3-1997

Learning Science beyond the Classroom

Linda Ramey-Gassert
Wright State University

Learning Science beyond the Classroom

Linda Ramey-Gassert
Wright State University

The Elementary School Journal
Volume 97, Number 4

0013-5984/97/9704-0009$01.00

Abstract

Science education reform documents call for science to be taught in the manner that students learn best, by conducting hands-on, engaging investigations using simple everyday materials. Often overlooked in the redesign of science education, informal science learning environments such as science centers, museums, and zoos provide students with captivating science experiences that can be related closely to curricular objectives. In this article I examine a cross-section of craft knowledge and research-based literature on science learning beyond the classroom, describe informal science education programs, and discuss implications for enhanced science teaching. The article focuses on the importance of informal science learning experiences, in the context of a variety of out-of-school science environments, for children and for in-service and preservice teachers. Informal science education environments provide students with unique, engaging science learning opportunities and classroom teachers with a wealth of science teaching resources. A model for enhanced school/informal science education and for school-level policy change is proposed.

Informal science education is an often overlooked area of science learning. Broadly defined, any science learning that takes place outside the school walls is an out-of-school learning experience (see Falk & Dierking, 1992). Wellington (1990) stated that science as it is presented in school bears little resemblance to the natural world where science and technology are everywhere. According to Wellington, there is enough science to keep one investigating for a lifetime, "on playgrounds, in kitchens, on sports fields and golf courses, in shop windows, in the back garden or on rubbish tips" (p. 250). Traditionally, providing students with out-of-school, informal science learning experiences has meant 1-day trips to natural history museums, science and technology centers, summer camps, nature preserves, zoos, gardens, and so on (Dierking, 1991). Informal science education can also include science investigations on the playground, perhaps initiated by an incident with a bug on the sidewalk, an interaction with a parent or classroom teacher, or by a playmate's comment. Trips to the produce section of the grocery store, visits to the veterinarian's office, or any number of experiences where children encounter new information about the world around them are informative. In this context, virtually all experiences where a child interacts with the natural world generate science learning in some sense.

Much has been written concerning out-of-school science learning, especially on field trips. Although this writing provides valuable insights into science learning beyond the classroom, craft knowledge needs to be distinguished from formal research in the field. In this article I discuss craft knowledge and research on science learning beyond the classroom, describe model informal science education programs, and discuss implications for enhanced science teaching and policy change. I also present evidence of the importance of informal science learning experiences in out-of-school science environments for children and for in-service and preservice teachers. Although museums house collections, science centers are more interactive, and nature centers have outdoor exhibits, I use terms such as "science museums" and "science centers" interchangeably throughout this article to denote informal science learning environments in a generic sense.

Informal Science Environments

Differences between In- and Out-of-School Learning Environments

What makes science museum learning experiences different from most traditional classroom settings? What does craft knowledge reveal about the characteristics of effective informal science learning environments? According to Ramey-Gassert, Walberg, and Walberg (1994, p. 351), "Museum learning has many potential advantages: nurturing curiosity, improving motivation and attitudes, engaging the audience through participation and social interaction, and enrichment. By nurturing curiosity, the desire to learn can be enhanced." In science, as in all learning, students must be engaged, attentive, and interested in an activity in order for learning to occur. Teachers often generate this interest and engage students in the initial phase of learning by using an object or puzzling phenomenon (Madden, 1985; Wolf, 1986).

Resnick (1987) elaborated on the differences between learning that occurs inside and outside school, stating that in-school learning tends to be solitary, based in symbols and the abstract, and divorced from real-world experiences, with little or no connection with the actual objects or events represented. In contrast, out-of-school learning more commonly involves the accomplishment of an intellectual or physical task by a group that is interacting using real elements, which allows learning to take on greater meaning (Resnick, 1987). Beer (1987) noted that a museum does not need to look like a school to have a strong educational purpose. Gardner (1991) called for schools to take on the attributes of museums to encourage well-rounded education. Indeed, many science centers have education departments run by former classroom teachers and curricular materials designed to enhance science teaching in informal settings. Whether it is because teachers are unaware of how to incorporate museum materials into their science curricula or because they are unfamiliar with science education resources, many teachers seldom use out-of-school science learning environments.

