Learning Science in Informal Environments: People, Places, and Pursuits

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People, Places, and Pursuits

Committee on Learning Science in Informal Environments

Philip Bell, Bruce Lewenstein, Andrew W. Shouse, and Michael A. Feder, *Editors*

Board on Science Education

Center for Education

Division of Behavioral and Social Sciences and Education

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First, we acknowledge the support and sponsorship of the National Science Foundation (NSF). We particularly thank David Ucko, deputy division director of the Division of Research on Learning in Formal and Informal Settings, whose initial and continuing engagement with the committee supported and encouraged the development of the report.

We also acknowledge the contributions of participants in the planning process. In particular, a number of people participated in a planning meeting to define the scope of the study. We thank Alan Friedman, New York Hall of Science for chairing that meeting. We also thank Lynn Dierking and John Falk, Oregon State University; Kathleen McLean, Independent Exhibitions; and Martin Storksdieck, Institute for Learning Innovation, for preparing papers to elicit discussion at the planning meeting. The success of the meeting was largely due to the insights provided by the meeting participants, including Sue Allen, The Exploratorium; Dennis Bartels, TERC; Rick Bonney, Cornell Lab of Ornithology; Kevin Crowley, University of Pittsburgh; Zahava Doering, Smithsonian Institution; Sally Duensing, King's College London; John Durant, at-Bristol; Kirsten Ellenbogen, Science Museum of Minnesota; Patrice Legro, Koshland Museum of Science; Bruce Lewenstein, Cornell University; Mary Ellen Munley, Visitor Studies Association; Wendy Pollock, Association for Science-Technology Centers; Dennis Schatz, Pacific Science Center; Leona Schauble, Vanderbilt University; Marsha Semmel, Institute of Museum and Library Services; Cary I. Sneider, Boston Museum of Science; Elizabeth Stage, Lawrence Hall of Science, University of California, Berkeley; David Ucko, NSF; and Ellen Wahl, Liberty Science Center. Following the planning meeting Julie Johnson, Science Museum of Minnesota, consulted with the project to help assemble the committee.

Over the course of the study, members of the committee benefited from discussion and presentations by the many individuals who participated in our four fact-finding meetings. In particular, our initial framing of the domain of science learning in informal environments underwent significant revisions and refinements as a result of the scholarly and thoughtful contributions made by the background paper writers, presenters, and responders. At our first meeting, Lynn Dierking, Oregon State University, gave an overview of the informal learning field in science, technology, engineering, and mathematics. Shalom Fisch, MediaKidz Research and Consulting, discussed the effects of educational media. Sheila Grinell, Strategic Designs for Cultural Institutions, spoke about the recent evolution of practice in informal science. George Hein, Lesley University and TERC, discussed the need for the field to be both cautious and bold. Jon Miller, Northwestern University, described a framework for understanding the processes through which children and adults learn about science, technology, and other complex subjects.

The second meeting included a diverse set of presenters. Maureen Callanan, University of California, Santa Cruz, described the sociocultural and constructivist theories of learning. Kevin Dunbar, University of Toronto, summarized the cognitive and neurocognitive mechanisms of science learning and how they play out in informal environments. Margaret Eisenhart, University of Colorado, Boulder, discussed the aspects of informal learning environments that afford opportunities to underserved or underrepresented populations. Leslie Goodyear, Education Development Center, Inc., and Vera Michalchik, SRI International, presented methods and findings from evaluations of informal programs that serve underrepresented or underserved populations. Kris Gutiérrez, University of California, Los Angeles, gave specific examples of how informal learning environments serve diverse populations. Karen Knutson, UPCLOSE, University of Pittsburgh, discussed views of learning science in informal environments inherent in programs and evaluations. K. Ann Renninger, Swarthmore College, gave an overview of theories of motivation and how they map to learning in informal environments.

At the third meeting, the committee heard evidence about the science learning that takes place in various informal venues and pressing policy issues in the field. Bronwyn Bevan, The Exploratorium; Christine Klein, an independent consultant; and Elizabeth Reisner, Policy Study Associates, participated in a panel discussion of current policy issues in informal learning environments. Deborah Perry, Selinda Research Associates, Inc., described how exhibits and designed spaces are constructed for learning science. Saul Rockman, Rockman Et Al, discussed the evidence of science learning from traditional forms of media. Bonnie Sachatello-Sawyer, Hopa Mountain, Inc., gave an overview of the design and impact of adult science learning programs.

At the fourth meeting, the public session was concerned primarily with the status of the papers prepared to support the committee's work and the organizational structure being implemented in NSF as it relates to this project. David Ucko provided an overview of the new organizational structure and focus of the education program offices at NSF.

At our final meeting, the committee discussed the planned practitioner volume on science learning in informal environments that the Board on Science Education is developing as a resource for practitioners based on the evidence, findings, and conclusions of this consensus study. Two of the current study members are also members of the oversight group for the practitioner volume: Sue Allen, The Exploratorium, and Gil Noam, Harvard University. The five other members of the practitioner volume oversight group also attended our final meeting: Myles Gordon, consultant; Leslie Rupert Herrenkohl, University of Washington; Natalie Rusk, MIT Media Lab; Bonnie Sachatello-Sawyer; and Dennis Schatz, Pacific Science Center. We are grateful to each member of the group for providing us with excellent feedback. The practitioner volume, sponsored by NSF's Division of Research on Learning in Formal and Informal Settings, the Institute for Museum and Library Services, and the Burroughs Wellcome Fund, will be released following publication of this report.

We also acknowledge the efforts of the eight authors who prepared background papers. Arthur Bangert and Michael Brody, Montana State University, along with Justin Dillon, King's College London, were asked to review the literature on assessment outcomes. Laura Carstensen and Casey Lindberg, Stanford University, along with Edwin Carstensen, University of Rochester, were asked to synthesize the literature on older adult learning in informal environments. Shirley Brice Heath, Stanford University and Brown University, was asked to describe how issues of diversity influence individual conceptions of science. The Institute for Learning Innovation was asked to review the evidence in evaluation studies of the impact of designed spaces. Bryan McKinley Jones Brayboy, University of Utah, and Angelina E. Castagno, Northern Arizona University, were asked to review and synthesize the literature on native science. K. Ann Renninger, Swarthmore College, was asked to review research on interest and motivation in the context of learning science in informal environments. Rockman Et Al was asked to provide a review of the evidence of the impact of traditional media (e.g., television, radio, print). Sarah Schwartz, Harvard University, was asked to provide a synopsis of the scope and institutional investments in after-school and out-of-school-time programs.

Many individuals at the NRC assisted the committee. The study would not have been possible without the efforts and guidance of Jean Moon, Patricia Morison, and Heidi Schweingruber. Each was an active participant in the deliberations of the committee, helping us to focus on our key messages and conclusions. In addition, they made profound contributions to the development of the report through periodic leadership meetings with the

committee co-chairs and the NRC staff. We are grateful to Victoria Ward and Kemi Yai, who arranged logistics for our meetings and facilitated the proceedings of the meetings themselves. We would also like to thank Rebecca Krone for assisting with the construction of the reference lists in each chapter of the report. The synthesis of the diverse literatures reviewed in this report would not have been possible without the efforts of Matthew Von Hendy, who conducted multiple literature searches and acquired copies of studies essential to our review.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the NRC. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their review of this report: David Anderson, Department of Curriculum Studies, University of British Columbia; Bronwyn Bevan, Informal Learning and Schools, The Exploratorium, San Francisco, CA; Ilan Chabay, Public Learning and Understanding of Science (PLUS), University of Gothenburg, Sweden; Lynn D. Dierking, Free-Choice Learning and Department of Science and Mathematics Education, Oregon State University; Shalom Fisch, Office of the President, MediaKidz Research and Consulting, Teaneck, NJ; Shirley Brice Heath, Anthropology and Education, Stanford University and Department of Education, Brown University; Bonnie L. Kaiser, Office of the Dean of Graduate and Postgraduate Studies, The Rockefeller University; Frank C. Keil, Department of Psychology, Yale University; Leona Schauble, Peabody College, Vanderbilt University; and Cary I. Sneider, Boston Museum of Science, Portland, OR.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Adam Gamoran, Center for Education Research, University of Wisconsin–Madison, and May Berenbaum, Department of Entomology, University of Illinois, Urbana–Champaign. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report, however, rests entirely with the authoring committee and the institution.

Philip Bell and Bruce Lewenstein, *Co-chairs*
Andrew W. Shouse, *Senior Program Officer*
Michael A. Feder, *Senior Program Officer*

Contents

Summary

Science is shaping people's lives in fundamental ways. Individuals, groups, and nations increasingly seek to bolster scientific capacity in the hope of promoting social, material, and personal well-being. Efforts to enhance scientific capacity typically target schools and focus on such strategies as improving science curriculum and teacher training and strengthening the science pipeline. What is often overlooked or underestimated is the potential for science learning in nonschool settings, where people actually spend the majority of their time.

Beyond the schoolhouse door, opportunities for science learning abound. Each year, tens of millions of Americans, young and old, explore and learn about science by visiting informal learning institutions, participating in programs, and using media to pursue their interests. Thousands of organizations dedicate themselves to developing, documenting, and improving science learning in informal environments for learners of *all* ages and backgrounds. They include informal learning and community-based organizations, libraries, schools, think tanks, institutions of higher education, government agencies, private companies, and philanthropic foundations. Informal environments include a broad array of settings, such as family discussions at home, visits to museums, nature centers, or other designed settings, and everyday activities like gardening, as well as recreational activities like hiking and fishing, and participation in clubs. Virtually all people of all ages and backgrounds engage in activities that can support science learning in the course of daily life.

The Committee on Learning Science in Informal Environments was established to examine the potential of nonschool settings for science learning. The committee, comprised of 14 experts in science, education, psychology, media, and informal education, conducted a broad review of the literatures that inform learning science in informal environments. Our charge specifically included assessing the evidence of science learning across settings, learner age groups, and over varied spans of time; identifying the qualities of learning experiences that are special to informal environments and those that are shared (e.g., with schools); and developing an agenda for research and development.

The committee organized its analysis by looking at the places where science learning occurs as well as cross-cutting features of informal learning environments. The "places" include everyday experiences—like hunting, walking in the park, watching a sunrise—designed settings—such as visiting a science center, zoo, aquarium, botanical garden, planetarium—and programs—such as after-school science, or environmental monitoring through a local organization. Cross-cutting features that shape informal environments include the role of media as a context and tool for learning and the opportunities these environments provide for inclusion of culturally, socially, and linguistically diverse communities.

We summarize key aspects of the committee's conclusions here, beginning with evidence that informal environments can promote science learning. We then describe appropriate learning goals for these settings and how to broaden participation in science learning. Finally, we present the committee's recommendations for practice.

PROMOTING LEARNING

Do people learn science in nonschool settings? This is a critical question for policy makers, practitioners, and researchers alike—and the answer is yes. The committee found abundant evidence that across all venues—everyday experiences, designed settings, and programs—individuals of all ages learn science. The committee concludes that:

- Everyday experiences can support science learning for virtually all people. Informal learning practices of all cultures can be conducive to learning systematic and reliable knowledge about the natural world. Across the life span, from infancy to late adulthood, individuals learn about the natural world and develop important skills for science learning.
- Designed spaces—including museums, science centers, zoos, aquariums, and environmental centers—can also support science learning. Rich with real-world phenomena, these are places where people can pursue and develop science interests, engage in science inquiry, and reflect on their experiences through sense-making conversations.
- Programs for science learning take place in schools and community-based and science-rich organizations and include sustained, self-organized activities of science enthusiasts. There is mounting evidence

that structured, nonschool science programs can feed or stimulate the science-specific interests of adults and children, may positively influence academic achievement for students, and may expand participants' sense of future science career options.
- Science media, in the form of radio, television, the Internet, and handheld devices, are pervasive and make science information increasingly available to people across venues for science learning. Science media are qualitatively shaping people's relationship with science and are new means of supporting science learning. Although the evidence is strong for the impact of educational television on science learning, substantially less evidence exists on the impact of other media—digital media, gaming, radio—on science learning.

