish. Much has been written about object-based learning (for an overview, see Paris, 2002). The fact that informal environments possess authentic objects, collections, or phenomena is one obvious reason why inquiry is so deeply associated with them. This raises questions about how schools might more strategically deploy field trips to help children approach concepts through tactile and visual, rather than only verbal, approaches. How would the regular integration of such props, in key conceptual domains, affect student learning? What role does the environment play in such experiences, or could the same exhibits be experienced similarly in classroom settings?

We posit that there are other, perhaps less obvious, affordances, referenced in Part One, that may be even more critical for allowing inquiry practices to blossom—namely, flexible uses of time, low-stakes/non-judgmental contexts, and multiple ways into and modes through ideas or concepts. These elements may support students' affective engagement with the subject matter, leading to the development of genuine and personally compelling questions, creating the low-stakes space that supports exploration and a commitment to the time-intensive processes of inquiry.

The programs we reviewed provide examples of collaborations that seem to indicate that such programs, experienced in informal settings, but deeply tied to, and sustained by, the school curriculum can expand students' opportunities to develop their cognitive-affective relationship with science, gain insight and understanding of concepts that may be more difficult to grasp verbally or to care about in the abstract, and gain views into possible personal pathways or trajectories that they could choose to follow. What role do both affect and cognition play in encountering and developing questions with authentic objects, animals, and settings? Are informal learning environments particularly well equipped to support students' cognitive-affective engagement? How can schools build on this? There are a range of studies that examine the ways in which informal settings engage children's affective and cognitive development (see NRC, 2009), but there are few that examine how these developments manifest themselves in school settings.

Developing and testing our understanding about the role and contributions of the social affordances of informal learning environments would clarify why the same objects or phenomena in the school classroom might be experienced or investigated differently than they would be in the informal environment. It would also provide informal learning institutions with guidance on what features they need to further develop, or to protect and sustain, in the face of institutional changes.

Theme 2: Boundary-Spanning Science Learning Communities

A second consistent theme in the programs we reviewed is the way in which formal-informal collaborations are organized around communities of learners, sometimes multi-generational (as in SCFG) and other times multi-institutional (as in LASER). These communities of learners establish shared valued purposes, and provide social and physical places for students and teachers to develop practices, dispositions, and understandings that they can use across multiple settings.

Some programs, such as YES, TIP, and SCFG have intentionally created communities as foundational design elements. But in other cases, where the foundational design elements are access to resources or settings (such as Urban Advantage or CEEP) or rooting science studies in local community practices (such as SPARK or Science Centre in School), program directors reported anecdotally that learning communities have emerged as a driving force for participants. Affiliation with the communities, at an affective, intellectual, and social level, they reported, sustained participation and commitment to the programs and to the core themes and subject matter the programs addressed.

The involvement of science-rich and community settings perhaps creates new possibilities for such communities. First, it grounds the activities and the relationships in physical spaces dedicated to the study of science, possibly generating a more deeply affective connection with the subject of study. Second, it underscores the connections between what is being done and learned inside classrooms to what is being done and learned beyond the school walls, illuminating both immediate purposes of the subject of study and also possible longer term trajectories in terms of careers or academic choices. We speculate that programs situated in science-rich settings may have the potential to help teachers or students begin to grapple with epistemologies of science in ways that more disciplinary-neutral settings cannot. All of these conjectures must be tested.

But beyond the notion of the emergent community of learners, which are powerful in their own rights, these programs suggest possible ways of organizing community resources at a systemic level, mapping onto the institutional affordances of the different community settings. The CLUSTER project, for example, provides a model of a low-stakes, multi-modal informal setting being leveraged to support the development of more flexible and perhaps more broad-minded conceptions of science for science teachers. The LEAP program shows how libraries can build on flexible timeframes and boundary-spanning objects such as kits to provide drop-in and lending materials to advance science engagement and learning. In what ways can informal environments, including the after-school setting, be better leveraged as preservice teacher development sites? This also begs the question about how communities, including school systems, can develop better and more integrated systems for, or habits of, understanding how science interest and learning that develops out of school is brought to and capitalized on during school.

There are a range of researchers working on questions and problems related to learning communities, identity development, and place-based learning (Bekerman, Burbules, & Silberman-Keller, 2006; Leinhardt, Crowley, & Knutson, 2002; Mahoney et al., 2005), but not often from a systemic perspective of making change happen at an macro-institutional level. The point our inquiry group grappled with is how to imagine, build, and test such a system at scale.