One major distinction between in- and out-of-school science experiences is that learning in a museum depends less on verbal or written symbols for communication, thus permitting learners to interact with real-world objects without the additional learning of often new or confusing terminology. Teaching in the traditional sense relies heavily on the use of symbols in reading and mathematics and on oral communication. In contrast, informal science environments offer learners more direct nonverbal experiences, objects and visual displays, instead of discourse to relay information (Beer, 1987; Falk, Koran, & Dierking, 1986). Serrell (1990) cautioned that, although learning styles research may have implications for museum learners, it has evolved from school-based studies of extrinsically motivated learners. One primary difference is that learners in an informal setting are intrinsically motivated to gain personal meaning from their learning, which has greater value than memorizing facts or doing well on a test.

Characteristics of Informal Science Learning Environments

Motivational, engaging, enjoyable, and nonthreatening. Informal learning centers and museums have long recognized that visitors are individuals—an eclectic assortment of sizes, ages, inclinations, abilities, and propensities to learn—arriving with differing interests, learning styles, prior knowledge, and experiences in science (Beer, 1987; Feber, 1987). Wellington (1990) examined features of museums that are most effective in developing visitors' interest in and understanding of science. He pointed out that students in science centers display interest, enthusiasm, motivation, alertness, awareness, and a general openness and eagerness to learn, characteristics that tend to be neglected in school science. Wellington concluded that the overall atmosphere of informal science learning, including features such as "voluntary, unstructured, nonassessed, open-ended, and learner-centered" (p. 248), led to interest and learning. Semper (1990) noted that intrinsic factors—such as curiosity, enjoyment of learning, and mastery of challenge—are potent motivational tools. He added that science centers provide a rich learning environment for students with a variety of learning styles while implementing four themes in educational theory: curiosity or intrinsically motivated learning, multiple modes of learning, play and exploration during the learning process, and the existence of self-developed world views and models among people who learn science.

Chambers (1990) related the discovery of a new idea or newly revealed understanding, often called an "aha" experience, to the behavioral psychologist Mihaly Csikszentmihalyi's research. Much of Csikszentmihalyi's work on the role of motivation in learning has been conducted in museums. Csikszentmihalyi (1987) studied the motivational basis for intrinsically rewarding activities and termed a high degree of participation in such an activity as a "flow" experience. Flow has been described as the deep involvement and effortless progression learners feel when an activity goes smoothly. Flow, then, is what motivates learners to spend time doing something that has no reward other than the activity and resultant learning (Chambers, 1990; Csikszentmihalyi, 1987).

Csikszentmihalyi (1987, p. 81) stated that to behavioral psychologists, learning was wholly a cognitive, conceptual process and that the manipulation of information within the learner's mind was the key issue. "But learning involves the whole person, not just the rational mind. It involves the senses, the desires, the longings, the feelings, and the motivations as well. The difficult thing with people is to turn them on to learning. Once they are motivated, once they are ready to start, the major obstacle is over. How to present information is secondary because the learner will go out and find the information no matter how difficult it is to get it. The question is how to get them to want to learn in the first place."

Csikszentmihalyi (1987) theorized that there are two components to how people learn. The first presents the primary instructional task as transmitting or passing along to the learner as much information as possible. The second component involves strategies for making sense out of the new information. These two components are often presented as separate, but in the ideal learning environment they go hand in hand. The learner needs to possess prior knowledge and have opportunities to discover and to investigate that permit discovery of new information and foster understanding of the natural world (Csikszentmihalyi, 1987). Doris (1993) described the rediscovery of this "aha" experience in an action research project involving her second and third graders. She suggested ways to keep children's natural curiosity and sense of wonder alive and to overcome the barriers to effective science teaching such as allowing children time to learn to wonder as well as to generate and ponder self-perpetuating questions.

Grinell (1988) provided another, perhaps intuitive clue, that enjoyment should be recognized as a precursor to learning. To summarize, students must be engaged by the learning task and actively involved in enjoyable, stimulating learning tasks to sustain the motivation needed to understand and assimilate new information. The mechanisms at work are the focus of much study and theorizing.