DEFINING APPROPRIATE OUTCOMES

To understand whether, how, or when learning occurs, good outcome measures are necessary, yet efforts to define outcomes for science learning in informal settings have often been controversial. At times, researchers and practitioners have adopted the same tools and measures of achievement used in school settings. In some instances, public and private funding for informal education has even required such academic achievement measures. Yet traditional academic achievement outcomes are limited. Although they may facilitate coordination between informal environments and schools, they fail to reflect the defining characteristics of informal environments in three ways. Many academic achievement outcomes (1) do not encompass the range of capabilities that informal settings can promote; (2) violate critical assumptions about these settings, such as their focus on leisure-based or voluntary experiences and nonstandardized curriculum; and (3) are not designed for the breadth of participants, many of whom are not K-12 students.

The challenge of developing clear and reasonable goals for learning science in informal environments is compounded by the real or perceived encroachment of a school agenda on such settings. This has led some to eschew formalized outcomes altogether and to embrace learner-defined outcomes instead. The committee's view is that it is unproductive to blindly adopt either purely academic goals or purely subjective learning goals. Instead, the committee prefers a third course that combines a variety of specialized science learning goals used in research and practice.

Strands of Science Learning

We propose a "strands of science learning" framework that articulates science-specific capabilities supported by informal environments. It builds on the framework developed for K-8 science learning in *Taking Science to School* (National Research Council, 2007). That four-strand framework aligns tightly with our Strands 2 through 5. We have added two additional strands—Strands 1 and 6—which are of special value in informal learning environments. The six strands illustrate how schools and informal environments can pursue complementary goals and serve as a conceptual tool for organizing and assessing science learning. The six interrelated aspects of science learning covered by the strands reflect the field's commitment to participation—in fact, they describe what participants do cognitively, socially, developmentally, and emotionally in these settings.

Learners in informal environments:

Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.

Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.

Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.

Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.

Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.

Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.

The strands are distinct from, but overlap with, the science-specific knowledge, skills, attitudes, and dispositions that are ideally developed in schools. Two strands, 1 and 6, are particularly relevant to informal learning environments. Strand 1 focuses on generating excitement, interest, and motivation—a foundation for other forms of science learning. Strand 1, while important for learning in any setting, is particularly relevant to informal learning environments, which are rich with everyday science phenomena and organized to tap prior experience and interest. Strand 6 addresses how learners view themselves with respect to science. This strand speaks to the process by which individuals become comfortable with, knowledgeable about, or interested in science. Informal learning environments can play a special role in stimulating and building on initial interest, supporting science learning identities over time as learners navigate informal environments and science in school.

The strands serve as an important resource from which to develop tools for practice and research. They should play a central role in refining assessments for evaluating science learning in informal environments.

BROADENING PARTICIPATION

There is a clear and strong commitment among researchers and practitioners to broadening participation in science learning. Efforts to improve inclusion of individuals from diverse groups are under way at all levels and include educators and designers, as well as learners themselves. However, it is also clear that laudable efforts for inclusion often fall short. Research has turned up several valuable insights into how to organize and compel broad, inclusive participation in science learning. The committee concludes:

- Informal settings provide space for all learners to engage with ideas, bringing their prior knowledge and experience to bear.
- Learners thrive in environments that acknowledge their needs and experiences, which vary across the life span. Increased memory capacity, reasoning, and metacognitive skills, which come with maturation, enable adult learners to explore science in new ways. Senior citizens retain many of these capabilities. Despite certain declines in sensory capabilities, such as hearing and vision, the cognitive capacity to reason, recall, and interpret events remains intact for most older adults.
- Learning experiences should reflect a view of science as influenced by individual experience as well as social and historical contexts. They should highlight forms of participation in science that are also familiar to nonscientist learners—question asking, various modes of communication, drawing analogies, etc.
- Adult caregivers, peers, teachers, facilitators, and mentors play a critical role in supporting science learning. The means they use to do this range from simple, discrete acts of assistance to long-term, sustained relationships, collaborations, and apprenticeships.
- Partnerships between science-rich institutions and local communities show great promise for structuring inclusive science learning across settings, especially when partnerships are rooted in ongoing input from community partners that inform the entire process, beginning with setting goals.
- Programs, especially during out-of-school time, afford a special opportunity to expand science learning experiences for millions of children. These programs, many of which are based in schools, are increasingly folding in disciplinary and subject matter content, but by means of informal education.

RECOMMENDATIONS

The committee makes specific recommendations about how to organize, design, and support science learning. These recommendations provide a research and development agenda to be explored, tested, and refined. They have broad reach and application for a range of actors, including funders and leaders in practice and research; institution-based staff who are responsible for the design, evaluation, and enactment of practice; and those who provide direct service to learners—scout leaders, club organizers, front-line staff in science centers. Here we make recommendations to specific actors who can influence science learning in practice. Additional recommendations for research appear in Chapter 9.

Exhibit and Program Designers

Exhibit and program designers play an important role in determining what aspects of science are reflected in learning experiences, how learners engage with science and with one another, and the type and quality of educational materials that learners use.

Recommendation 1: Exhibit and program designers should create informal environments for science learning according to the following principles. Informal environments should

- be designed with specific learning goals in mind (e.g., the strands of science learning)
- be interactive
- provide multiple ways for learners to engage with concepts, practices, and phenomena within a particular setting
- facilitate science learning across multiple settings
- prompt and support participants to interpret their learning experiences in light of relevant prior knowledge, experiences, and interests
- support and encourage learners to extend their learning over time

Recommendation 2: From their inception, informal environments for science learning should be developed through community-educator partnerships and whenever possible should be rooted in scientific problems and ideas that are consequential for community members.

Recommendation 3: Educational tools and materials should be developed through iterative processes involving learners, educators, designers, and experts in science, including the sciences of human learning and development.

Front-Line Educators

Front-line educators include the professional and volunteer staff of institutions and programs that offer and support science learning experiences. In some ways, even parents and other care providers who interact with learners in these settings are front-line educators. Front-line educators may model desirable science learning behaviors, helping learners develop and expand scientific explanations and practice and in turn shaping how learners interact with science, with one another, and with educational materials. They may also serve as the interface between informal institutions and programs and schools, communities, and groups of professional educators. Given the diversity of community members who do (or could) participate in informal environments, front-line educators should embrace diversity and work thoughtfully with diverse groups.

Recommendation 4: Front-line staff should actively integrate questions, everyday language, ideas, concerns, worldviews, and histories, both their own and those of diverse learners. To do so they will need support opportunities to develop cultural competence, and to learn with and about the groups they want to serve.

REFERENCE

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Committee on Science Learning, Kindergarten Through Eighth Grade. R.A. Duschl, H.A. Schweingruber, and A.W. Shouse (Eds.). Washington, DC: The National Academies Press.

5
Science Learning in Designed Settings

This chapter describes informal environments that are intentionally designed for learning about science and the physical and natural world. Designed settings include institutions such as museums, science centers, aquariums, and environmental centers, and the smaller components contained within these settings, such as exhibits, exhibitions, demonstrations, and short-term programs. Like everyday learning, learning in designed settings is highly participant structured, but also reflects the intended communicative and pedagogical goals of designers and educators. And in important ways, designed spaces are unlike science learning programs. Science learning programs serve a subscribed group and recur over time, whereas learning in designed spaces tends to be more fluid and sporadic. An important feature for structuring learning in these environments is that they are typically experienced episodically, rather than continuously.

Another defining characteristic of designed spaces is that they are navigated freely, with limited or often no direct facilitation from institutional actors. Visitors may freely choose which of the exhibits to interact with, and they receive little guidance as to which path they should follow as they explore. This design is typical, and reflects the learner's personal choice about learning in these settings. Should the learner choose to design their own systematic study of a given topic, the option is available. Institutions typically shy away from directing a particular course, opting instead for multiple entry levels and possible navigational paths through the public space. Whereas classrooms have teachers and Cub Scouts have den leaders, designed settings rely primarily on objects, labels, spaces, recorded messages, brief interpretive guides, and occasionally docents or interpreters to facilitate learner engagement. They are designed to serve a diverse public in the myriad social configurations they assemble. Thus, individuals, families, and teen peer groups are all understood as participants whose needs and interests should be accommodated in designed spaces.

Individual learners and groups play an important role in determining their own learning outcomes in designed spaces (Moussouri, 2002). Contemporary views of learning as an active, constructive process have led to increased attention to learners' motivations, prior experiences, tacit knowledge, and cultural identity (National Research Council, 2007). While professional educators—designers, facilitators, teachers, curators—have scientific, social, practical, or other goals for participants, these are achieved only in partnership with learners. This is particularly salient in designed spaces, where learners are not assumed to operate under strong cultural pressures to participate or achieve a particular goal, as they may be pressured to do in schools, educational programs, and workplace settings. Participants in designed science learning settings control their own learning agenda.

The science learning that takes place in designed settings is shaped by elements of intentional design, personal interpretation and choice, and chance. The environment—both large-scale characteristics of the institution and small-scale features of exhibits and programs—helps to guide or mediate the visitors' attitudes or perspectives, their relationship with the content and the institution, the meaning of their activity there, and how the institution views them. Learners typically participate of their own volition and at their own pace. They may be scientific experts or novices, or anyone in between.

Not surprisingly, experiences in these spaces are often designed to elicit participants' emotions or sensory responses to scientific and natural phenomena. For example, zoos and aquariums may develop conservation themes linking plant, animal, and human well-being. Science centers use multimedia to engage multiple senses, or build larger-than-life models that make phenomena visible and inspire participants' awe. Emotional and interactive sensory experiences are design priorities, though they are typically accompanied by particular informational or cognitive goals as well.

From the perspective of science learning, a key educational challenge for designed spaces is to link emotional and sensory responses with science-specific phenomena. Associating scientific thinking with engaging and enjoyable events and real-world outcomes can create important connections on a personal level. Promoting or supporting a variety of emotional responses (surprise, puzzlement, awe) and a variety of processing modes (observation, discovery, contemplation) increases the likelihood of connecting with a greater variety of people and encouraging them as learners (Jacobson, 2006).

LEARNING IN DESIGNED SPACES

Although the process of learning itself is not necessarily different in designed settings than it is in everyday settings or in programs for science learning, designed spaces do use special methods for structuring, teaching, guiding, and prompting learning.

The scale of designed learning spaces varies, and so does the way that the public interacts with these spaces. At the institutional level, there are distinctions among the types of materials and objects housed or collected. Zoos, aquariums, and nature centers, for example, typically maintain live collections. Traditional museums and science centers typically (though not always) organize nonliving collections that may include scientific artifacts (e.g., mineral specimens), tools employed in scientific inquiry (e.g., telescopes), and pedagogical exhibits (e.g., a supersized panpipe designed to explore vibration and pitch). The substantive focus of a particular institution has important implications for its goals. For example, designed spaces with live animal collections may focus primarily on conservation goals—goals with observable behavioral implications (e.g., participants may make unique consumer choices that reflect a conservation ethic). Science centers may pursue somewhat broader or less easily observable goals, such as supporting future inquiry and inspiring curiosity.

Research on learning in designed spaces has provided evidence of learning across the strands. Some studies focus on the importance of developing scientific ideas and processes of science, in interaction with others (Ash, 2003; Crowley and Jacobs, 2002; Tunnicliffe, 2000). Other studies have described science learning in informal settings as an opportunity to appropriate the language or participate in the "culture" of science (Borun et al., 1998; Crowley and Callanan, 1998; Ellenbogen, 2003). Still others have explored the idea that learning involves a change in identity—specifically, how people view or present themselves, and how others see them (Holland, Lachicotte, Skinner, and Cain, 1998; Wenger, 1999).

