Constructing a Science Gallery for Children and Families: The Role of Research in an Innovative Design Process

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Received by 5 November 1996; accepted 15 May 1997

ABSTRACT: We describe the role of research in designing ScienceWorks, an innovative gallery at The Children's Museum of Indianapolis. The gallery, intended for 6–10-year-old children and their families, was constructed on the basis of existing and new research concerning how children think and learn about science. The gallery is atypical in several respects, but perhaps most fundamentally in its overarching agenda, to foster children's understanding. Each major component in the gallery contains a broad array of activities to support learning for casual visitors, but also includes opportunities for successively deeper levels of learning and engagement. Existing research on science learning was reviewed to develop the theoretical framework that guided the design process. Moreover, research informed the development of each of the major gallery components and its associated learning activities. Current ongoing research focuses on identifying effective forms of mediation in the gallery, which is more accurately conceived as a collection of tools for supporting children's learning at various levels of engagement, than as a series of stand-alone "exhibits." © 1997 John Wiley & Sons, Inc. *Sci Ed* **81:**781–793, 1997.

INTRODUCTION

This article describes an unusual design process that guided the development of a 12,000-square-foot science gallery within the world's largest children's museum, The Children's Museum of Indianapolis. The gallery, called ScienceWorks, is targeted for elementary-school-aged children and their families. Participants in the design included science educators and cognitive developmental psychologists, curriculum specialists, museum administrators, exhibit designers,

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 CCC 0036-8326/97/060781-13

development staff, educators, curators, collection staff, and community members, who worked together over approximately a 5-year period to plan, design, construct, and open the gallery. The planning, which spanned from 1991 to 1996, was informed by extensive analysis of existing science museums and galleries, traditional and reform science curricula, and research on children's science learning. During a 3-year portion of that period, the goals of the new gallery coalesced around a science agenda that was new for The Children's Museum and appears to be unusual for science museums and other children's museums, as well.

PURPOSE FOR THE GALLERY

At the heart of the process was the orchestration of an extended investigation into and debate about the fundamental question: What is a science gallery for? There are many legitimate goals that planners might hold for a science museum or gallery, beyond the obvious one of attracting large numbers of visitors and providing them with a good time. Among the goals often cited are: exciting visitors about science; helping visitors envision themselves in careers concerning science and technology; educating citizens about the role of science in everyday life; and providing a base of understanding to support scientifically informed decisions about public issues such as global warming, deforestation, development of nuclear power, and protection of endangered species. Yet, although agendas like these are sometimes articulated by museums, rarely is any one of them implemented in a consistent and coherent way. Instead, different constituencies—exhibit designers, education staff, the development department, physical plant, potential funders, museum trustees, schools, and community members—are likely to hold competing agendas, often without even being aware of the mismatches. Unless serious consideration and commitment are made to hammering out and adhering to a common vision, the result is often that multiple, and even competing goals may be embraced in parallel, and the gallery may become a hodgepodge of exhibits and activities that reflect no clear selection principle.

Occasions to reconsider first purposes tend to be infrequent in the life of institutions, because history and tradition reify the solutions of the past and carry them forward into the present. However, overall purpose becomes more salient when something brand new is created. In the case of The Children's Museum, there was wide consensus in the early 1990s that it was time to retire the existing science gallery, which featured exhibits that were popular but that, by and large, exemplified science principles that were opaque to the average visitor. In contrast, the primary agenda for the new gallery was framed from the beginning as being to foster understanding. There were several background conditions that contributed to this orientation. First, the early planning was managed through the Education Department of the museum. In the history of their interactions with other museums, the Education staff noted that, although often cited, children's understanding of science is rarely pursued seriously. Second, it is likely that the museum's central commitment to meeting the needs of children pushed it toward a somewhat different orientation than another kind of museum—for example, a science museum. Finally, The Children's Museum of Indianapolis includes visitor research as an integral part of its exhibit development process and has a reputation within the museum community for finding new methods to establish that learning can be one important outcome of a museum experience.

David Cassady, the Director of Education, framed the question that guided the planning process: "What do elementary-aged children need to learn about science, and how do they learn it?" Readers may recognize that this is the same question that guides contemporary movements to reform elementary school science teaching and learning. Early in the planning process, the museum staff approached members of the university research community to learn where the answers to this question might reside, apparently expecting that the solutions already existed and that locating them was a matter of identifying the right university partner to serve as a guide. Only gradually, over an extended period devoted to reviewing innovative science standards and curricula and reading research on children's science learning, did the staff become aware that a considerable gap remains between those issues on which consensus has been achieved about the general trajectory for elementary science learning goals and the level of detail that is needed to guide educational practice.