Hands-on, experiential, and personal. Museums are often viewed as repositories for collections of valuable and cherished objects, but with the creation of more interactive children's museums, a shift has taken place in science education institutions (Ames, 1988; Edeiken, 1992). Falk et al. (1986) pointed out that, by inviting interactive hands-on experiences with real objects, museums can enhance children's sense of wonder. By third grade, many students lose their natural sense of curiosity, insightfulness, and ability to learn from exploration when mostly rote classroom learning takes over (Harte, 1989; Semper, 1990). Unlike many classrooms, informal science learning environments provide free-choice, self-paced, multisensory, and socially interactive spaces for learning by doing. Exploration and discovery are vital to fostering a child's natural curiosity, which lays the foundation for conceptual science learning (Bresler, 1991). According to Semper (1990, p. 4), museum visitors "often say somewhat wistfully, 'If science had been taught like this when I was in school, I would have stayed with it.' " Informal science learning environments allow students to observe and investigate natural objects and phenomena and live specimens in ways that textbooks cannot (Semper, 1990).

Science centers are envisioned to entice learners to go beyond their present knowledge and to construct a newer, larger vista of scientific thinking. Resnick (1987) indicated that many successful in-school programs draw on real-world relevance and connectedness with outside-of-school learning to aid students in finding personal meaning in cognitive activity. Carr (1989, p. 55) stated that museum learning is not accidental but rather proceeds from "authentic encounters with order and meaning, pattern and explanation." According to Carr, science centers combine space and time for reflection with exhibit areas that promote experiential involvement in learning. Museums presuppose learners to be responsive, reflective, and observant visitors with prior knowledge and the ability to connect new information with their everyday lives. "Museums are to assist people to explore and develop what they know, . . . invite an avalanche of questions and foster the webwork of connections that configurate a learning life" (p. 55).

Informal science environments operate with the fundamental assumption that providing visitors with vivid experiences will allow them to develop conceptual connections between the museum experience and the everyday world—an "aha" experience when a sudden connection is made (Feber, 1987). Seletsky (1990, p. 16) described her frequent museum visits with her elementary class: "During all these visits, some children sketched, some wrote, some talked; some found links to things we'd been discussing in class, others made new discoveries. Each new discovery, . . . generates real excitement, and that means they want to do something. The trick, of course, is to capitalize on that excitement, seize the moment and build on it in ways that can be extended when we're back in the classroom. Connections and continuity are what I'm after." Hornung (1987) indicated that encouraging students to make connections between informal science learning and the everyday world illustrates one aspect of the complexity of teaching and that new teachers in particular need to develop this skill.

The critical role of "playing or tinkering around" in hands-on science learning has also been addressed in the science education literature. Experts believe that, even if children do not show immediate evidence of experience, tinkering can prove valuable for risk taking and problem solving in the future. According to Feber (1987, p. 87), exhibitry is specially designed so that, "at the cognitive level, interactive exhibitions have at their heart an invitation to play which is seductive to young and old. Fundamentally, the playing visitor is using experimental strategies, forming hypotheses, testing them, rejecting some ideas and retaining others; . . . [one] reason interactive exhibits are so appropriate for science subjects." Seletsky (1990, p. 17) stated that children have a natural tendency to reduce the "awe" of discovering their world "to manageable proportions by touching, holding, playing with, getting close to things." Some adults criticize children who appear to be playing in science centers because they think the children cannot be learning (Wellington, 1990). As any teacher or parent will attest, however, there is no valid distinction between so-called playing and learning for children. Wellington (1990, p. 249) interviewed teachers after a museum trip and found that "every teacher interviewed, without exception, felt that the centre they were visiting at the time was making some contribution to their pupils' science education. The fact that children are actually playing and being entertained is not seen as a drawback but as an advantage by those involved in educating the scientists and technologists of the future."

Wellington (1990) noted that in contrast to classrooms, science museums draw heavily on the psychomotor domain with the presence of gadgets and technology that develop skills in manipulating equipment, manual dexterity, and hand-to-eye coordination. Madden (1985) applied psychological principles, such as constructivist theory, to science learning. He found that active participation or personally interacting with new material increases the acquisition and retention of information.