Before delving into the specific strands, we should not lose sight of the fact that individuals choose to spend their time in these settings and that this choice in itself can be seen as an indication of their participation in science (as indicated in Strand 5) and at least a weak proxy for learning. As mentioned in Chapter 1, the scale of participation in designed settings, though crudely estimated, is certainly vast: U.S. museums and science centers tally hundreds of millions of visits each year. While counting heads is no substitute for careful analysis of how learners participate and what they learn, and there are significant biases in terms of the cultural and demographic characteristics of individuals and families that tend to participate in designed settings, nevertheless the fact that large numbers of people choose to attend, often paying for admission, is an important measure for a field that is predicated on learner choice. In addition, attendance records and many large-scale visitor surveys show that the public has a positive view of informal environments for science learning, seeks them out during leisure time (Hilke, 1987; Ivanova, 2003; Briseno-Garzon, Anderson, and Anderson, 2007; Moussouri, 1998), and values both the entertainment and learning aspects that these institutions offer. This suggests that such institutions are viewed positively on a broad scale. Some contend that they are part of the nation's science education infrastructure (St. John and Perry, 1993), one measure of system-wide impact. Although we focus primarily on designed settings, we also note that schools and field trips play an important role; Box 5-1 is a summary of the relevant research on field trips.

Strand 1: Developing Interest in Science

Some key assumptions about learning in informal environments are that exciting experiences lead to intrinsically motivated learning, and that these experiences are personally meaningful, providing experiential foundations for more advanced structured, science learning. Perry (1994), for example, proposes that curiosity, confidence, challenge, and play are among the essential elements of intrinsically motivating experiences in museums. This is an area of tremendous interest to informal science educators and has been documented extensively in evaluations and the accounts of practitioners. To provide an inclusive summary here, we integrate conventional forms of published, peer-reviewed literatures with anecdotes and excerpts from evaluation reports.

Excitement

Numerous evaluation studies show that visitors to informal environments report feeling excitement as a result of their experiences. For example, consider the following from Tisdal (2004, p. 24):

> Another visitor noted the pleasure he took in watching children get excited about science: "I was talking to the mother of the other boy that was there and just kind of—not necessarily small talk, but talking about the objects and how you could see how he was really excited when he was playing with it. And we had some jokes going on about (inaudible) when he had the football up in the air, and he got a little excited about the whole thing. It was cool to see him light up over something that—you know, science isn't normally fun for those kids. So I thought that was kind of cool, that we were having a good time over there" (Case 6, male, age 18).

Researchers also often observe signs of positive excitement among visitors. They cite expressions of joy, delight, awe, wonder, appreciation, surprise, intrigue, interest, caring, inspiration, satisfaction, and meaningfulness. For example:

"The size of animals that you have in there . . . I was just flabbergasted. But they are all extremely well maintained. I can tell by looking that everything is thriving. It's not just living" (120404-3) (Beaumont, 2005, p. 14).

"I think [the exhibition] is inspirational—that regular people can invent things. That is how I felt [when I read] about the lady [who invented] Kevlar [Stephanie Kwolek]" (National Museum of American History; female, age 42) (Korn, 2004, p. 44).

"It was fun. It was beautiful. The ice crystals, the colors in the ice crystals were beautiful. I think it is a great exhibit. It's the only time I've seen that kind of exhibit—it's sort of, each crystal is different, each time you do it will be different" (Tisdal, 2004, p. 29).

Allen (2002) notes that affective responses (defined as verbal expressions of feeling) were one of the three most common forms of "learning talk" in visitors' conversations while viewing an exhibition on frogs. Visitors expressed their feelings at 57 percent of all exhibit elements at which they stopped. The most common subcategories were surprise/intrigue (37 percent) and pleasure (36 percent).

Some evidence from experimental social psychology and neuropsychology suggests a link between excitement and other forms of learning (e.g., Steidl, Mohi-uddin, and Anderson, 2006). Models of the relation of mood to substantive cognitive processing, as well as studies of operant conditioning, have predicted and demonstrated that mood states or internal responses influence the information used during processing in laboratory situations (Bower, 1981; Eich et al., 2000). The precise relationship is not yet well understood, and the influence of excitement can alternately enhance or detract from learning. Specific connections between affect, thinking, and activity settings, moreover, have not been studied and are clearly needed.

Interest

The construct of interest takes one deeper into the question of what people learn from experiences in informal environments. Hidi and Renninger (2006) distinguish between situational interest (short-lived, typically evoked by the environment) and individual interest (more stable and specific to an individual). Based on a number of studies, they propose a four-phase model of interest development: (1) triggered situational interest, typically sparked by such environmental features as incongruous/surprising information or personal relevance; (2) maintained situational interest, sustained through the meaningfulness of tasks and personal involvement; (3) emerging individual interest; and (4) well-developed individual interest, in which the individual chooses to engage in an extended pursuit using systematic approaches to questioning and seeking answers. Interestingly, this sequence of increasing

BOX 5-1 Field Trips

School groups make up a large proportion of the visitors to science learning institutions. Several studies have pointed to possible long-term impacts of field trips—typically, memories of specific experiences (Anderson and Piscitelli, 2002; Falk and Dierking, 1997). In fact, all of the elementary and middle school students and adults interviewed by Falk and Dierking (1997), in a study of students who visited a museum on a field trip, were able to recall at least one thing they had learned on a field trip. The nature and more immediate impact of schoolchildren's visits vary widely, however (Kisiel, 2006; Orion and Hofstein, 1994; Price and Hein, 1991; Storksdieck, 2006). Although results are mixed regarding the impact of field trips to informal institutions on children's attitudes, interest, and knowledge of science, the majority of studies that have measured knowledge and attitudes have found positive changes (Koran, Koran, and Ellis, 1989). Most of the work on interpreted visits to museums looks at the structure of field trips and how their effectiveness can be improved.

In general, the impact of field trips made to such institutions as museums, zoos, and nature centers is dependent on several critical factors: advance content preparation (Anderson, Kisiel, and Storksdieck, 2006; Falk and Balling, 1982; Griffin and Symington, 1997; Kubota and Olstad, 1991), active participation in activities (Griffin, 1994; Griffin and Symington, 1997; Price and Hein, 1991), teacher involvement (Griffin, 1994; Price and Hein, 1991), and follow-up activities (Anderson, Lucas, Ginns, and Dierking, 2000; Griffin, 1994; Koran, Lehman, Shafer, and Koran, 1983).

Advance Preparation

Advance field trip preparation activities give students the framework for how to interpret what they will see and guide what they should pay attention to during the visit. Students who receive appropriate advance preparation from their teachers, in such forms as previsit activities and orientation, have been noted, via observational studies and pre-post survey-based studies, to concentrate and learn more from their visits (Griffin, 1994; Griffin and Symington, 1997; Anderson, Lucas, Ginns, and Dierking, 2000; Orion and Hofstein, 1994).

Advance preparation is most effective when it reduces the cognitive, psychological, and geographical novelty of the field trip experience (Kubota and Olstad, 1991; Orion and Hofstein, 1994). Such preparation has been linked to students spending more time interacting with exhibits (Kubota and Olstad, 1991) and learning from their visits (Orion and Hofstein, 1994). Studies have shown, however, that teachers spend very little time preparing students for field trips (Anderson, Kisiel, and Storksdieck, 2006; Griffin, 1994; Griffin and Symington, 1997).

Active Participation in Museum Activities

A review of over 200 evaluations of field trips to informal institutions (Price and Hein, 1991) indicates that effective ones include both hands-on activities and time for more structured instruction (e.g., viewing films, listening to presentations, participating in discussions with facilitators and peers). In general, children who were able to handle materials, engage in science activities, and observe animals or objects were excited about and enjoyed their field trip experience and displayed cooperative learning strategies. Similarly, Koran and colleague's review of earlier field trip studies—from 1939 to 1989—revealed that hands-on involvement with exhibits results in more changes in attitudes and interest than passive experiences (1989). At the same time, Griffin and Symington (1997) argued for the inclusion of structured activities to help keep students engaged throughout their field trip experience. Observing 30 unstructured classroom visits to museums, they noted that very few students continued purposefully exploring the museum after the first half hour of hands-on activities. Instead, most students were observed talking in the coffee shop, sitting on gallery benches, copying each other's worksheets, or moving quickly from exhibit to exhibit.

Involvement by Teachers and Chaperones

Classroom teacher involvement is a key ingredient to successful field trips, yet studies have consistently found that teachers often play a very small role or no role in the planning or execution of excursions and that institution staff are responsible for connecting exhibits to classroom content (Anderson and Zhang, 2003; Griffin, 1994; Griffin and Symington, 1997; Tal, Bamberger, and Morag, 2005).

There is wide variation in the amount and level of teacher involvement

continued

BOX 5-1 Continued

during field trips (Griffin, 1994; Griffin and Symington; 1997; Kisiel, 2006; Price and Hein, 1991). Price and Hein (1991) found a range of teacher involvement, from cases in which teachers congregated in such areas as the cafeteria and were not involved in the field trip activities, to cases in which teachers remained with the students and were actively involved in all phases of the trip. This review indicates that teacher involvement in various aspects of field trip planning and implementation is important. For example, a correlation was found between involvement in planning field trip activities and greater buy-in by teachers. When teachers are involved in planning, it is more likely that the activities will align with classroom curriculum and be viewed as valuable experiences by the teachers. Furthermore, alignment of classroom and field trip content and teacher buy-in are important, because they have been connected with student learning from field trips (Price and Hein, 1991; Griffin and Symington, 1997).

Reinforcement After the Field Trip

Teachers often plan to do follow-up after visiting informal institutions but in fact do little more than collect and mark student worksheets completed

investment and meaningfulness has parallels with work done by a group of museum professionals (e.g., Serrell, 2006) in generating criteria for exhibition excellence based on principles from the visitor studies literature. This group defined an "excellent exhibition" as one that is (1) comfortable—opening the door to other positive experiences; (2) engaging—enticing visitors to attend; (3) reinforcing—providing reinforcing experiences and supporting visitors to feel competent; and (4) meaningful—providing personally relevant experiences that change visitors cognitively and affectively (Serrell, 2006).

Research in various settings has shown that interest is in fact a gateway to deeper and sustained forms of learning. For example, when participants have a more developed interest for science, they pose curiosity questions and are also more inclined to learn and/or to use systematic approaches to seek answers (Engle and Conant, 2002; Kuhn and Franklin, 2006; Renninger, 2000). Interested people are also more likely to be motivated learners, to seek out challenge and difficulty, to use effective learning strategies, and to make use of feedback (Barron, 2006; Csikszentmihalyi, Rathunde, and Whalen, 1993; Lipstein and Renninger, 2006; Renninger and Hidi, 2002).

during the field trip (Griffin, 1994; Griffin and Symington, 1997). In Griffin's (1994) study of field trips taken by students in 13 Australian schools, about half of the teachers reported they planned to do follow-up activities, but only about a quarter of the teachers reported doing so. Furthermore, no students expected to receive meaningful follow-up, which may indicate that this was a common experience for them.

Developing productive post-visit activities is often complicated by the fact that the topics being covered in the classroom do not align with the field trip (Griffin and Symington, 1997). This can make it difficult to plan follow-up activities without disrupting regular classroom activities. However, even when the topics covered in the classroom align with the field trip content, connections between field trip experiences and classroom topics are often not made (Griffin, 1994). In addition, when post-visit activities do occur, they are often not designed to have any lasting impact. For example, a study of 36 field trips revealed that only 9 of the 18 teachers who reported conducting post-visit activities did more than ask students if they enjoyed the experience (Storksdieck, 2001). However, when well-designed examples of classroom follow-up have been noted, they are associated with positive educational impacts (Anderson et al., 2000; Griffin, 1994).