Hence, to guide both global and local decisionmaking, three "levels" of research were planned and conducted by members of the planning team. These levels were conducted sequentially, so that decisions made at the first level constrained those made at the second, and those at the second constrained those made at the third. At the first level, the group spent an entire summer together working intensively to develop a theoretical framework that would address Cassady's original questions: What do children need to learn about science?, and How do they learn it? Then, building on that framework, the team worked for approximately 3 years to settle on an overall gallery design and a plan for each of its major components. At the second level, this process was informed by existing and museum-sponsored research that elaborated the details of children's learning in domain-specific topics of subject matter. Third, as construction of the gallery neared completion, the team turned its attention to the forms of mediation or teaching that would need to be established within the gallery to achieve its learning potential. The bulk of the current research effort is presently devoted to these questions about forms of mediation.

We next describe and summarize the research that contributed to each of these three phases as a way of articulating the role of research in the larger design process. We complete the paper by speculating about why such a process is not more widely used in museum planning.

LEVEL 1: THEORETICAL FRAMEWORK AND OVERALL GALLERY DESIGN

Typically, museums depend for their existence on attracting and pleasing large crowds of visitors who are in a "leisure time" frame of mind. The strength of museums is in their breadth of materials, resources, and activities, which collectively invite visitors with varying interests and backgrounds to sample the museum widely and to become engaged at varying levels, spanning the continuum from browsing an exhibit to participating intensively in a long-term project. Ironically, this very breadth and multiplicity often effectively preclude visitors from spending substantial time on any one experience and serve as barriers to moving beyond "grazing" to process information deeply, reflect about one's prior conceptions on the basis of new information, or engage in systematic study or exploration. The last two decades of research on children's science learning suggest that these prevailing visitor expectations and museum resources may not always align easily with the goal of supporting learning. This research has shown that science knowledge is constructed slowly by learners over an extended period of time, and that in some domains of science, simply encountering new ideas does little to change prevailing conceptions (e.g., an annotated bibliography by Pfundt & Duit [1991] abstracts over 2000 of these studies of student conceptions). In the face of these findings, one might wonder whether it might be more realistic to back off a commitment to learning and understanding in favor of a less ambitious approach organized around entertaining or trying to influence general attitudes about science. So what's a museum to do?

In the theoretical framework constructed during the first summer of planning the Science Planning Team (1991) specifically addressed this challenge. The framework suggests that priority should be given to forms of learning that can be accomplished successfully in museums, especially to those that can occur uniquely in museums. The framework explicitly acknowledges that the gallery plans would need to be responsive to the fact that science learning is constructed by the learner in a long-term process, raising the question, what role can a museum best play in a long-term developmental process?

A "Funnel Approach" to Gallery Design

The strategy proposed by the theoretical framework was to adopt a "funnel approach" featuring a wide array of options at entry level for browsing visitors and successively narrower and deeper learning options for visitors who elect to spend more time and more focused participation in parts of the gallery. Consistent with this funneling design, the major exhibit components in ScienceWorks were designed to pull visitors immediately into activity that foregrounds "big ideas" in science. For example, The Creek is a large stream table that affords experimentation with principles of turbulence, flow, and buoyancy. It immediately attracts visitors into building and racing boats of various designs; experimenting with a set of working canal locks; building and testing systems of pipes and valves; moving water from one part of the stream to another with buckets, pumps, paddlewheels, and an Archimedes screw; and manipulating components of the stream, such as its depth, width, curvature, and obstacles. It is not unusual for visitors to spend an hour or more investigating these features. However, like each of the major gallery components, The Creek also includes an area where visitors go beyond "attract mode." These are quieter, restricted areas or "discovery labs" where visitors engage in deeper exploration of or more systematic experimentation about the ideas or concepts in the exhibit. For example, adjacent to The Creek is the Dock Shop, where visitors explore various aspects of boat design; for example, different-shaped hulls and their effect on carrying capacity, different kinds of sailboats and their racing speed as tested with a powerful wind machine, paddlewheel boats of different design, and hovercrafts, among others. Boxed kits in each of the discovery areas provide instructions and materials for preplanned investigations that parents and children can pursue together; in addition, each discovery area provides a range of materials and tools to support more open-ended exploration. The Dock Shop has shelves holding a variety of kinds of boats to try out in The Creek, but it also has bins of rubber bands, Styrofoam bowls, cardboard, balloons, and other materials for designing a boat "from scratch." Finally, at the deepest portion of the "funnel," the team planned activities and experiences designed for repeat visitors, typically family members of the Museum or children from the local neighborhood. These activities were designed to build upon and extend activities first encountered at the museum into other contexts, such as the child's home, school, or backyard. Visitors can borrow materials and activity kits from the museum through Rex's Lending Center, an information center that is housed within the museum and coordinated with the local libraries. Through "Science Postcards," children mail back the results of their home-based investigations to the Museum, where they are added to databases that visitors can manipulate and query. With curatorial staff supervision, the experienced or well-informed visitor can design and conduct a research project with museum collections or in the nearby Ritchey Woods, a nature preserve owned and managed by the museum.