The Social Component of a Museum Experience

Miller (1987, p. 177) stated that "the most effective source of attitudes toward science and mathematics is the family. The family can socialize either a very positive or a very negative attitude toward science. . . . Parents want their children to study science and mathematics and encourage that through the selection of toys, visits to museums, subscriptions to science magazines, and talk about topics and problems that involve science." The importance of the social component, including family interactions, during a museum visit is a major theme in research on informal science education settings. Learning in a museum generally takes place in a social context where learners interact spontaneously with one another, their parents or teachers, and the museum environment (Harte, 1989; Semper, 1990). Sharing excitement and new discoveries stimulates children and is conducive to retention and reinforcement of learning. Feber (1987) suggested that visitors' need to range freely, to explore while being gregarious, and to congregate perhaps makes museum science learning meaningful and memorable. According to Wellington (1990), many museum visitors file new information away in memory only to have it resurface weeks, months, or years later. The initial museum visit has value, but the stored memories also represent valuable learning, "by sowing seeds and leaving memories which may ultimately lead to understanding" (p. 250).

According to the experts, then, informal science learning environments can engage and excite students to experience science in ways uncommon to the classroom. By offering science through real-world objects and natural phenomena, science centers can provide hands-on, exploratory science learning in a nonevaluative, relaxed context. In short, informal settings have the potential to extend classroom science learning by providing students with a range of rich, motivating experiences.

Research on Informal Science Learning Environments

Field Trips

Often, out-of-school science is limited to a one-time excursion remotely connected to classroom science teaching. According to Prather (1989, p. 10), "A field trip, by definition, is any journey taken under the auspices of the school for educational purposes." Prather (1989) documented that for the last 75 years field trips have been part of American public education and that, when used properly, they are an effective hands-on science teaching method. He found considerable research evidence that, compared to other teaching methods, well-conducted field trips enhance students' attitudes toward science and their informational gain depending on the concept taught and the learning objective.

Productive field trips where students focus on learning objectives enable students to connect more abstract classroom learning with real-world science (Prather, 1989; Ramey-Gassert & Prather, 1994). Planning, including becoming familiar with the field trip site (restrooms, possible waiting lines, terrain, etc.), will reduce inappropriate student behavior and increase learning. The field trip organizer must be prepared for all foreseeable contingencies while allowing learners' experiences to be open-ended and exploratory.

One variable that has received substantial study is the effect of novelty, or first-time exposure to a field site (Bitgood, 1991; Kubota & Olstad, 1991). Novelty may generate learners' interest (Rice & Feher, 1987), or it may distract from learning and lead to the "running around" and other undesirable behaviors often associated with field trips (Falk, Martin, & Balling, 1978; Martin, Falk, & Balling, 1981). Bitgood (1991), Harrison and Neaf (1985), Harte (1989), and Prather (1989) found that preparing students by familiarizing them with the field trip site, either by more than one visit, videotapes, slides, or informed discussion, may be a critical factor in learning. Field trips are less effective when used as a diversion rather than as a means to reinforce learning.

Factors Affecting Learning

Rice and Feher (1987) used Piagetian-style interviews to study 40 8–14-year-old students' concepts of light and vision after students had visited a related science center display. The researchers were able to identify deficiencies in students' thinking that could be used to guide instruction. They concluded, however, that "there is more involved here than insights that inform the traditional instructional task of correcting misconceptions and filling conceptual gaps" (p. 638). Their findings have been used to improve the design of museum exhibits and classroom activities that facilitate learning by strengthening students' curiosity, motivation, and ability to make predictions and find sound explanations. According to Feher and Rice (1988, p. 638), "Immersion in such a phenomenon-rich environment is undoubtedly a necessary, even if not sufficient condition for learning to occur" (p. 649).

Birney (1988) described a series of studies based on children's learning of science concepts during visits to museums and zoos. Students reported that they learned better and retained more if they were prepared, believed there was information to be learned, and had control over their learning (i.e., learning was self-paced; they could discuss a discovery with a classmate; and they could engage in physical as well as mental activities). In research on the thought processes of children as they performed a set of tasks at an exhibit on optical phenomena, Feher and Diamond (1990, p. 27) reported that the "children's predictions and explanations showed the existence of modes of thought or 'mental models' that are widespread and consistent."