Another aspect of Strand 1 is motivation. Some researchers distinguish between intrinsic motivation, in which people do activities that interest them or provide spontaneous enjoyment, and extrinsic motivation, in which people do activities as a means to desired ends (such as good grades or career advancement). Deci and Ryan (2002) argue that intrinsic motivation is key for learning throughout the life span, because much of what people learn stems from spontaneous interests, curiosity, and their desire to master problems and affect their surroundings. They point to a body of work that documents the advantages of this type of learning in various settings. For example, Grolnick and Ryan (1987) conducted an experiment with 91 fifth graders who read material after they were told either that they would be tested on it or that they would be asked questions about how interesting and difficult they found it. The results showed that students in the second group had both higher interest and understanding in the material, and that, overall, students with more self-determined learning styles showed greater conceptual learning.

A meta-analysis by Utman (1997) showed that both intrinsic and extrinsic motivation was effective for simple tasks, but that intrinsic motivation led to greater success on creative or complex performance tasks. Of particular relevance, Zuckerman and colleagues (1978) found that intrinsic motivation was enhanced when problem-solvers could choose the activities and amounts of time they spent on them. More recently, research on motivation for learning has emphasized a broader set of constructs in "goal-orientation theory," which includes needs, values, and situated meaning-making processes (reviewed by Kaplan and Maehr, 2007). However, this theory has yet to be applied to informal environments.

Comfort

Finally, while Strand 1 focuses primarily on arousing emotions, such as excitement, many studies have shown the importance of comfort, both physical and intellectual, as a prerequisite to learning in designed settings. For example, Maxwell and Evans (2002) link the physical environment to learning through psychological processes, such as cognitive fatigue, distraction, motivation, and anxiety, and they offer some evidence that learning is enhanced in quieter, smaller, better differentiated spaces. Physical and conceptual orientation (using maps, guides, and films) has also been shown to contribute to learners' comfort, presumably by reducing cognitive overwhelm and allowing them to make more informed choices about what to attend to. Much of this literature is summarized in Serrell (2006) and Crane, Nicholson, Chen, and Bitgood (1994).

Strand 2: Understanding Scientific Knowledge

There is some research demonstrating that people gain understanding of scientific concepts, arguments, explanations, models, and facts, even after single museum visits. For example, Guichard (1995) studied the effect of an interactive exhibit designed to help visitors understand the form and function of the human skeleton. The exhibit consisted of a stationary bicycle that a visitor could ride, next to a large reflecting pane of glass. When the visitor pedaled the bicycle, the exhibit was arranged so that an image of a moving skeleton appeared inside the pedaling person's reflection. The movements of the legs and skeleton attracted the visitor's attention to the role and structure of the lower part of the skeleton.

Even without any additional mediation, this exhibit experience seemed to transform children's understanding. Children ages 6-7 were given an outline of a human body and asked to "draw the skeleton inside the silhouette" after the cycling experience. Of the 93 children in the sample, 96 percent correctly drew skeletons whose bones began or ended at the joints of the body; this result was in sharp contrast to the figure of 3 percent for a sample of children of similar age in a previous study who did not experience the exhibit. Even more impressively, the children's understanding persisted over time, with

92 percent of them retaining the idea of bones extending between places where the body bends 8 months after their museum visit and without any additional schooling, practice, or warning that they would be tested.

Multifaceted cognitive learning of this type has also been documented over a collection of exhibits. For example, Falk, Moussouri, and Coulson (1998) used the technique of personal meaning mapping, in which visitors complete pre- and post-exhibit diagrams, to record the deepening and broadening of their understanding of a science topic as a result of visiting an exhibition.

Typically, exhibition evaluations include self-reports from visitors that they have learned some content knowledge, usually small-scale, counterintuitive facts rather than large-scale abstractions or principles. For example:

> More than one-half of interviewees said they learned something new about plants while visiting the Conservatory. While learning was highly individualized and personal, all of these interviewees consistently referred to topics presented in the Conservatory exhibits and text. Several mentioned carnivorous plants, for example, and being surprised about the Venus flytrap's small size or the pitcher plant's feeding mechanism. A few expressed amazement by the water lily pollination story, while a few others appreciated experiencing a bog firsthand. Other topics mentioned by a few interviewees were: epiphytes ("plants can grow on top of other plants"), the co-evolution of plant nectar and pollinators ("different concentrations of nectar attract different animals"), the precipitation level of Los Angeles compared with a rain forest, and elephants as seed dispersers. The remaining responses were idiosyncratic; for example, one interviewee learned that "leaves have holes" and another that orchids are the source of vanilla beans (Jones, 2005, p. 8).

> Most visitors' conceptual understanding was articulated as surprise at a counterintuitive phenomenon, that is, objects floating on a stream of air:

> "Oh, yeah. I was like, oh, I didn't know that. I didn't know it could stay up for so long. I thought eventually it would just die down and the weight would overcome the air pressure and stuff. But it just kept on floating. Like the football kept on doing misties and stuff. It was pretty cool" (Case 6, male, age 13) (Tisdal, 2004, p. 28).

> "[The exhibition is about] all the different life forms that we have on our planet and how there's a possibility that these life forms can exist on other planets. I just learned about the vents in the ocean. I never knew there were those kinds of things. And now I can understand how maybe there is life on Mars underneath all that ice. It's something I never understood before so I think it kind of expanded my world" (Adult) (Korn, 2006, p. 18).

Occasionally an exhibit experience may be powerful enough to challenge a common conception held by visitors. In a classic visitor study of the impact of short-term exposure to exhibits, Borun, Massey, and Lutter (1993) documented that, at least in the short term, many visitors changed their mistaken belief that gravity needs air in order to work after interacting with an exhibit showing a ball in a tube that could be evacuated.

For children, play may result in science learning of this kind, although some kinds of play seem more fruitful than others. Rennie and McClafferty (1993), working with schoolchildren using interactive exhibits, showed that they were more likely to learn the scientific ideas and principles that the curators intended if they were engaged in investigatory rather than fantasy forms of play. This may be because older children are familiar with school routines and expectations, and so benefit more from experiences structured around those kinds of expectations.

Conceptual change over the long term has not been studied in great depth in informal settings. There is certainly evidence that visitors can synthesize the big ideas of an exhibition or program and recall them or elaborate on them over time, although memories fade or change depending on many subject and condition variables (for a review of the museum memory literature, see Anderson, Storksdieck, and Spock, 2007). Measuring the long-term impact of museum visits is problematic because of the many variables at play (see discussion in Chapter 3). But as an example of a positive finding, Stevenson (1991) visited British families at home six months after their museum visits and interviewed 79 adults and children. The study found that each person was able to remember spontaneously, on average, 5 of the 15 exhibits in the exhibition, often clearly and in detail. Furthermore, over one-quarter of the memories were classified as "thoughts" (rather than feelings or exhibit descriptions), providing evidence of thinking or reflection about the exhibit in some way.

A commonly reported outcome from exhibition evaluations is that learners self-report a deeper understanding of a concept by virtue of having a direct sensory or immersive experience. For example, Korn (2006) collected the following observation from an adult participant following a visit to the *Search for Life* exhibition:

> I think the water exhibit is really brilliant. I can read something in a paragraph and not really have a sense of how much water 16 gallons is. It was just beautifully illustrated and really surprising. I had no idea that that much water is in our body. I think the [New York Hall of Science staff] do a great job of taking abstract contents and making it concrete so you can touch it and see it. That's why I like to bring my kids. You're going to absorb something somehow, even if you're not really trying at all (p. 17).

In addition to the key role of direct experiences, there is evidence that interpretive materials, such as labels, signs, and audio-guides, contribute significantly to this strand of science learning. For example, controlled experimental studies of exhibits in various science and natural history museums have shown that visitors showed significantly greater cognitive gains when objects were accompanied by interpretive labels than when they were experienced purely as sensory phenomena (Allen, 1997; Borun and Miller, 1980; Peart, 1984).

There is also substantial literature on the environmental design of informal science learning settings, including architectural and interior design, exhibit arrangement, label design and positioning, graphical and textual design, lighting, and other physical characteristics. Much of this involves recommendations based on practice, although there have also been many experimental studies, summarized in such reviews as Bitgood (2002), Bitgood and Loomis (1993), and Screven (1992). Given the scope of this report, the committee did not review this literature in detail because, although it has contributed significantly to practice, it mostly emphasizes such outcomes as visitor movements and behaviors rather than direct assessments of learning, as described in the strands.

Another commonly reported outcome from the evaluation literature is that learners self-report being reminded of learning experiences earlier in their lives. Since rehearsal is key to memory (Belmont and Butterfield, 1971), we regard this as a significant form of activity in Strand 2. For example, Jones (2005) heard the following from an adult male participant in a botanical conservatory:

> (What did you like most about the Conservatory?) "One place that I particularly liked and was pleased with was the Plant Lab because it showed me the way plants come to form life and the microscopes show you the different shapes of the seeds, the leaves, the roots—so many things that I didn't know before. . . . I came here and many of them refreshed my memory of when I was a child and took classes at school" (male, age 28; translated from Spanish) (p. 5).

In sum, there are documented cases showing that people who participate in a designed educational experience can generate, explain, and apply new knowledge to new examples and think in generalities (abstractions) about phenomena both familiar and new. Conceptual understanding and mental models of phenomena on which knowledge is built, however, take time to form (National Research Council, 1999, 2007; Lehrer and Schauble, 2000) and seem to depend on a person's existing knowledge base (Inagaki and Hatano, 2002; Carey, 1985) and cultural practices (Rogoff, 2003). Determining whether designed environments support more elaborated forms of conceptual knowledge development would probably entail longer time scales and close analysis of learning across settings.

Strand 3: Engaging in Scientific Reasoning

The investigatory processes of science, often clustered under the title "scientific inquiry," are seen as a vital part of science literacy by educators and researchers alike (e.g., American Association for the Advancement of Science, 1993; Minstrell and van Zee, 2000; National Research Council, 1996, 2000). Designed environments provide opportunities to engage in many of these processes, and visitors have been observed to manipulate, test, explore, observe, predict, and question, as well as to make sense of the natural and physical world. The most studied environments in which visitors engage in these processes are physically interactive exhibits at science centers, which typically support a broader range of investigatory behaviors than animals or living ecosystems. The most common audience studied has been family groups, which is the largest single audience (numerically and economically) at many science centers.

Interactivity

A key finding from the field is that learners are engaged by experiences that offer interactivity, which is defined by McLean (1993) in terms of reciprocity: "The visitor acts upon the exhibit, and the exhibit does something that acts upon the visitor" (p. 92). The field of practice is committed to this idea which, in a generic sense, has strong support from research. Learning—whether viewed in a purely mental or more broadly social perspective—is essentially interactive.

Summative evaluations of museum exhibitions frequently show evidence that learners, particularly parents, are aware of interactivity as a design feature of these environments and embrace it, although they often use related terms, such as "hands-on," to express this idea. For example:

> "[The exhibition] is trying to get kids involved in science [by] letting them know that it is fun. It is not all [about] some boring book somewhere. There are really fun, hands-on things that you can do. [It is] trying to give them opportunities to learn more complex principles with hands-on materials" (National Museum of American History; female, age 33) (Korn, 2004, p. 45).

It is well established that interactive exhibits tend to attract more visitors and engage them for longer times than static exhibits (e.g., Allen, 2007; Brooks and Vernon, 1956; Borun, 2003; Korn, 1997; Rosenfeld and Terkel, 1982; Serrell, 2001). At the same time, the specific impact of interactivity tends to be difficult to determine because authentic interactive exhibits usually differ in multiple design properties from noninteractive ones, and also because it is difficult to separate the effect of longer time spent from intellectual stimulation (Lucas, 1983). Koran, Koran, and Longino (1986) did find that simply removing the plexiglass cover from an exhibit case of seashells increased the number of visitors who stopped there and the amount of time they spent, even though only 38 percent of those who stopped actually picked up a shell.