The planning team recommended that "entry level" material—the portion of gallery content occupying the widest portion of the funnel—should feature concepts that can be learned cumulatively. Understanding these ideas does not require conceptual shifts or radical insights; rather, understanding these ideas typically emerges from a cumulative acquisition and restructuring of knowledge that can occur gradually over an extended period of time. For example, Carey's (1985) work on the development of biological knowledge suggests that most children successfully construct an adult-like theory of biological knowledge over the elementary school years. Increasingly, living beings come to be regarded as sharing the need to accomplish a common set of biological functions, such as reproduction, respiration, and digestion. According to Carey, acquiring a biological theory is a matter of gradually constructing a knowledge base that is structured in appropriate ways. Her research suggests that this acquisition is not particularly problematic, and that most children achieve it without notable difficulties. Developing a biological theory typically does not entail overcoming deep-seated misconceptions that are resistant to instruction, suggesting that biological concepts about the characteristics shared by living organisms are among the good candidates for populating the wide portion of the visitor funnel. The theoretical framework suggested that it would be a good strategy to feature some of these ideas in ways that make the familiar intriguing. An example is Nature's Backyard, a major gallery component that simulates the familiar setting of a child's backyard. Included in this component are an Indiana freshwater pond with living plants and "critters," a watershed table with its own rainmaker that simulates the area around Fall Creek; a rock-climbing wall that fronts on a simulated fossil dig where visitors find, identify, and chart fossils in the slump material at the bottom of the wall; and an underground crawl-through with two different tunnels, in which visitors explore the habitats of animals that live underground. Near the pond, a picnic table holds tools and materials to learn about the microscopic life in the pond and in the soil around the pond. Microscopes, well slides, stain, eye droppers, magnifying glasses, and guidebooks help visitors to investigate animals and plants that cannot be seen with the naked eye. A video microscope allows larger numbers of visitors to receive an "up close and personal" view of the microscopic life in the pond. In the nearby Nature's Workshop, there are a variety of related collection materials and tools to help visitors investigate the living animals and plants in this environment. The exhibit is designed to help young visitors begin to build on their knowledge of natural watershed environments, animal habitats, animal characteristics and life cycles, wetlands, and fossils, and to strengthen skills in observation, inference, measurement, and communication.

In contrast to the biological concepts featured in Nature's Backyard, there is a considerable corpus of research documenting the misconception-proneness of some other ideas that people find more difficult to understand, such as force, energy, density, momentum, and work. Although researchers disagree about how to help children understand these concepts, many believe that in early grades, we should concentrate on helping children develop sound intuitions that can form the basis for later formal instruction (diSessa, 1982, 1983; White, 1984). This is the approach taken in The Construction Site, adjacent in the gallery to Nature's Backyard. The Construction Site provides a context in which young children play as "construction workers," engaged in moving large loads (piles of foam "rock" and "cinder blocks") with full-sized bulldozers, cranes, and dump trucks that they operate by controlling systems of gears and levers. Wheelbarrows of different design are used to move "rock" up ramps of different length and inclination. The ramps are designed to pose problems for visitors to solve. For example, one ramp has a bumpy surface that needs to be "patched" with a board. Wheelbarrows are constructed by visitors, who choose the wheels and handles that they wish to affix. Systems of pulleys and buckets, dollies, and platforms and rollers are used to transfer construction materials from place to place, so that children can fill in portions of the construction wall. As children experience first-hand the trade-offs between effort, distance, and load lifted, their intuitions about machines are supported in ways that traditional school instruction about simple machines usually cannot provide. Materials and curricula commonly found in schools typically do not encourage children to negotiate these trade-offs in the context of play situations that afford extended practice, and those materials that do exploit mechanical advantage in design contexts are typically small-scale and thus do not provide the opportunity for children to experience these ideas "with their bodies." In the museum, these ideas are further addressed in mediated activities that are conducted in the discovery labs located in each of the major exhibit components. For example, the Construction Site Workshop, located on a second story landing directly above the Site, supports a range of activities in engineering and design, including several that extend concepts in the gallery.