Another series of studies focused on the effects of social interactions on learning in an informal science setting. In a study at Scotland's first interactive science center, The Stratosphere, Tuckey (1992) found that peer teaching was evident. Older students showed more understanding of the exhibits' concepts than did younger children, who tended to give descriptive accounts of their visit. Approximately one-fourth of the students' statements were attitudinal ("I learned that science can be fun," "I learned that science is more exciting when you are doing it yourself") (p. 36). Tuckey also found that students tended to recall the most information from exhibits that demanded their full attention and required active mental as well as physical involvement, whereas little was recalled of purely visual displays. Tuckey cautioned that "the educational value of interactive science centers should not be conceived in a narrowly didactic sense but should include an assessment of the motivation aroused and the benefits of social interaction as well as the learning taking place" (p. 28). Schibeci (1993) compared 107 adults' and 151 early adolescent students' knowledge of the relation between physical exercise and health before and after exposure to a prescribed learning sequence at an interactive sports exhibit. Although both groups were initially well informed, only the adolescents showed a significant increase in understanding of the benefits of exercise when posttested.

In research on families' social interactions in museums, Birney (1988) noted that one's ability to gain conceptual understanding from exhibits may be a result of how he or she was taught to approach exhibits during family visits. "Point and name" behaviors where parents approach an exhibit, point to and identify the animal to their children, then quickly move to the next exhibit are less conducive to forming higher-level concepts than observation and open-ended questioning. Similarly, Feher and Diamond (1990, p. 27) found that "transfer of information within family groups is strikingly bi-directional, occurring as often from children to parents as vice-versa. This finding contrasts with the commonly held notion that teaching is the passage of information from a wiser to a more naive person." In an observational study of visitors to a Lawrence Hall of Science physics discovery room, Eratuuli and Sneider (1990) found that social interactions and teamwork between parents and children were important aspects of the visit. They concluded that the vast majority of visitors engage in learning activities that are enjoyable and develop understanding rather than move randomly through exhibits.

Stevenson (1991) investigated long-term retention of information by family groups visiting the interactive Launch Pad exhibit at London's Science Museum. He found that most visitors recalled detailed information about their visit and that over one-quarter had spent time since the visit reflecting on the experience or had related the information gained to a recent event in their lives. Stevenson observed that children spent over twice as long (53% of their time) interacting with the exhibits as did adults, 29% of their time observing, and 15% moving from one exhibit to another. This contradicts the notion that children spend most of their time "rushing around."

According to Stevenson (1991), "Analysis of the tracking data revealed few differences in the way that males and females interacted with the exhibits, which provides encouraging news to those who hope ISTCs [interactive science technological centers] provide equal opportunities for both genders" (pp. 529–530). Kremer and Mullins (1992) studied gender differences in 419 K–3 children's behaviors at the Center of Science and Industry (Columbus, Ohio) and offered suggestions for creating gender-balanced science learning in school as well as out of school. They pointed out that museums can offer interactive experiences designed to enhance *all* children's science readiness by promoting an equitable science learning environment through creation of exhibits that emphasize the use of cross-gender skills—boys engaging in social and verbal skills and girls manipulating objects and exercising spatial visualization skills. Diamond (in Feher & Diamond, 1990) observed that boys approached and manipulated objects significantly more often than did girls at San Francisco's Exploratorium and the Lawrence Hall of Science. It is interesting to note that Linn and Hyde (1989) proposed that the disparity in science scores between male and female students on the Scholastic Assessment Test could be narrowed considerably if females were given more opportunities for hands-on manipulation of tools and scientific equipment.

Several researchers have compared differences in students' learning after a museum visit that included an intervention. Wright (1980) studied sixth-grade students' comprehension and application of knowledge of human body concepts using students from six comparable intact classrooms that were randomly assigned to the experimental or control group (random assignment of individual students was not possible). Six classroom teachers were instructed in delivery of the curriculum, then randomly assigned to a class. All classes received 5 weeks of instruction totaling 15 hours. While the control group classes received a review during week 6, the experimental classes visited the Kansas Health Museum where they viewed films, discussed human body concepts, and independently investigated related exhibits. A pretest did not indicate any significant differences between control and experimental classes, whereas the experimental group had higher posttest scores. Wright contended that, "This result supports the idea that multisensory, hands-on experiences provide sixth-grade students with concrete ways to assimilate and apply complex concepts concerning the human body" (p. 103).