Even in institutions with live animals, visitors seek out interactivity in particular. For example, Taylor (1986) found that families sought out interactions with live aquarium creatures. Goldowsky (2002) studied this experimentally by comparing the learning experiences of visitors to an exhibit on penguins. This was an experimental study in which the control condition used a typical aquarium exhibit, including live penguins, naturalistic habitat, and graphics. The interactive condition added a device designed to mediate interaction between participants and penguins, which allowed participants to move a light beam across the bottom of the pool, which the penguins would chase. Videotaped data were analyzed for 301 visitor groups (756 individuals). Goldowsky found that those who interacted with the penguins were significantly more likely to reason about the penguins' motivations.

Apart from supporting interaction with the physical world, interactive exhibits may also create a broader temporal space in which additional learning can transpire, including stimulating constructive exchanges between parents and children more frequently than static exhibits (Blud, 1990). Visitors self-report a variety of outcomes from interactives, including learning knowledge and skills, gaining new perspectives, and generating enthusiasm and interest (Falk et al., 2004).

While interactive experiences are prevalent across designed settings, they are not uniformly desirable in all exhibits and may be overutilized. For example, Allen and Gutwill (2004) documented several examples of exhibit designs that incorporated too many interactive features, leading to participant misunderstandings or to their feeling overwhelmed. Problematic design features included multiple undifferentiated options, features that allow multiple users to interfere with one another, options that encourage users to disrupt the phenomenon being displayed, features that make the critical phenomenon difficult to find, and secondary features that obscure the primary feature.

Doing and Seeing

Given the widespread embracing of interactivity in designed spaces, it is unsurprising that the most frequently observed processes of science are those that Randol (2005) characterized as "do and see": Visitors manipulate an exhibit to explore its capabilities and observe what happens as a result. Randol conducted very detailed studies of visitors' inquiry behaviors at eight interactive exhibits from three science centers. The exhibits were selected to optimize the possibilities for scientific inquiry processes, as well as family learning as defined by Borun, Chambers, and Cleghorn (1996) in an influential study. In particular, there were many possible outcomes, so families were able to conduct a range of investigations of their own choosing. Randol discovered that visitors used the exhibits purposefully and successfully, and that their main interactions were focused on doing what the exhibit afforded (turning a dial, rolling a wheel) and watching what happened. These two actions, coded as "manipulate variable" and "observe," accounted for more than half of visitors' inquiry-related actions at the exhibits (see Figure 5-1). A similar pattern of typical family behaviors was reported by Diamond (1986).

Interestingly, Rennie and McClafferty (2002) found that these same inquiry activities did in fact lead to conceptual learning of science by children, supporting the notion that the strands are mutually reinforcing. Using Hutt's (1981) distinction between symbolic or fantasy play ("What can *I* do with this object?") and investigation ("What can this *object* do?"), they studied children using an interactive science exhibit. The exhibit, *Magnetic Maze*, was designed to support a range of learning experiences: enjoyment, mystery, role-playing, and development of hand-eye coordination, in addition to the goal of understanding that magnets can attract some objects, even at a distance and through materials. Rennie and McClafferty found that this latter science content goal was reached almost exclusively by children who took an investigatory approach to the exhibit. In other words, the "do and see" approach observed so frequently by Randol did enhance children's understanding of the intended science content.

Another common form of observation is pointing out to others a feature of particular interest. Allen (2002) calls this kind of spoken observation "perceptual talk" and regards it as a significant process measure of learning because it is an act of identifying and sharing what is significant in a complex environment. She defined four subcategories: identification ("Oh, look

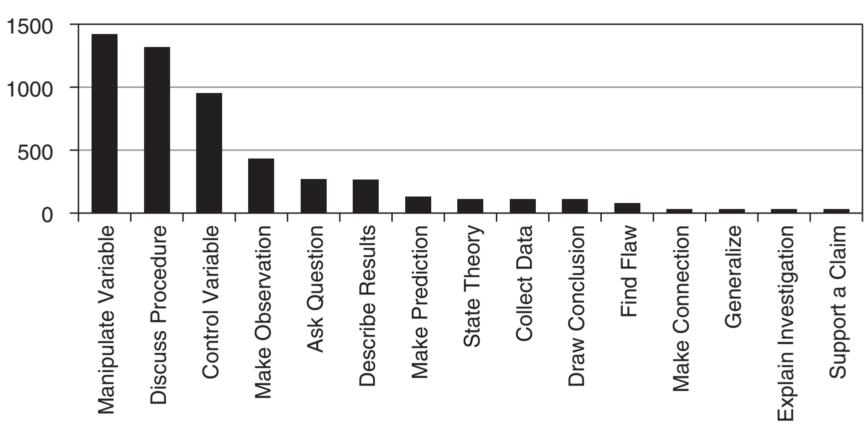

FIGURE 5-1 Frequency of visitor actions at interactive exhibits.
SOURCE: Randol (2005).

at this guy"), naming ("It's a Golden Frog"), pointing out a feature ("Check out the bump on his head"), and quoting from a label. Audio-recorded visitors engaged in perceptual talk at 70 percent of the exhibit elements they stopped at, the most common category of talk in Allen's scheme. Similarly, Callanan and Jipson (2001) argue that this kind of talk is an important way in which adults help guide children's scientific literacy. They propose that adults who point out salient features of the environment are helping children guide their attention, interpret their experiences, and frame them in terms of relevant domains of knowledge. This same benefit need not be limited to parents talking with children but could also apply to the contributions of any member of a group communicating with other members.

Meaning-Making and Explanation

Meaning-making (i.e., interpreting experiences to give them personal significance) has become so central to descriptions of learning in informal environments that it is sometimes regarded as the essential learning behavior (e.g., Silverman, 1995; Hein, 1998; Ansbacher, 1999; Rounds, 1999). Callanan and Jipson (2001) make the point that visitors vary not only in terms of how they interpret experience, but also in terms of what they find worthy of interpretation. The degree and quality of sense-making have been the basis of a number of systems for coding learning. For example, Borun and colleagues (1998) defined three levels of family learning in informal environments: identifying, describing, and interpreting/applying. They found that 88 percent of families fell within the first two levels. Similarly, Leinhardt and Knutson (2004) list four levels of interpretation: listing, analysis, synthesis, and explanation.

Explanation has also been the subject of extensive study. The research consensus seems to be that explanations in designed spaces tend to be concrete, local, and incomplete. In studying the parents' explanations to their children in a museum context, Callanan and Jipson (2001) defined three types of explanation: (1) abstract scientific principles (e.g., "It's because of the gravitational attraction") were used in only 12 percent of explanations; (2) causal connections (e.g., "Each of those pictures is a little different pose on the horse, and it makes it look like it is galloping") constituted 54 percent of the explanations; and (3) connections to prior experience (e.g., "Remember the stethoscope at the doctor's? We can listen to your heart beat") made up a further 25 percent of the adults' explanations. The authors argue that the connections to prior experience served the purpose of contextualizing the experience for children by linking it to their previous knowledge and history, giving weight to a design strategy that has been used for over a century by practitioners to help visitors find personal meaning in exhibitions and programs. Similarly, studies in various designed settings (e.g., Crowley and Jacobs, 2002; Taylor, 1986) have shown that parents tend to focus on helping children to understand the particular event at hand, rather than learning more abstract principles.

In related work, Callanan, Jipson, and Soennichsen (2002), studying families' use of representational objects, such as maps and globes, found that parents tended to explain to children by using specific referents as if they were the real objects (e.g., "There's your school!"), rather than explaining the more abstract relationships between the representation and real world it shows. The authors point out that it is not just children who learn from fragments of scientific reasoning; adults and even scientists can learn this way as well.

Gleason and Schauble (1999) show that parents may not coach their children equally in all aspects of scientific inquiry at an exhibit; they may in some ways limit children's access to cognitively complex tasks. The researchers asked 20 highly educated parent-child pairs to design a complex experiment at an interactive exhibit in which a boat was towed down a small canal. Specifically, each parent-child pair was asked to spend 45 minutes designing and interpreting a series of experimental trials to determine the features influencing how quickly the boat would be towed. The researchers found that the parent-child pairs spent considerably more time on experimentation with materials than on interpretation of results. Parents did support and advance their children's reasoning, but they tended to do the more challenging conceptual parts of the activity themselves (such as looking up the results of previous trials and drawing conclusions aloud) and only rarely encouraged their children to take these on, even over time. By comparison, children did the logistical or mechanical aspects (such as releasing the boat in the canal, operating the stopwatch). At the end of the 45 minutes, it was the parents rather than the children who made gains in understanding regarding the true causal features of the boat and canal system. The findings from this study raise intriguing questions about how designed settings might better support parents and other adult care providers to take advantage of these opportunities.

Questioning and Predicting

Questioning and predicting are typically inquiry behaviors that involve articulating ideas to others prior to physical experimentation. The study by Randol (2005) shows that, while visitors did engage in questioning and predicting at interactive exhibits, these were approximately 10 times rarer than manipulating and observing. Even lower frequencies of prediction (3 percent) were found by Allen (2002) in her analysis of visitors' conversations in a multidisciplinary exhibition about frogs. She noted, however, that this figure may be particularly low because many of the elements were live animals rather than interactive exhibits.

Questioning is widely regarded by educators as one of, if not the, central inquiry behaviors that support learning in informal environments. Borun et al. (1996) found that asking and answering questions were some of the key behaviors that discriminated among levels of family learning as defined in their study: families that asked and answered questions were more likely to engage in the processes of "describing" (including making connections between an exhibit and their personal experience) rather than the lower level of "identifying." So it is perhaps surprising that these behaviors, too, appeared relatively infrequently in Randol's (2005) study. One explanation for this is that the asking and answering of questions may be taking place implicitly, rather than being spoken by participants. For example, if it is true that the most common approach to interactive exhibits is "What can this object do?" this already frames an implicit question that need not be publicly stated. Similarly, visitors' common expressions of surprise and intrigue (a mainstay of the "counterintuitive" genre of exhibit design) suggest that some form of implicit prediction must have been made to evoke a surprised response. Callanan and Jipson (2001) report that in contrast to other settings explanatory conversations at museum exhibits were started only rarely by a "why" question from a child. The elements of physical interactivity and novel phenomena available in a museum may encourage a form of discourse that is more of an implicit "what if" than a "why."

Humphrey and Gutwill (2005) showed that the number and kinds of questions visitors ask depends in part on the design of the exhibits they are using. Their team created and studied a class of interactive exhibits that supported active prolonged engagement (APE), a combination of inquiry behaviors that included visitors staying at an exhibit for an extended time, asking and then answering their own questions. These exhibits took several forms, based on the primary form of activity they supported: exploration, investigation, observation, and construction. The APE exhibits were compared with more traditional "planned discovery" exhibits, in which visitors are surprised by a single intriguing phenomenon that is explained in a label. The researchers found that, in interactions with APE exhibits, the number and type of participants' questions varied. Visitors asked more questions overall, and more of them related to using or understanding the exhibit, rather than questions about the logistical aspects of working the exhibit or about what others were experiencing. Also, the team found that visitors using APE exhibits were more likely to answer their own questions by using or discussing the exhibit rather than reading the label. Related studies by Hein, Kelley, Bailey, and Bronnenkant (1996) showed that a series of open-ended exhibits at the Boston Museum of Science also encouraged visitors to ask questions, although no quantitative comparisons were made with other exhibits on the floor.

Drawing conclusions, generalizing, and argumentation are much less frequently observed inquiry behaviors in designed settings. Randol's study of eight interactive exhibits found that, although the exhibits were selected for their ability to support a range of inquiry actions, some actions were very rare. The rarest observed were supporting a claim, explaining an investigation, generalizing, and making a generalized connection between an exhibit phenomenon and a situation outside the museum. These behaviors were observed roughly 100 times less often than manipulation of variables. After looking at the inquiry-related actions through several different theoretical lenses, Randol concludes that most visitors in his study did not engage in what experts consider to be high-level inquiry behaviors, such as drawing conclusions or making generalizations. Nor did they tend to engage in such actions as presenting alternatives or supporting claims, key aspects of building and testing theories in science. Randol attributed this latter finding to visitors' reluctance to do anything that might seem confrontational in a situation focused on leisure and social interaction with companions.