Structure of the Gallery

In contrast to many science galleries, ScienceWorks does not consist of a set of exhibits organized into a hierarchy of familiar science concepts and subtopics. Rather than illustrating concepts from the elementary science curriculum, the gallery is designed to exemplify a few overarching themes or “big ideas” in science as they occur in the places where children live. Consistent with recommendations by national science standards movements, such as Project 2061 and the National Research Council, these organizing themes, including “Change and Motion,” “Structure and Function,” and “Interactions,” appear across contexts and levels of the major gallery components. If diagrammed, the conceptual organization of the gallery would look more like a multiply connected web than a hierarchical tree structure. Within these overarching themes, topics for the gallery were selected for their centrality in domains of science, their consistency with the organizing themes, their suitability for supporting learning in a museum context, their affordance of cross-connections, and their developmental felicity with respect to children’s appropriate next targets for learning. For example, research suggests that evolution is a difficult and perhaps overly ambitious topic for young elementary school students, especially in an informal learning context. In contrast, adaptiveness between organisms and their environments, maintenance of an organism’s identity across the life cycle regardless of changes in appearance, inter- and intraspecies diversity, and inheritance of species characteristics from parents are within closer reach, and provide an important foundation for later understanding of natural selection.

The interconnectedness of concepts in the gallery means that young children are likely to encounter the same idea across a range of contexts that superficially look quite different. For example, the machines featured under the “Change and Motion” theme in The Construction Site (gears, levers, inclined planes) also appear in Nature’s Backyard in the rock-climbing equipment used for scaling the climbing wall. They reappear in the analyses of animal movement that are conducted under the porch in Nature’s Workshop. When students are invited in a mediated activity to construct a model that “works like their elbow,” they are encouraged to evaluate the adaptational advantages of the trade-off between effort and reach effected by the design of the human elbow (Penner, Giles, Lehrer, & Schauble, 1997), which is basically a third class lever (in this case, the “Structure and Function” and “Change and Motion” themes intersect). In The Creek, systems of pulleys, levers, screws, and buckets can be used to move water from place to place. Finally, in the exhibits at the doorway of the gallery, two giant Rube Goldberg machines use levers, gears, and planes to deflect a series of colored balls around an obstacle course. The planning staff deliberately programmed in these kinds of “cross connections” whenever it was feasible to do so, to provide visitors with an opportunity to revisit a core set of ideas across multiple settings. And, as these examples illustrate, the gallery does not honor the traditional bifurcation into “life sciences” and “physical sciences.” Our premise was that the world does not come prepackaged into “physics,” “biology,” “earth sciences,” and other artificial subject-matter boxes, and such an organization would be especially misleading in a gallery meant to render the familiar world more understandable.

Finally, ScienceWorks adopted the general strategy of encouraging children’s extended play with materials, situations, and contexts that foreground important ideas in science. Learning through the medium of play is an approach particularly suitable for elementary-school-aged children in informal learning environments. Emphasis was given to fostering cooperative play and other forms of social interaction, both among children and between children and participating adults. The team found helpful the metaphor of a sandbox; that is, a large, publicly sharable space where many play at one time, each at his or her own appropriate level of entry, and where it is evident immediately what activities can be pursued there. The "science sandbox" metaphor helped to orient the team toward designing compelling scenarios that suggest a common "script" and clear roles—as construction workers, fossil hunters, or city planners, for example. Compelling scripts and roles help to organize children's activity, orienting them quickly about "what you are supposed to do," without overprescribing or constraining children's interactions. The science sandbox metaphor influenced the design of several gallery components, including The Construction Site, The Creek, the watershed table, and the fossil dig.