Martinello and Kromer (1990) investigated the development of inferential thinking about ecology concepts of 283 lower socioeconomic status fourth-grade Hispanic students. The 14 experimental classroom groups took a 2-hour tour of an interpretive ecology exhibit followed by classroom instruction of a four-lesson ecological sequence in a 2-week intensive program or in one lasting 6 weeks. Each lesson lasted about 50 minutes, and instruction was provided by students' teachers, who received training in using the curriculum. A pretest/posttest research design was used. Two groups of students and two teachers who taught their regular science program and did not tour the exhibits served as controls. The researchers reported that "neither group excelled in using descriptors, but the six-week treatment group produced more and/or better inferences than the two-week or control groups" (p. 21). In both the Wright (1980) and Martinello and Kromer (1990) studies, students who spent more time with museum objects and exhibits developed a deeper, more complex understanding of science than students who had little or no exposure to the museum setting.

Assessment of Learning in Informal Science Environments

Frank Oppenheimer (1975), the originator of the Exploratorium in San Francisco, argued against formal assessment in science centers. He saw the inherent value of informal learning in promoting science education and science and opposed the dominant, narrow view of science education taken in traditional, in-school science. He noted that, because learning in science museums is not graded, no one "flunks" an informal encounter with science. So, very similar to assessment of learning after hands-on activities, assessment of learning in museums is an unresolved issue generating much debate and many attempts, some successful, some not, to evaluate the amount and quality of learning that takes place.

Wellington (1990) stated that difficulties in assessment of learning in informal settings lie in "unpacking" the many facets of museum learning. Price and Hein (1991) reported findings from 15 years of science museum studies. Crane (1994) discussed indepth the complexity and difficulties of accurately assessing components of learning such as changes in attitudes, levels of performance, and concept mastery in informal science environments. Semper (1990) noted that the more subtle but nonetheless valuable learning experiences that museums provide are hard to document using traditional methods. Birney (1988) pointed out that assessment of science learning in museums is different because learning is extremely individualized and is not assessed using prescribed standards such as letter grades or scores. She cited, as an example, the educational value of information presented in an exhibit or demonstrated by an activity on an unguided tour that generates spontaneous student discussion. This lack of evaluation is one of the obvious strengths and attractions of informal science learning. Wellington (1990) noted that, compared to school science, learning in science museums typically is more social, open-ended, learner-directed and learner-centered, less planned and sequenced, voluntary, nonevaluative, and has many unintended outcomes, particularly outcomes that may be difficult to measure. These important distinctions illustrate why it is difficult to assess informal science learning. I believe that projects, with appropriate scoring rubrics, where students combine science content from the classroom and the museum, are the best way for students to demonstrate this type of learning.

Informal Science Learning Programs

Gartenhaus (1991) and St. John (1990) reported on many innovative programs conducted by science museums. Both authors elaborated on program offerings, including kits of museum objects loaned out for classroom investigations; field trip and cocurricular planning packets; overnight, Saturday, and summer programs; programs for gifted, minority, and female students; as well as preservice and in-service teacher programs. Another informal science learning area is afterschool math and science programs (Seidman, 1989; Shroyer, Ramey-Gassert, Hancock, Walker, & Moore, 1995). In this section I describe several well-documented programs that use informal science education settings.

Programs for Students and Parents/Children

Seidman (1989) described an urban after-school science and math resource and activity center that targeted minority students and their families. This center was part of a teacher-developed program emphasizing topics of interest to students and teachers that can be linked with classroom curriculum. "Wednesdays are family nights when students are accompanied by a parent. These popular sessions usually include an experiment in which all can participate, along with time for independent exploration" (Seidman, p. 26). Kyle, Bonnstetter, Sedotti, and Dvarskas (1990) described ScienceQuest, a hands-on, out-of-school science program. They stated that, in addition to enhancing students' and teachers' attitudes and knowledge of science, this program also incorporated factors to "integrate a balance of science processes and concepts; provide students with opportunities to identify and solve problems; enhance higher cognitive processes and skills; go beyond the mere possession of information to the application of concepts; and include societal issues" (p. 20).