Theme 3: A Commitment to More Inclusive Science

A third theme we see across more than half of the programs is an explicit commitment to engaging students, and teachers of students, from high-poverty communities in order to expand access and develop a more inclusive science-engaged populace. Indeed a 2007 study of museum programs for schools found that almost half of school audiences, on average, were composed of children or teachers from high-poverty schools (Phillips, et al., 2007). This stands in stark contrast to typical general admission demographics, which find museum-goers to be typically white, college-educated, and middle class.

This contrast indicates the essential role that formal-informal collaborations can play in expanding the reach and opportunities of science-rich cultural institutions to children from communities who may not otherwise access the resources or sites. In this sense, expanding formal-informal collaborations becomes an issue of equity and access.

Youth, after-school, and library programs are already serving children from high-poverty and underrepresented communities. Expanding their program repertoires to include science provides their audiences with opportunities to develop interest and capacities that can allow them to access new academic and career trajectories, as well as develop lifelong engagement with a variety of subjects.

Although the programs that we highlighted did not study this issue specifically, we conjecture that some of the affordances of informal settings are particularly likely to support more inclusive participation in science learning. Studies have found that children from high poverty and cultural and linguistic minority communities find science to be alienating, boring, and difficult (Nasir et al., 2006; Tobin, 2006). The authenticity of setting and objects, the connections of many programs to local communities and community needs and resources, and the more learner-centered approaches to science teaching and learning can operate to make science more accessible and appealing. Some studies have documented these effects in the informal setting (National Research Council, 2009), but few have traced how these effects contribute to or interact with science learning in the formal setting.

Theme 4: A Lack of Documentation and Evidence

While there is substantial evidence that there is a great deal of formal-informal collaboration, there is substantially less evidence related to the outcomes of these collaborations.

Many programs are evaluating the experience that their program provides teachers or students (whether they understood, were engaged, liked, thought that they would use), but extremely few are evaluating whether the experience translates to changes in practice, or anything else, outside of the program. Even in the few cases where programs had impact evidence, much of the time that evidence was collected in ways that did not reveal the particular strengths and contributions of the institutional partners and therefore could establish the value of the collaborations. Whether, for example, the museum or youth aspects of the program changed thinking and practice was not as closely considered as whether or not the inquiry experiences (which could be offered by formal institutions as well) were impactful. The levels of reliability and validity associated with the different data collection methods are widely varied.

A major challenge to the field, as noted by the recent NRC report (2009), is that existing measures of change and impact have not been designed to take into account the values and contributions that science-rich cultural institutions and youth development programs bring to science learning. School tests are attuned to specific aspects of schooling, and not necessarily to deeper conceptual understandings, inquiry practices, or career interests. There is a pressing need for the development of appropriate methods for uses in informal environments—methods of assessment that do not fundamentally alter or confound the experience of learning in non-school settings, but do identify and describe measures of learning that have valence to both formal and informal stakeholders. There is significant theoretical and methodological work needed to identify these measures and how they may map to standard measures used in schools (e.g., test or achievement scores) and informal settings (e.g., levels of active engagement and positive dispositions).

Theme 5: The Challenge and Benefits of Collaboration

Collaborations, by definition, require substantially more time and resources than projects undertaken by just one organization. Almost all of the programs highlighted here shared with us some of the struggles that they had in developing and maintaining their collaborations. But seldom do funders recognize or support this extra layer of work. Collaborators are not only embroiled in designing, implementing, and assessing their programs—they are struggling with new cultures, uses of language, expectations about time and documentation, protocols, people, and practices. School personnel are often subject to more complex systems of administration and hierarchies and therefore may have less flexibility or autonomy. Informal educators may have less familiarity with the pressures or constraints that school personnel must address from their many constituents, ranging from children to parents to community and government stakeholders. At the same time informal education, as a field, is underpaid, more transient and precarious, and less clearly a recognized professional track. This creates more instability in the system.