Strand 4: Reflecting on Science

A number of designed environments have created exhibitions and programs that focus specifically on issues in science or on the processes of science from a social and historical perspective. Such exhibitions give visitors the opportunity to reflect on science as a human endeavor and to think about the nature and generation of scientific knowledge.

Perhaps the best known example is *A Question of Truth*, created at the Ontario Science Center, which invites visitors to consider the cultural and political influences that affect scientific activity. The three main themes of the exhibition are (1) frames of reference (e.g., sun-centered versus earth-centered); (2) bias (e.g., concepts of race, eugenics, and intelligence testing); and (3) science and community (e.g., interviews with diverse groups of scientists). Pedretti (2004) conducted interviews with casual visitors, as well as students on school field trips, and found that the exhibition contributed to their understanding of science and society by considering science and social responsibility, controversy and debate, decision making, and ethics. She found that 84 percent of the comment cards left by visitors were overwhelmingly positive, "applauding the science center's efforts to demystify and deconstruct the practice of science while providing a social cultural context" (Pedretti, 2004, p. S43). For example, a visiting student commented, "The exhibit makes us think a lot about our beliefs and why we think in certain ways. . . . I didn't think that the gene that affects the color of your skin was so small and unimportant. Most people don't think of things like that." Another student challenged the view of science as being amoral: "We view science as often being separate from morals, and it's kind of negative because it allows them to do all sorts of things like altering human life, and it may not necessarily be beneficial to our society. . . . Some scientists are saying, should we actually be doing this?"

Pedretti and colleagues (2001) argued that such exhibitions encourage visitors to reflect on the processes of science, politics, and personal beliefs, and they achieve this by personalizing the subject matter, evoking emotion, and stimulating debate by presenting material from multiple perspectives.

Self-Reflections on Learning

Designed environments also provide opportunities for visitors to reflect on their own learning processes, although this has been less frequently studied than other inquiry-related actions. Randol (2005) found that visitors using eight interactive exhibits at science museums frequently made some kind of self-reflective comment, typically with a focus on the way they were using the particular exhibit they were engaged with. Specifically, he reported that over 70 percent of the groups observed made at least one statement regarding the group's progress toward their goal (e.g., "Okay, just two more") or a comment regarding possible problems in procedures (e.g., "Wait, wait—they have to start at the same time").

By contrast, Allen (2002), in her recorded conversations with pairs of visitors at an exhibition on frogs, reported much lower frequencies of self-reflective comments. She distinguished among three subcategories of such talk. (1) Metacognitive comments, in which visitors talked about their own state of current or previous knowledge, were heard at 9 percent of the elements visitors engaged with. Of the 66 elements in the exhibition (exhibits or other components), the element that most frequently evoked metacognitive comments was *Mealtime*, a compilation of video clips of frogs catching and eating their food. Visitors reflected on their surprise at the variety and nature of what frogs ate: "I never would have believed . . ." or "I didn't realize they got them with their tongue." (2) Comments about exhibit use were heard at 16 percent of the stops, for example: "You have to start from here, and then jump as far as you can." (3) Evaluative comments, in which visitors judged their performance or actions, were heard at 8 percent of the exhibit stops. The element that evoked most comments in the latter two categories was *Croak Like a Frog*, an audio-based multimedia exhibit in which visitors could listen to a variety of prerecorded frog calls and record their own imitations. Visitors' comments included: "You have to do it before the red line disappears or it doesn't record," and "This was right, except I made it too long." Allen proposed that several exhibit features probably accounted for the high frequency of evaluative talk: high overall appeal of the exhibit, a challenging interface to problem-solve, and computer-generated graphs that supported visitors' efforts to visually compare their vocalizations with the standard frog calls.

A large body of evidence also shows that visitors are able to reflect on their own learning if asked. Many exit interviews used in summative evaluations of exhibitions ask visitors whether there was anything that they had not previously known, realized, or appreciated. While these are cued reflections rather than spontaneous ones, they provide evidence that visitors can and do reflect on their own learning in designed settings. For example:

> You learn—it's amazing. . . . I'm going on 74 and . . . and you're learning something new everyday. And when you see a statement like scientists still don't agree about algae whether they're plants. You know they work a little like a plant but then they don't and so some say, "yes it is" and some say "no it isn't." I'm looking at the spores—amazing tiny little specimens underneath the microscope—the variety. It's quite intriguing. I think anyone would find it interesting (male, age 73 years) (Jones, 2005, p. 6).

Strand 5: Engaging in Scientific Practices

> By the end, [my son] was working collaboratively with four other kids, which was very nice. They were total strangers. That is how it happens in the lab sometimes when you are working on one thing and your colleagues get together and you start working on something together. . . . He would try something, and then another kid would try something. When it did not work, they would try a different way (National Museum of American History; female, age 43, with male, age 7) (Korn, 2004, p. 42).

In informal settings, participation in science is expected and deliberately designed into the experiences. Children do projects with each other, their parents, or other adults, such as group leaders and museum staff; adults on nature trails or families in zoos and botanical gardens walk and observe together. They use tools and instruments like microscopes or rulers that may be helpful for learning (Jones, 2003; Ma, 2002) but are not necessarily scientific equipment.

Verbal communication, or discourse, is a particularly prevalent and well-studied form of scientific practice in designed settings. In fact, the importance of discourse in learning is broadly acknowledged across a range of subject areas and settings (e.g., Cazden, 2001; National Research Council, 2007) and is of considerable interest to classroom-based science education. Researchers have found that successful science education depends on the learners' involvement in forms of communication and reasoning that models that of scientific communities (Gee, 1994; Lemke, 1990; National Research Council, 2007). There is increasing interest in designing programs and exhibitions that explicitly support social mediation and conversation (e.g., Morrissey, 2002; Schauble and Bartlett, 1997).

Leinhardt and Knutson (2004) combined into a single learning model the notion of conversation as both an outcome and a means of learning. After studying exhibitions at five different types of museums, they listed four levels of visitors' interpretation: listing, analysis, synthesis, and explanation.

They then studied how these contributed to overall learning, defined as a combination of holding time and frequency with which visitors mentioned the exhibition's intended themes during an interview after their visit. While their measure of learning is unorthodox, they found that it was slightly higher for visitors who had higher levels of interpretation while in the exhibition space.

The nature of participant explanation and commentary observed in designed settings varies according to many factors, including gender (Crowley, Callanan, Tenenbaum, and Allen, 2001a), age of the children (Gleason and Schauble, 1999), educational approach or goal (Schauble et al., 2002; Ellenbogen, 2002), available resources, and the skill and background of the leader and of the participants as well as situational demands (e.g., summer camp versus school group field trip). Gelman, Massey, and McManus (1991), for example, found it very difficult to design a stand-alone exhibit that promoted scientific observations and experimenting, as did Schauble and Bartlett (1997).

Parent-Child Interactions

Much of the research on language use has focused on interactions in family groups in museums and science centers. This work dates back over two decades (e.g., Hensel, 1987; McManus, 1987; Taylor, 1986) and is largely comprised of detailed descriptive studies characterizing how adults and children behave and talk while visiting aquariums, museums, and the like. A common emphasis of this work is parent-child interactions.

One critical finding in this literature is that the participation of a parent improves the quality of child engagement with exhibits. For example, Crowley and colleagues (2001a) observed 91 families with children ages 4-8 as they interacted with a zoetrope exhibit in the Children's Discovery Museum in San Jose, California. They found that children who participated with their parents discussed evidence over longer periods of time and in a more focused manner than children who participated without their parents. Parents, they observed, played an important role in helping children select appropriate evidence and identify it as such. When using interactive exhibits with their children, parents tend to focus their explanations on the functions and mechanics of the exhibit, connecting the exhibit with real phenomena, and making connections to formal science ideas (Crowley and Callanan, 1998). Such explanations are often brief and fragmented—Crowley and Galco (2001) call them "explanatoids"—but they seem well targeted to a moment of authentic, collaborative parent-child activity. When parents explain a feature in an exhibit, children are more likely to talk about their experiences with the exhibit. Similarly, as previously noted, Gleason and Schauble (1999) found the educational potential of exhibits in a science gallery depended on mediation by parents. Parents tended to assume the most difficult conceptual tasks, delegating manual tasks to the children. Furthermore, there was little emphasis on science talk or thinking by parents and staff. Callanan, Jipson, and Soennichsen (2002), observing dyads at a science exhibit, noted that parents focus on specific events rather than general principles. They suggest, but do not explore empirically, that this may set the stage for more complex thinking. Parents who have experience in science may be comfortable enough to use the exhibits as props for sharing their knowledge on a particular topic. For example:

> One father described how he used Pulley Table to explain and demonstrate to his son: "Well, mostly I was explaining to my son what it was doing. Showing him that—for instance, there was one pulley that powered and the difference in putting the string on the smaller wheel as compared to the larger wheel, what it does to the other wheels. . . . Another boy walked up as well, and so I showed them the faster you turn it, the faster it plays, depending on the size of the pulley you use will also determine the power" (Case 24, male, early 40s) (Tisdal, 2004, p. 12).

Parents' conversations also depend on what they believe about the setting in relation to their children's learning. For example, Schauble et al. (2002) observed 94 parents of children ages 6-10, as well as 16 museum staff interacting with children at an exhibit in a science gallery. The researchers also conducted interviews to find out the beliefs about learning of each group and what each thought would help children's learning at the exhibit. Nearly half the parents believed that activity, observing, and fun with hands-on materials would lead to learning through sensory experience and excitement; many of these parents sat back and watched their children play, believing that the best assistance was to keep out of their way. Other parents seemed to distinguish play from learning and wondered about how learning could be enriched by resources in the museum. They tended to be less sure about how to assist their children. The museum staff were more likely than parents to value adult mediation (getting involved in children's activities), and some were critical of parents they perceived as passive. The staff talked about a variety of different ways to help children learn and emphasized asking them provocative questions or explaining how things work, compared with the parents' more frequent focus on logistical forms of help. The researchers point out that the staff's larger repertoire of assistance techniques presumably results from their experience in deciding how to mediate visitor experiences on a daily basis in the gallery.

Specialized Science Talk

Not all forms of talk are equally effective supports for science learning in designed settings. For example, Crowley and Jacobs (2002) showed that higher levels of certain kinds of talk by parents were associated with children's learning. In particular, they found that children of parents who read artifact labels aloud (in this case, for fossils) and helped children make connections to shared family history were better at identifying fossils after their museum visit.

Another form of specialized talk, of great interest in classrooms, is argumentation (National Research Council, 2007; Bell and Linn, 2000; Driver, Newton, and Osborne, 2000; Duschl and Osborne, 2002). While there is little research on science-specific modes of argumentation and discussion in informal environments, most observers agree that typical presentations of science in such institutions are built on everyday language in order to engage a general public. Studies of classroom-based science argumentation have found that such discourse generally requires extensive instruction and support, intentional development of shared norms, and long-term practices of reflection (National Research Council, 2007). Thus, even in the cases in which inquiry and scientific talk are encouraged in designed settings, it may be that the experiences are not extended enough to be internalized by the learner. And as noted previously, it also seems plausible that scientific argumentation can be perceived as threatening to the social interactions and leisure goals learners have for their visit. There is no immediate reward for challenging the conceptual structures of others in the group, especially in multigenerational groups in which power is unequally shared. Thus, it is not yet clear whether scientific argumentation can be incorporated into these settings without jeopardizing defining properties of informal environments.