The Theoretical Framework: One Constraint among Many

It would be misleading, however, to suggest that the gallery plan followed directly and unproblematically from the theoretical framework. Instead, the framework is most accurately conceived as providing one set of constraints among many others as members of the science planning team negotiated with other stakeholders about the overall configuration of the gallery. Often these multiple constraints competed for the attention and consideration of planning team members; frequently, a series of meetings would be held and substantial progress would be made. However, at a later point, new considerations or issues would intrude on the process, derailing it or thrusting the planning off in an orthogonal direction. Hence, rather than being a rational, linear process that proceeded straightforwardly from a start state to an end state, the design process at times seemed to proceed simultaneously in disparate directions, backtrack, or, too often, begin all over again at "square one." These other constraints on the design covered a very wide array of issues, and many did not emerge until the planning was well downstream. For example, they included: the aesthetic preferences of exhibit designers, who wanted to construct a gallery that would look fresh, "hip," and new; the Museum administrative staff's concerns about the appropriate balance between spending on infrastructure versus programming; trade-offs between the attractiveness of large, constructed environments that would necessarily be relatively difficult to change versus those that would be relatively plain in design yet flexible and adaptive; the relative novelty of proposed gallery components in comparison to those staff had observed at other science and children's museums; and the construction engineers' concerns about how the fifth floor location planned for the gallery could support the large quantities of water (which would also have to be filtered and contained!) in the planned exhibits.

The design process was like an exaggerated version of that described by Reitman (1965), who asked a musical composer to think aloud as he composed a new piece of music, a fugue. According to Reitman, during the composition process constraints proliferated simultaneously in two directions: forward, so that a choice made at a given point in the musical piece then served to constrain the choices that could follow it, but also backward, so that a musical decision might also entail the need to revise parts of the composition that preceded it. We refer to the gallery design as an "exaggerated version" both because the design constraints in this case operated over much longer periods of time (a decision made at one point might entail backward revisions of other decisions originally made up to 2 or 3 years earlier), and because the values, agendas, and concerns of so many disparate groups of people were involved in generating constraints. A constraint was more likely to "win" the competition over other competing constraints if it was considered to be a "make or break" decision (e.g., decisions about finances, safety, and feasibility tended to override decisions about aesthetic preference or educational value) or if it was championed by a particularly powerful participant in the process (e.g., a member of the Museum's administrative staff). Design decisions that provided particularly apt ways of addressing a relatively narrow set of considerations (e.g., The Construction Site seemed a particularly fortuitous solution to the problem of introducing children to ideas about machines in a context that would inspire symbolic play) tended to be given more credit than acceptable but less innovative solutions that in fact might solve wider sets of problems. These constraints typically competed over long periods, so it commonly occurred that strong advocates for one position ended up being persuaded to a different point of view. Hence, persistence, clarity, and the ability to justify proposed design decisions were fundamentally important in keeping the educational concerns "alive" through this process, as was the fact that the planning team was led by members of the Education staff. Final responsibility—and hence, final decisionmaking—rested on individuals who were personally and professionally invested in the educational perspective developed initially, a fact that doubtless helped to preserve the central emphasis on learning.

Approximately 3 years into the design process, the overall design of the gallery was finally settled, and most of the major components were identified (although because of spatial and financial considerations, some of these continued to change right up to the opening of the gallery). Consistent with the emphasis on making the familiar understandable, the gallery would be an Indiana landscape with approximately half a dozen components loosely linked by theme. The gallery would include The Creek area and Dockshop, described above; The Construction Site and The Construction Site Workshop; Nature's Backyard, with the rock climbing wall, the fossil dig, the underground crawl-through, the watershed table, The Pond, and Nature's Workshop, a house with a live animal habitat located under its porch; and an Underground Sewer Room, entered through a descending "elevator," where more systematic experimentation would be conducted in a mediated context. Having finally decided on the major components of the gallery, the planning team next turned its attention to designing the components in detail, a process that was informed by more specific consideration of student understanding within the domains and topics to be featured in the gallery.

LEVEL 2: LEARNING HOW CHILDREN THINK WITHIN DOMAINS OF SCIENCE

The second level of research contributing to the ScienceWorks planning process is familiar to science education researchers; it involved reviewing existing research and conducting novel research to learn about elementary-school children's learning and understanding of the wide range of topics featured in the gallery. We believed that to be developmentally appropriate, the design of gallery components should be informed by a sound understanding of children's typical beginning knowledge about the topic of interest, identification of knowledge targets that are both desirable and feasible, and awareness of the pathways by which children's knowledge usually develops from typical beginning state to desired target state. Although these objectives sound familiar, they are not easy to achieve, because little of the research concerning children's scientific thinking is developmental; instead, it typically presents snapshots of knowledge rather than characterizing patterns of change, and it attends primarily to products, rather than processes of learning. Moreover, research about children's knowledge of science is spotty, at best, tending to emphasize a few topics, touch on others, and entirely overlook many. Hence, the role for research at this stage was to find and interpret existing research that could profitably be brought to bear on the design of gallery components, and to fill in where existing research did not exist.