These constraints are not easily overcome and will usually take years to work themselves through. During that time, key personnel may move to new positions, and the work of building relationships must begin anew. At the same time, leaders of the highlighted programs anecdotally remarked on the great professional strides they have made at individual and also institutional levels through collaborating with colleagues from other types of institutions. Something we heard consistently was the way in which formal-informal collaborations benefited staff at the informal learning institutions. Staff at science-rich cultural organizations talked about what they had learned about children, by spending more consistent time with the same group of children, and about teaching, from working with teachers to construct coherent science learning activities that unfolded over a period of weeks. Some reported how their work with teachers and school systems had led them to better understand current theories of learning, current research, and current educational policies that impacted their work. A study conducted by the Center for Informal Learning and Schools showed statistically significant growth in staffing and budgets when science-rich cultural institutions reported that they were collaboratively developing their school programs with school personnel, and when they were evaluating impacts in terms of changes in the school (not necessarily test scores) (http://cils.exploratorium.edu/cils/page.php?ID=134). We speculate that close collaboration with schools prompts reflection and challenges informal educators to think more deeply about how their work connects into the larger timeframes and trajectories of people who come through our doors, sometimes for just a few hours in a year. The vast body of research and policy conducted around school science in some cases might help informal educators more carefully hone and direct their efforts.

NSF has made investments in large-scale centers to better understand and explore the potential of learning across formal and informal contexts. The LIFE (Learning in Informal and Formal Environments) Center, Center for Inquiry in Science Teaching and Learning (CISTL), and Center for Informal Learning and Schools (CILS), are three multi-year, multi-million dollar investments in research, development of young scholars, and professional community that address different aspects of many of the issues raised in this report (as well as many not addressed here). The European Union (EU) also funds cooperation between formal education institutions and informal learning settings. For example, in 2001 the EU funded the School-Museum European Cooperation project to focus on the use of museums and science centres as resources for school science teaching and learning, by supporting collaborations among museums, schools, and teacher-training institutions from eight countries. The project resulted in activity designs, classroom resources, and museum programs for students as well as in-service training course School and Science Museum: Cooperation for Teaching, Learning and Discovery. The course is currently in its fifth edition and is run by an international group of experts. A central feature is that it includes both school teachers and informal/museum educators from all EU-member countries. This offers the opportunity for educators coming from different institutions to work together on common goals, exchange experience and expertise, and explore the potential of shared, structured, and sustained collaborations. In 2004, the EU funded a 13-nation formal-informal collaboration called PENCIL. This effort produced a number of program innovations and evaluation studies that showed how the informal institutions supported student motivation, understanding, and interest (Permanent European Centre for Informal Learning, PENCIL, 2009).

Despite these impressive system-level examples, the walls between formal and informal learning professional fields are only beginning to crumble. There is too little transfer of practice, learning, and community. People developing life sciences curriculum for middle schoolers are often unaware of the work being done by museum exhibit developers or zoo educators on developing approaches and pedagogies to engage learners with core themes and questions. And similarly, informal educators are largely unaware of research findings related to classroom work on mutual topics or audiences of interest. Educators in formal-informal collaborations are at the frontlines spanning these boundaries. More research is needed to document the ways in which collaborations among institutions create communities of learners at the institutional level, and how this may change institutional priorities and programs.

Summary

We identified five recurrent themes that ran through the formal-informal collaborations that we highlighted in Part 3:

1) Formal-informal collaborations lead to conceptually rich and compelling science learning programs that build on both the structural and social affordances of informal settings and objects.
2) Formal-informal collaborations have led to the creation of learning communities that could develop practices, dispositions, and understandings that are of value across multiple institutional settings and boundaries.
3) Formal-informal collaborations have created more equity and access for children, and teachers of children, from high-poverty communities.
4) There is a lack of strong, valid, and meaningful evidence of the impacts of formal-informal collaborations, largely due to the lack of a well-theorized methodology that captures and describes impacts that have valence to both formal and informal stakeholders.
5) Formal-informal collaborations take significant time and energy, often unacknowledged by sponsors of the work, but are a continuing but valuable process of evolution for participating individuals and institutions.

We present these themes not as conclusive findings, but as preliminary observations, all of which need to be subjected to more rigorous experimentation and research. While there is a good deal of research looking at different elements or aspects of these themes, little of the research (with the notable exception of the work of the LIFE Center) is taking a systems perspective to understand how interest, learning, and commitment develop across time and space, and incorporate both formal and informal learning opportunities and institutions.

Part 5: Conclusion

We began this report with the observation that current understanding about science learning points to the importance of developing and better understanding the potential of formal-informal collaborations to more inclusively engage children, ages K–12, in science and science learning. These trends are:

1) Scientific literacy involves a rich array of conceptual understanding, ways of thinking, capacities to use scientific knowledge for personal and social purposes, and an understanding of the meaning and relevance of science to everyday life. No one institution acting alone can achieve the goal of developing science literacy.
2) Learning, and the development of a sustained commitment to a discipline, develops over multiple settings and timeframes. Lack of collaboration across settings can create barriers to learning and development.
3) Science education, as it is traditionally constituted, fails to engage and include a significant portion of society; most notably, women and people from high-poverty and non-dominant communities are underrepresented in science professional, academic, and organized leisure-time activities.