There are documented examples of the use of scientific terminology and language on occasions when museum visitors read labels aloud (Crowley and Jacobs, 2002; Borun et al., 1996) and explain or comment on exhibit features to each other (Tunnicliffe, 1996; Ash, 2002). The time frames of such studies are generally too short to assess whether learners internalize such scientific terminology and use it in other settings. There has not been sufficient work analyzing participation in designed settings over months or years to explore how the use of scientific language might deepen over time in designed spaces.

Scientific Tools

Research on learning broadly employs varied notions of tools, which include not only conventional scientific tools (e.g., laboratory equipment), but also a broader range of representational tools, such as language, graphs, and mathematical formulas. This broader notion of tools is evident in the growing body of research on classrooms (National Research Council, 2007). However, there has been very little emphasis on tools in research on learning science in designed settings. Furthermore, how people are introduced to conventional scientific tools in informal environments has not been directly evaluated, but at least some programs involve participants in inquiries that go beyond communicating scientific language and ideas and require them to use lab equipment, research tools, and measurement tools. For example, in the Cell Lab Exhibition at the Science Museum of Minnesota, participants use a number of tools as they visit the exhibition and its seven wet lab experiment benches. Visitors have the opportunity to use a number of scientific instruments and tools, including microscopes, cameras, monitors, glass slides, test tubes, incubators, dry baths, and UV detectors (National Science Foundation, 2006).

Again, available resources, the skill and background of the leader and the participants, and situational demands are likely to determine the depth of contact and talk, rather than the design of the space or materials alone (Gelman et al., 1991; Gleason and Schauble, 1999; Schauble and Bartlett, 1997). Gleason and Schauble (1999) found that the educational potential of exhibits in a science gallery depended on the mediation, which may be particularly important the more individual exhibits or stations require participants to use scientific tools.

Social Group Influences

There is some evidence that use of scientific language may be influenced by gender (see Chapter 7). One body of work looks at the ways in which parents and facilitators interact with boys and girls. Several studies (Crowley et al., 2001a; Tenenbaum and Leaper, 1998; Tenenbaum, Snow, Roach, and Kurland, 2005) have found that parents engage in modes of discourse associated with higher cognitive demands at higher rates with boys, than with girls. Crowley and colleagues (2001b), for example, examined 298 naturally occurring conversations among parents and their children at interactive exhibits in a science museum. They observed interactions of families with boys and girls, girls only, and boys only and with one, two, or no parents present. They found that parents, both fathers and mothers, tend to provide causal explanations of phenomena to boys more frequently than to girls. Although families seemed not to make gender-based distinctions in bringing children to museums, engaging them in interactive science activities, talking about what exhibits do, or talking about what to perceive in an exhibit, they placed significantly greater emphasis on explaining science to boys. This subtle distinction could have consequences for girls' science learning, raising concerns for parents and educators who design and facilitate learning in designed settings. In *Alice's Wonderland*, an exhibit designed with a theme that parents would think of as interesting to girls, no gender differences in explanations were found, suggesting that modifications to exhibits could influence parents' tendency to engage girls with science (Callanan et al., 2002).

Level of expertise is another factor that may shape group learning processes in designed settings. The varied expertise of group members can influence learning interactions. For example, an individual with a lot of information, even a child, may play an important role in facilitating the learning of others by pointing out critical elements or information and by providing input and structure for a more focused discussion of science (Moll, Amanti, Neff, and Gonzalez, 2005; Palmquist and Crowley, 2007). In a small study of an exhibition about glass, Fienberg and Leinhardt (2002) found that adults with high prior knowledge and interest in glass tended to engage in more explanatory talk (discussing how or why something happened or worked), than those with less prior knowledge or interest.

Vom Lehn, Heath, and Hindmarsh (2001) reported that visitors' activities at an exhibit could be significantly affected by the behavior of other visitors, either companions or strangers. Meisner and colleagues (2007) showed that visitors sometimes turned their interactions with interactive exhibits into spontaneous performances with a theatrical flavor, which allowed them to be shared with other family members or even strangers. And Koran, Koran, and Foster (1988) documented that visitors can learn exhibit-related behavior from strangers, even without any conversation taking place. They found that museum visitors, especially adults, were more likely to engage in such behaviors as touching a manipulative exhibit, listening to headphones, or attending to an exhibit for an extended period if they had previously witnessed a person silently modeling these behaviors.

Strand 6: Identifying with the Scientific Enterprise

Informal environments for science learning, like all educational institutions, can be seen as places of enculturation (Bruner, 1996; Martin and Toon, 2005; Pearce, 1994). Enculturation is about developing identity as a part of a community, and informal settings include different environments that may influence people's identities as science learners (Ivanova, 2003).

Personal identity, viewed as "the cluster of knowledge, dispositions, and activities brought with the visitor" (Leinhardt and Knutson, 2004, p. 50), highly influences museum visitors' conversations (Fienberg and Leinhardt, 2002) and can shape learning experiences more broadly (Ellenbogen, Luke, and Dierking, 2004; Leinhardt and Gregg, 2002; Falk et al., 1998; Leinhardt, Tittle, and Knutson, 2002; Anderson, 2003; Anderson and Shimizu, 2007). For example, Falk, Heimlich, and Bronnenkant (2008) used the following categories to classify 1,555 visitors to a group of four zoos and aquariums:

1. Explorers are curiosity-driven and seek to learn more about whatever they might encounter at the institution.
2. Facilitators are focused primarily on enabling the experience and learning of others in their accompanying social group.
3. Professional/hobbyists feel a close tie between the institution's content and their professional or hobbyist passions.

4. Experience seekers primarily derive satisfaction from the fact of visiting this important site.
5. Spiritual pilgrims are primarily seeking a contemplative and/or restorative experience.

The researchers reported that 55 percent of the visitors showed one dominant kind of motivation under this scheme. The motivations accounted for about a quarter of the variation in visitors' conservation-related attitudes and also correlated with aspects of visitors' long-term memories, suggesting that aspects of identity served as a framework for visitors to make sense of their experience.

Identities such as these may be drivers for what participants do and learn in designed settings. For example, parents who want to develop a particular family identity are able to quickly adapt the general museum experience, as well as specific content, to reinforce the desired identity. Everything from expectations ("We don't bang on the computer screen like that") to personal narrative history ("Do you remember the last time we saw one like that?") can be used to reinforce the values and identity of the family (Ellenbogen, 2003).

Agenda

One aspect of identity is the learners' agenda, that is, the cognitive, affective, or social expectations and goals the individual expects to pursue or satisfy during the event. For example, families tend to see visits as social events (Laetsch, Diamond, Gottfried, and Rosenfeld, 1980) and pursue an identity-related agenda as they generate their own pathway through museums (Cohen, Winkel, Olsen, and Wheeler, 1977; Falk, 2008). For example, Falk tells of Frank, a 40-year-old father whose agenda in museum visits is closely tied to his own childhood experiences. Frank's father, a busy academic, spent little time with him as a child, although he valued science. Similarly, Frank sought to explore science with his own daughter and, at the same time, to play a more active role in his daughter's life. Museum experiences gave him occasion to pursue deep, identity-building experiences. The goals of individuals and groups may be multiple (e.g., pursuing learning, enjoyment, and socialization in a single event) and may incorporate additional practical agendas as well, such as providing tours for out-of-town visitors and for entertaining young children.

Several researchers have interpreted their data to argue that learners act purposefully to meet their individual family's learning goals. Hilke (1989), for example, concluded from her detailed analysis of family behavior in an exhibition that families are pursuing an agenda to learn during their visits to museums.

Anderson and colleagues (Anderson, 2003; Anderson and Shimizu, 2007) have found that the degree to which a learner's agenda is satisfied or frustrated can greatly affect his or her memories of learning experiences. In interviewing participants about world expos they attended after almost two decades of elapsed time, they found that visitors' "social context," which includes the participants' agenda, "dominated their recall of their . . . experiences [15 to 17 years] after the event—more than any other encounter or episode they were able to report" (Anderson, 2003, p. 417).

The participants' agendas and the pedagogical or communicative goals of a particular designed setting may coincide, conflict, or simply fail to connect. Dierking, Burtnyk, Buchner, and Falk (2002), for example, conducted a literature review on participation and learning in zoos and aquariums. They observed frequent disconnects between the agendas of zoo visitors and the ecological goals of zoos. The staff and institutional commitments of zoos typically espouse ecological conservation. However, individuals who visit zoos may fail to perceive ecological principles and conservation commitments in their visit. In fact, they found that even individuals who were zoo-goers and who also made financial contributions to nonzoo ecological organizations may fail to link their ecology and conservation interests to zoo visits. Rather, zoos were seen simply as places to see animals up close.

Science-rich institutions have historically varied in the degree to which they take seriously the agenda of visitors (Doering, 1999). Viewing the visitor as "stranger" reflects a tradition in which the personal collections of gentry were used for their own individual investigations of natural history. When visitors are seen as strangers, the institution focuses primarily on its responsibility and interest in its collection or subject matter and not on the interests or needs of the visiting public. When visitors are viewed as "guests," the institution is inclined to attend to their interests through educational and entertainment activities. Objects and ideas are still central to the institution's values and work, but they also give significant credence to their visitors. For example, a visitor who reads a meteorite exhibit label may choose not to focus on fundamental scientific aspects of the text—the origin of the meteorite, evidence of impact, what it tells us about the universe. Instead, the visitor may focus on an aspect of the label that is personally meaningful to herself or to her family (e.g., the meteorite was found in Alberta, Canada) and use this observation as an opportunity to explore family identity (e.g., recalling that a family member was once in Alberta) rather than a strictly scientific meaning (Ellenbogen, 2003).

Designers and researchers have explored various ways to embrace visitors' agendas, such as supporting visitors to write, speak, or draw their own ideas (McLean and Pollack, 2007) or by changing their scientific labels to embody a conversational tone more compatible with visitors' own (McManus, 1989; Rand, 1990; Serrell, 1996). Both techniques have been shown, at least in some cases, to increase visitors' engagement with scientific material.

Prior Knowledge and Experience

Another aspect of identity is prior knowledge and experience, long recognized as critical to learning by cognitive and sociocultural theories of learning. More recently, analyses of conversations in museum exhibitions have shown that families regularly make verbal connections between prior experiences and novel observations (Callanan and Jipson, 2001; Allen, 2002). Crowley and Jacobs (2002) have suggested that young children learn science by building "islands of expertise," or topics in which they become interested and knowledgeable about over a period of weeks, months, or years. These topics become integrated into family activities, such as field trips, reading books, and dinnertime conversations. In this sense, previously developed ideas and interests influence the trajectory of learning activities over a sustained period of time, becoming a focal point of activity for individuals, peers, and family members.

Practitioners have long been aware of visitors' desire to make links from their sensory experiences in designed settings to their prior knowledge and experiences. Typically, practitioners talk about this as creating "hooks" from science content to everyday life and familiar activities. Such connections are commonly reported in evaluations, as suggested in the following excerpts (Korn, 2004, p. 59):

> "I am very interested in the way scientists are working to map cells and create tools to diagnose [disease]. At my age I'm very interested in health protection" (female, age 55).

> "[I feel connected to the invention process] in everyday life, especially as a mother, when I am called upon [to] solve some kind of problem. When I don't have the right materials [to solve the problem], I have to look at what I have [around me] and try to be creative and come up with some solution" (female, age 48).

Anderson et al. (2002) found that, for children, experiences that were embedded in familiar sociocultural contexts of the child's world, such as play, story, and familiar objects, acted as powerful mediators and supported children's recollections and reflections about their activities. Facilitator-led narrative discussions were particularly memorable. Interestingly, the children's memories were very idiosyncratic. Still, the most memorable aspects of their experience tended to be those that took a familiar form (e.g., play and storytelling). The researchers concluded: "exhibits and programmatic museum experiences that provide context and links with children's own culture . . . will provide greater impact and meaning than [those] that are decontextualized in nature" (p. 229).