For example, to support the development of The Construction Site and The Construction

Site Workshop, we sought out the research concerning children's understanding of simple machines (Schauble, 1992). Little such research existed, and most of it focused not on characterizing children's knowledge about machines *per se*, but on broader aspects of children's thinking, such as their causal reasoning. Concurrent with the design of the gallery, the first author (L.S.) began, with Richard Lehrer, a 3-year program of research supported by the National Science Foundation to study children's learning about simple machines in design contexts (Lehrer & Schauble, submitted; Schauble, 1996; Schauble & Lehrer, 1995a and b). The results from this research helped to shape the design of the gallery. Similarly, previous work on children's understanding of hydrodynamics and hydrostatics (Schauble, 1990, 1996) undergirded the development of The Creek. As mentioned earlier, work by Carey (1985) and others who have been charting children's early biological theories, inspired the development of The Pond and other elements in Nature's Backyard.

With the assistance of The Children's Museum, who provided scientific information, publications, and fossil collections to serve as research stimuli, Susan Carpenter and Leona Schauble conducted a cross-sectional study comparing 60 first-graders', third graders', and fifth graders' conceptions of fossils (Carpenter & Schauble, in preparation). We conducted a systematic interview study of children's conceptions about fossils and their formation, including how children identify fossils and distinguish them from nonfossils, what they think fossils are, how they believe that fossils are formed, whether they can match parts to counterparts and parts of fossils to wholes, what they believe about the relationships between living plants and animals and their fossilized forms, what they think fossils are "made of," and related concepts such as superposition and time scale. Like the other programs of research at this second level, results of the fossil study were used to inform the design of the fossil dig, but perhaps even more important, were used to develop learning activities arranged nearby the dig that supplement the "built" components of the gallery, provide participation and activity for children at deeper levels of the "funnel," and provide additional learning opportunities.

Readers may be wondering in what ways these exhibits are new or unique. Certainly, many museums include exhibits about ponds and pond life, fossils, and simple machines. In our view, it is not the selection of subject matter for the exhibits that comprises the main contribution of the gallery. Rather, it is the focus on the development of children's thinking that typically results in an emphasis or an approach that might not otherwise be considered. For example, in The Construction Site, children are encouraged to take a design or engineering stance toward the task of moving heavy objects and materials. In our work on children's understanding of simple machines (Lehrer & Schauble, submitted; Schauble & Lehrer, 1995a and b), we have noted that explaining principles to children or inviting them to observe how machines work is not sufficient for changing their conceptions—children often fail to see things that adults might consider obvious. In our research, large proportions of our young participants looked directly at moving mechanical parts (e.g., on gearboards, or in eggbeaters, or bicycles) and misdescribed the speed or direction (or both!) of components that were clearly visible. Instead of merely demonstrating principles to children, we have had considerably more success in asking them to apply those principles in the context of inventing successful solutions to design problems, an approach that we have also adopted in the ScienceWorks gallery. Similarly, in other parts of the gallery, we have attempted to contribute a child's-eye view to content or activities that may otherwise seem similar to those that appear in other museums.

LEVEL 3: MUSEUMS AS PLACES FOR TEACHING AND LEARNING

ScienceWorks opened its doors in the summer of 1996. The gallery indeed appears to be highly effective in attracting children and their families and engaging them for sustained periods of time.

Yet much research remains to be done, because the gallery remains a work in progress. (At the time this article was written, the gallery had just opened.) For one thing, the museum is exploring forms of education that will help parents and other visitors, as well as trustees, teachers, and other community stakeholders, to understand the goals and approach of ScienceWorks, which looks very different from a traditional science museum. A related issue concerns preparing professional museum mediators, teenage volunteers, and parents to become thoughtful at assisting children's learning, not only during play and casual interaction, but especially at the narrower and deeper levels of the "funnel." Many of the opportunities for educational participation in the gallery are not immediately obvious upon casual inspection, especially because they are situated within large, compelling environments that invite play. Most of the gallery components are designed to be used in a wide variety of ways, extending from play to systematic experimentation. For example, at The Creek, children can explore a wide variety of phenomena at an entry level, but at deeper levels, the potential exists to conduct a series of systematic experiments; for example, to determine which combination of boat shape and stream-bed configuration results in the fastest travel time. However, the second kind of option is not likely to be pursued by children unless thoughtful mediation is provided, both to alert children to possibilities that they may not perceive and to provide sensitive assistance to foster their participation and understanding.