Using a theoretical lens described in Part One, we reviewed a number of formal-informal collaborations that showed evidence that they had impacted participants in terms of conceptual understanding, inquiry skills, dispositions, career awareness and interest, school achievement, and classroom teaching practices. We grouped these programs into five clusters: 1) Supplementary classroom enrichment, 2) Integrated classroom resources, 3) Sustained student learning communities, 4) Sustained teacher learning communities, and 5) District infrastructure development.

The programs drew on different affordances, both structural and social, both formal and informal. Most but not all used three-dimensional objects or immersive experiences to engage participants, but some of the most highly structured programs did not use exhibits or 3-D objects at all. Many, but not all, relied on the sense of place to engage participants in cognitive and social commitments to the programs. Some used the low-stakes environments of informal settings to encourage risk taking and experimentation. Others did not draw on this affordance at all. Some were sequenced and assessed, others were more flexible in allowing participants to develop their own agenda for activity and did not formally assess learning outcomes beyond self-reports. We found that five themes ran through the programs we highlighted:

1) Formal-informal collaborations lead to conceptually rich and compelling science learning programs that build on both the structural and social affordances of informal settings and objects.
2) Formal-informal collaborations have led to the creation of learning communities that could develop practices, dispositions, and understandings that are of value across multiple institutional settings and boundaries.
3) Formal-informal collaborations have created more equity and access for children, and teachers of children, from high-poverty communities.
4) There is a lack of strong, valid, and meaningful evidence of the impacts of formal-informal collaborations, largely due to the lack of well-theorized methodology that captures and describes impacts that have valence to both formal and informal stakeholders.
5) Formal-informal collaborations take significant time and energy, often unacknowledged by sponsors of the work, and are a continuing but valuable process of evolution for individuals and institutions.

We have thus tried to show that formal-informal collaborations can be powerful mechanisms for building engagement and understanding in science. They build on the different, but often complementary, affordances of both formal and informal institutions to create science learning programs that are accessible, authentic, and conceptually rich.

We close this report with five recommendations:

1) Expanding the research base. There is a need for more studies of existing and robust programs, studies that address the different issues we raise above, and studies that take a systems perspective to understand how learning in formal or informal settings affects the other.
2) Addressing funding barriers. There is a need for more funding for formal-informal collaborations. Many current funding agencies have difficulty knowing how to classify these hybrid programs, and as a consequence they oftentimes fall between the cracks of funding categories. Funders need to look to the goals of the projects (enhanced teenage understanding of science, or improved teaching practices, for example) rather than the mode. The mode of work is what needs expansion and experimentation. In peer review panels, this means that panelists must be selected who have an understanding of both formal and informal environments.
3) Expanding professional development for informal educators who work with formal audiences. There is a need for more professional development for informal educators that addresses the nature of work with schools and teachers, including school policies, assessment policies and trends, theories of learning, and program design and evaluation. More teacher preparation programs should include introductions to informal learning institutions, resources, pedagogies, and people.
4) Expanding systems perspectives and programs. There is a need for more program experiments that test models of systems integration—after-school settings can serve as sites for teacher development and undergraduate training for future behavioral scientists; science-rich cultural institutions providing science pedagogical leadership in after-school or youth settings; or co-development of K–12 science curriculum and activities.
5) Institutionally valuing formal-informal collaborations, and the expertise required to advance them. In the end, there is a need for greater understanding and support within science-rich cultural institutions for work with schools. Too often schools and teachers are seen as a "market" for field trips or other paid programs, rather than as a stakeholder audience. The extent to which science-rich cultural institutions conceptualize themselves as educative rather than entertainment organizations will be reflected in the depth of their collaborations with K–12 schools. A part of being deeply committed to science education must involve working with the more diverse populations of science learners that exist in local public schools and engaging their families in the life of cultural institutions.

There is a great deal of work already happening in formal-informal collaborations. Many people are pioneering new ideas and approaches, some of which were included in this report. Many are increasingly concerned with documenting the results of these collaborations in meaningful and useful ways. We have argued in this report that so long as public opinion polls continue to find that the public, especially the public from communities underrepresented in the sciences, characterizes science as alien, boring, overly difficult, or not directly relevant to their lives, we must increase our efforts in formal-informal collaborations to reach the greatest number of people, for the most sustained amounts of time, in ways that can be achieved at scale.

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