At the same time, the effect of prior knowledge on learning is not fully understood in informal settings. Leinhardt and Knutson (2004), in a study of learning in an art museum, found that the background knowledge visitors bring to the museum was the best single predictor of how long they spend and what they learned from an exhibit: the more people already knew, the longer they stayed and the more they tend to talk about and learn from the curatorial themes. These findings, however, conflict with the results of a study by Falk and Storksdieck (2005). They found that while prior knowledge was the most potent predictor of learning in museums, in this case, the more a visitor knew about life science when entering the exhibition, the less they gained, suggesting a ceiling effect or a limitation in the type of gains that could be measured (rather than a disavowal of the importance of prior knowledge). It seems possible that the role prior knowledge plays could depend on many factors, including the domain in question, exact nature of the museum offerings, particular visitors studied, and assessment methods. Clearly, more research is needed to determine how to interpret these findings.

Personal Commitment to Action

Another aspect of personal identity in relation to science is the gradual understanding of the implications of one's own actions on the world and the potential to change those actions in light of scientific evidence.

Many exhibitions and programs at aquariums and zoos focus on this aspect in particular, emphasizing conservation and stewardship, and some have seen results. For example, Falk et al. (2007) studied visitors to two museums and two zoos. They concluded that such visits prompted 54 percent of individuals to reconsider their role in conservation action and to see themselves as part of the solution to environmental problems. Other studies have shown less success in promoting this aspect of identity. For example, Dierking et al. (2004) found that visitors to Disney's Animal Kingdom Conservation Station showed significant short-term increase in their level of planned action, but follow-up phone calls two months later revealed that they had not initiated the intended activities.

Schneider and Cheslock (2003) reviewed studies from a number of fields related to behavior change, including visitor studies and environmental education. They concluded that the most successful programs were those that targeted actions, tailored interventions to the particular audience, built self-efficacy, and used prompts or tools to trigger action. Hayward (1998, in an aquarium exhibition study reported by Yalowitz, 2004) showed the importance of suggesting specific behaviors visitors can engage in to ameliorate environmental problems; without these, visitors left more disillusioned and less empowered than a control group.

One embodiment of this principle is Monterey Bay Aquarium's Seafood Watch, a program that has been operating for over a decade on a national scale. Seafood Watch offers visitors wallet-sized cards containing information about the environmental impact of various fishing practices and makes recommendations about which types of seafood to avoid purchasing. Findings from a large-scale evaluation, using surveys and focus groups, found that participation in Seafood Watch was correlated with changes not only in the purchasing patterns of visitors but also in the selling practices of seafood restaurants across the country (Quadra Planning Consultants, Ltd., 2004). Although linking environmental knowledge to behavior has often proven elusive, the Seafood Watch evaluation found evidence that increased knowledge strengthened pro-environmental attitudes and behavior.

Several studies indicate that an individual's prior interest and involvement in conservation may serve as a better predictor of their responses and actions than typical demographic variables, such as age, gender, ethnicity, or education. For example, visitors with high interest in conservation stopped at more of the exhibits in a conservation-themed aquarium exhibition (Yalowitz, 2004; Hayward, 1997), and zoo visitors' emotional responses to animals were more closely associated with emotional or personality variables (Myers, Saunders, and Birjulin, 2004) than demographic variables.

A common assumption in the field is that affective responses, such as caring for individual animals, will provide a basis for future behavior change. Carol Saunders at the Brookfield Zoo is developing the notion of "conservation psychology" to describe an emerging field that studies how humans behave toward nature, in particular how they come to value and care for it (Saunders, 2003). For example, a detailed study of zoo visitors' self-reported emotional responses showed that certain emotions, including love, sense of connection, and amusement, related powerfully to their interest in the animals' subjective feelings and to their desires to preserve the animals. Such emotions tended to be selectively felt, evoked by some types of animals more than by others. At the same time, the emotions of wonder and respect were also correlated with a desire to save the animal concerned, and these were "equal opportunity" emotions that were experienced at high levels by visitors watching a range of types of animals (Myers et al., 2004). Interestingly, emotions related to love and caring were elicited more frequently by active animals than by passive ones, and a visitor's sense of connection to an animal was particularly enhanced if the person perceived the animal to be attending to them or to other people.

Several evaluation studies suggest that a range of designed settings for science learning afford learners opportunities to experience this kind of wonder and respect toward the natural world. For example:

> "I learned all about plants—where they come from and how they live—so that makes me respect them [plants] more" (male, age 50; translated from Spanish) (Jones, 2005, p. 9).

> "[I think the main purpose of this Africa Savanna exhibit is . . .] to make people aware of the problems regarding the Savanna; it helps personalize it so if you hear about problems regarding the Savanna one is more likely to help" (Meluch, 2006, pp. 16-21).

Building Science Identity Across Age and Background

One of the most common underlying agendas of informal environments is not only to interest people in science, but also possibly to propel children into science careers and engagement in lifelong science learning through hobbies and other everyday pursuits. Compelling stories from leading scientists and science educators often point to museums and similar settings as a contributing influence on their lifelong passion for science (Csikszentmihalyi, 1996; Spock, 2000). Such experiences may serve as a general or specific impetus for a brilliant career, for example:

> A fairly typical childhood is one recalled by Isabella Karle, one of the leading crystallographers in the world, a pioneer in new methods of electron diffraction analysis and X-ray analysis. Her parents were Polish immigrants with minimal formal education and limited means. Yet even during the worst years of the Great Depression Isabella's mother saved from her housekeeping money so that the family could take two-week vacations to explore the East Coast. The parents took their children to the library, to museums, and to concerts. . . . So even though a child need not develop an early interest in a domain in order to become creative in it later, it does help a great deal to become exposed early to the wealth and variety of life (Csikszentmihalyi, 1996, p. 163).

> [E.O.] Wilson wanted to be an entomologist by age ten; some issues of the National Geographic and a visit with a friend to the Washington zoo confirmed that what he wanted most to do in life was to become an explorer and a naturalist (Csikszentmihalyi, 1996, p. 267).

A study by Sachatello-Sawyer and colleagues (2002) shows that adults seeking learning experiences in their midlives often turn to subjects that were of interest to them around the age of 10. These studies highlight the impact of experiences in informal environments at an early age on later life decisions for some, offering evidence of ongoing learning progressions in science. Interestingly, these progressions may falter and stall, especially without continuing involvement. For example, Jarvis and Pell (2005) interviewed children ages 10-11 two months after their visit to a space center, including a mediated group experience at a Challenger Center simulation. They found that 20 percent of the students were more interested in science careers after their visit than before, but that this interest declined over a 4-5 month period following the experience.

Some attempts have been made by practitioners to extend the learning trajectories of participants over space and time. For example, Schauble and Bartlett (2002) designed an extended trajectory for science learning by using the notion of a funnel, in which the outermost, largest physical space is designed to invite learners through easily accessible, compelling, and loosely structured experiences. The outer edge of the funnel would serve all learners, and those who chose to continue to pursue the big idea in question would move further into the funnel. The second level of the funnel was a series of quieter, restricted areas that they called Discovery Labs. One example of these was the Dock Shop, where participants could explore boat design, including the design of different types of hulls tested for carrying capacity and various sail types tested with a wind machine. The deepest portion of the funnel was designed for repeat visitors, such as members and children from the local neighborhood. The activities in this portion of the gallery were designed to build on children's prior experiences in the museum, at home, and at school. Visitors would borrow kits that were housed in the museum and also distributed through local libraries. These kits contained materials that allowed children to extend their explorations in more detailed, sustained studies and to send in their results to the museum through Science Postcards. For learners who wished to pursue a particular topic in depth, they would need to find ways to extend their learning over time, perhaps over the course of a 90-minute visit or for return visits and for additional activities (e.g., future reading, watching educational television). Similarly, many institutions have created systems for lending visitors objects and interpretive materials, such as books, for a period of time, and some (e.g., Science North in Canada) have borrowed or bought reciprocal contributions from visitors, which they have developed doing science outside the institution.

Some examples of longer term identity development come from studies of youth interns at science centers (Beane and Pope, 2002; Gupta and Siegel, 2008). Such studies suggest that the combination of appropriate mentorship, support, responsibility, and resources provided by these internships can support the personal learning and empowerment that lead a young person to choose a science-related career. An example of this is the New York Hall of Science Explainer Program, which has created an institutionalized career path for its young docents, providing them direct access to a science teaching training program. Since 1987 that program has followed approximately 400 young people using various forms of communication and involved them in four formal evaluations. The museum staff found that the program builds knowledge and teaching skills, skills for careers in a variety of professions, social bonds, and leadership (Gupta and Siegel, 2008).

Intensive programming for science learning has also been shown to have a long-lasting impact on children's identities as learners. A longitudinal study of young women from urban, low-income, single-parent families who participated in an after-school science museum program found that more than 90 percent of the participants went on to attend college (Fadigan and Hammrich, 2004). For those young women, careers in medical or health-related fields, followed by careers related to science, mathematics, and technology, were the highest ranking chosen career paths four to nine years after initial participation in the program. The young women pointed to three characteristics—having staff to talk to, learning job skills, and having the museum as a safe place to go—as most influential on their chosen educational and career paths. Extended programs are discussed in greater depth in Chapter 6.

As is discussed in Chapter 7, institutions tend to represent or reflect the dominant culture, which may present a conflict for those from nondominant groups (Ivanova, 2003). In order to manage these differences, a child from a marginalized culture may temporarily adopt an identity for science learning experiences (Heath, 1982). If one can better understand how children come to integrate science into their home cultures, rather than temporarily adopting an identity, such knowledge can be used to create science learning environments that are more accessible and meaningful (Warren, Rosebery, and Conant, 1994).

To find out whether individual learners integrate experiences in informal environments with their personal and community-related identities, further study and models are needed to explore the long-term impacts of these experiences. It may be that temporarily adopting a science-specific identity does not advance a long-term or permanent sense of oneself as a science learner. It may be, however, that experimenting with identities in informal environments is an important form of creative play in a low-stakes situation. Further work is needed, then, on identity development and sustainability in relation to learning science in informal environments over time, focused on learners' multiple identities and how exploring a new identity or integrating multiple identities can lead to greater participation in science.

CONCLUSION

The literature on designed settings for science learning provides considerable evidence of learning across the strands. For Strand 1 there is evidence of learner excitement and strong positive emotional responses to experiences of science and the natural world. This may lead to other forms of valuable learning (sustained interest, flexible reasoning, etc.), although the evidence on this is less clear and the research is limited. There is also clear evidence for learning science content (Strand 2), in the form of factual recall after experiences in designed settings. Recollection seems to be supported by experiential linkages that ground abstractions in sensory experiences. It is unclear how learners draw from these experiences to assemble broader conceptual knowledge. This is an issue for future research, which is likely to require tracking participants over time and across settings. Strand 3 has strong support as learners engage in exploration and interaction, "doing and seeing," questioning, explaining, and making sense of the natural and designed world. There is some evidence for aspects of Strand 4, reflecting on science, in designed settings. Although analysis of visitor behavior suggests that reflection is limited, in the context of interviews, researchers and evaluators have found that participants can reflect on the enterprise of science and on their own thinking about science in the context of designed settings. Facilitation appears to be critical to supporting reflection. However, in designed settings, extensive facilitation by professional staff may not be feasible. And it may not always be desirable, as it can interfere with leisure experiences and interrupt other important developments in the participant experience.

Strand 5, engaging in science, is also strongly supported, especially in the general form of social interaction, in which learners jointly explore and interpret the natural world. Social interaction is a notable strong tendency in multigenerational group visits. However, participating in practices such as scientific argumentation as is often studied in school settings is not explored here. Further, it is likely not an appropriate goal for most designed settings for science learning which do not afford for facilitated, longer term investigations within a community of learners.

For Strand 6, there is evidence of learners' attempts to personalize and integrate science learning experiences with their values and identity. This lends support to the educational practice of adjusting science content and learning experiences to be compatible with learner agendas.

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