In our view, mediation in museum contexts, whether it is managed by museum artifacts like labels, or by museum staff or parents, is currently poorly understood. In fact, our understanding of museums as learning contexts probably lags behind our understanding of classrooms by about 15 years. For example, it is only relatively recently that research has begun to focus seriously on characterizing what it is that good teachers do (Leinhardt & Greeno, 1986; Shulman, 1986). Rather than attempting to explain student learning by a combination of student traits, like intelligence or socioeconomic level, on the one hand, or forms of curriculum, on the other, these recent fine-grained studies of expert teaching hold promise of explicating relations between the details of teaching and the learning that results. These studies illuminate how teachers coordinate and juggle multiple agendas, drawing on multiple knowledge sources to guide teaching decisions "on the fly." Teachers' knowledge resources include knowledge not just of subject-matter content, but also of benchmarks and trajectories of student thinking (Peterson, Fennema, & Carpenter, 1991).

Ironically, our theories of learning in museums, like our earlier theories of learning in classrooms, tend to render teaching invisible. In fact, the folk theory of museum design probably considers those galleries that require the least amount of mediation to be those that are the most successful. Yet, mediation is central and omnipresent, even when museum staff think they are not providing it. Mediation, broadly construed, includes the signage, gallery layout, tools, and notations that signal meaning within the museum space, as well as the way that children's interactions with each other and with adults contribute to the meaning that gets constructed. For example, Leichter's (Leichter, Hensel, & Larsen, 1989) work clarifies the central role that parents and other adults take, not merely in explaining specific content to their children, but in communicating broader expectations and values about being in a museum: the way one behaves there, what function it serves in the ongoing life of a family, and what one is likely to observe and experience.

Mediation, then, is the heart and soul of museums. It is always present and it needs to be planned for. Rather than trying to design the need for person-to-person mediation out of existence, museums would be better off opening it up as a topic of study and investigation. An important lesson from classroom studies is that studying forms of student learning often makes little sense without studying forms of teaching. The implication is that to take learning seriously as a goal, museums will need to become much more self-conscious and systematic about developing and studying the varieties and forms of mediation that they provide and/or shape.

Current research in ScienceWorks is focusing on these problems. In addition to the traditional museum concern with tools, signs, layout, and other forms of built-in mediation, we are thinking seriously about the mediation provided by museum staff and adult visitors. Now that we have constructed a gallery that is sensitive to children's understanding, we are working to help our museum staff become knowledgeable about children's thinking. In traditional galleries that transmit facts about science, these forms of expertise may be less important for museum staff to possess. But the gallery components in ScienceWorks are perhaps more appropriately considered as tools rather than exhibits, and like good tools, they can be put to best use when they are managed with thoughtfulness and intelligence. Helping visitors make the most of these tools requires sensitivity to children's thinking and willingness to learn about the forms of assistance that will push that thinking to the next step.

Work toward this objective involves conducting workshops with staff about the specifics of children's thinking within the subject-matter content domains that the gallery features. Equally important, we have also begun together to delineate those areas in which research has not been conducted, and where little is known about children's understanding. The museum staff believe that a central part of their job is to learn as much as they can about how children think and understand the science topics featured in the gallery, and to work together to use that knowledge to develop, try out, and revise the forms of teaching and assistance that occur on the floor.

Concurrently, research is focusing on identifying effective ways that parents can assume effective mediating roles. For example, we are currently completing a study (Gleason & Schauble, in preparation) in which 20 parent–child dyads were videotaped as they worked for 45 minutes on an open-ended experimentation problem like those found in many parts of the gallery. Previous research (Schauble, 1991, 1996) demonstrates that adults tend to use strategies and problem-solving approaches in these contexts that preadolescent children fail to employ and, as a result, adults in general are much more successful at solving these problems than children are. However, we do not know if parents are likely to assist their children with these strategies spontaneously when parent and child work together, nor do we know what forms of parental assistance will be most effective at bolstering children's problem solving. In this study we are focusing our analysis on these issues, with the objective of providing exhibit designers and parents with specific information about how best to assist children's learning.

CONCLUSION: WHY DOESN'T THIS HAPPEN ROUTINELY?

We conclude this study by considering why this kind of research-design collaboration remains relatively uncommon in museums and other informal learning environments. Although more and more museums are incorporating research about visitor response, too often research is framed by museum staff and funders as "evaluation," that is, as a way of demonstrating the success of a completed project, and not as a compass for guiding the unfolding design. In our view, this kind of evaluation mentality is short-sighted. It clearly appeals to funders and contributors, but an overemphasis on the effectiveness of a product (like a gallery or exhibit) may do little to change the process of future designs. Hence, a museum where research serves primarily an evaluative function may not be a museum best organized to learn and grow.

Of course, an obvious barrier is that research costs money. At a time when many museums are struggling for their very existence, research may be regarded as a luxury that cannot be afforded. In the case of ScienceWorks, generous support from the National Science Foundation and other contributors helped to surmount that barrier. However, it is worth noting that costs for research were very modest across the life of the project, especially when compared with other parts of the design process.

Museums also struggle to attract and involve researchers over the long term in an enterprise that may not be central to their professional identity. Although a small group of researchers has worked seriously on problems of informal learning over the past several decades, for better or for worse, most university researchers consider themselves “scientists,” not engineers or designers. Yet the latter roles are arguably a much better match to the activities needed in this kind of enterprise. Unfortunately, the field of education has a tendency to dichotomize research and practice in unproductive ways, and long-term programs of research like that conducted in Indianapolis have no natural home either in the museum or in the university. Museum staff are understandably oriented toward completing the details of planning and implementation. Moreover, the product valued by university departments is professional publications of research, not galleries and exhibits. Hence, the hours spent on work that has no valued “payoff” make this work risky to university researchers. This situation is unlikely to change as long as educators conceptualize teaching and learning as the scientific study of naturally occurring phenomena, rather than as a design enterprise (conceiving of education as a design profession was proposed by Glaser as early as the 1970s and has been argued more recently by Ann Brown, Alan Collins, and Rich Lehrer, among others).

A related problem is that informal learning has begun to be taken seriously only recently by the mainstream research community. Subfields such as educational psychology and instructional psychology have organized around school learning, but as yet, there is no recognized disciplinary subspecialty that has coalesced for the purpose of generating constructs and methodologies to address the challenges of studying informal learning. Although an intrepid group of researchers has worked for a long time to study these forms of learning, they remain a relatively small group, and these problems have not yet grabbed the imagination of the larger research community. However, there are signs that this may be changing.

Perhaps it is the dwindling of resources for formal education that is inspiring citizens to take a second look at other community resources for education—from organizations like the Boys’ and Girls’ Clubs to 4-H clubs and hobbyist societies to local sports leagues. Recently, the Carnegie Council on Adolescent Development (1992) emphasized the importance in children’s lives of having available a broad array of educative contexts that can supply overlapping and reinforcing opportunities for learning, practicing, and applying skills and knowledge in productive and positive surroundings. Perhaps it is the general interest in taking a critical look at the assumptions and structures of formal schooling that brings renewed attention to features of out-of-school contexts where children voluntarily pursue personal interests, develop personal knowledge, and contribute to learning projects in ways that are often quite impressive (Resnick, 1987, Schauble, Bankes, Coates, Martin, & Sterling, 1996). Perhaps it is our growing understanding that school learning always occurs within the broader context of the values and norms promulgated by family and community, and the acknowledgement that it is essential to align these value systems if children’s learning is to be optimized (Lehrer & Shumow, 1997). For all these reasons and perhaps others, the good news is that interest in children’s learning in out-of-school contexts is growing.

Finally, as in other cross-disciplinary partnerships, much depends on success in building interpersonal relationships, trust, and shared history that can support the long-term negotiation of competing goals and agendas, the search for common languages for communication, and the development of a shared aesthetic. These processes do not occur easily, nor do they occur overnight. Yet the fruitfulness of research-museum partnerships will depend on whether participants can make the time and space for them.

We are grateful for assistance from The Science Planning Team and other helpful staff at the Children’s Museum and from Richard Lehrer, Susan Carpenter, David Penner, Nancy Giles, and Mary Gleason, who participated in research that informed the development of ScienceWorks.

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