In a well-received museum program described by Downs (1989), visitors received an engaging, user-friendly "logbook" and a mystery "fragment." Children, parents, scout groups, and other visitors were directed to use the investigative notes and clues in the logbook to solve the "Mystery of the Five Fragments." This program has also been developed into kits that include pre- and postvisit activities for classroom use. Intriguing programs such as this allow parents and children to work together using science processes and investigative skills.

Wallach and Callahan (1994) described their efforts as teachers in primary classrooms to base student assessment on Gardner's work on multiple intelligences, as part of a learner-directed plant science unit for 52 first graders. Students visited museums in the St. Louis area, and the authors developed a Likert rating scale for students to evaluate the museums' presentation of information. The students then used this knowledge to develop a plant museum, complete with 26 student-researched interactive exhibits, student-developed reference materials, even a "museum store." The teacher researchers stated that the final products clearly assessed and demonstrated students' development of genuine understanding and independent learning in a multitude of "intelligences."

Williams (1993) described a 6-day environmental camp for sixth graders from inner-city, rural, and urban settings. The camp began in 1966 and has served over 150,000 students. This popular outdoor program has a 6-week preparation component and a follow-up resource guide for teachers. The curriculum includes ecological concepts, ecosystem connectedness, as well as attempts to change students' attitudes by developing their awareness and respect for the natural world through outdoor activities such as soil composition, soil erosion, topography, climate, and the web of life. "Reverence for nature was evident in the behavior of the sixth graders and the staff; more important, nature was not viewed as something 'out there', but rather connections were sought between human lives and nature, as the complex dependency of living things was explored and experienced" (Williams, 1993, p. 102). Each year 1,400 high school students are trained and serve as volunteer junior counselors for the 6,500 students who attend the camp. This program addresses a problem area in informal science education—involvement of adolescents.

Leroux (1989) described a Canadian museum program designed to challenge both teachers in graduate courses and high-ability students. The program benefited participants in many cognitive and affective ways, allowing them to discover the enjoyment of scientific investigation. St. John (1990) described several science museum programs such as those offered for classroom teachers and K–12 students at Cranbrook Institute of Science in Detroit. For several years an intensive 4-day program has been offered to area fifth- and sixth-grade students and their teachers. This program focuses on providing high-quality science and natural history experiences using exhibits and other museum and natural outdoor areas. Undergraduate and graduate teacher candidates who act as program facilitators gain much-needed firsthand experience with students in the area of science. Classroom teachers and university instructors who participated in the program spoke of the science learning opportunities that both students and teachers otherwise would not have had.

Programs for Teachers

Martinello and Gonzalez (1987) described a collaborative effort between a university and area museums that prepared preservice and in-service teachers to teach science and addressed some science needs of local schools. This program helped teachers to use the museum's vast resources. The collaborative university-science center program has helped "teach practicing teachers how to engage their students with the content of museum exhibits ... starting even earlier by building museum practice into preservice teacher education programs" (p. 16).

Chesebrough (1994) and Martinello and Gonzalez (1987) elaborated on the benefits of using museum settings to prepare preservice teachers to teach science. These authors concluded that, compared to traditional classroom science teaching, informal science learning environments improved students' attitudes toward science and provided preservice teachers with unique insights into children's ways of understanding and learning about the natural world. Teachers' knowledge of museums' curricula and resources can be crucial for successful science teaching (Martinello & Gonzalez, 1987; Sakofs, 1985).

Boykie (1986) described a collaborative in-service program (StarLab) involving local colleges and the New York Hall of Science. This program offers teachers opportunities to explore scientific principles and to gain expertise with hands-on experiences during 4 day-long sessions. The program's objectives were to acquaint teachers with resources for teaching astronomy to K–12 students and with activity-oriented planetarium techniques and to increase their understanding of basic astronomy principles. The program also attempted to establish a closer connection between the New York Hall of Science and the school community. The StarLab program far surpassed the 81 teacher participants' expectations (Boykie, 1986). Sakofs (1985) discussed similar success with a teacher/science museum program. He cited the positive interactions and engaging discussions of newly acquired scientific understanding among teacher participants as they explored the museum's exhibits and collections.

Several authors have commented on the critical role of administrators in teacher professional development in informal science environments. Bailey (1988) reported on the benefits of a number of museum-based programs for in-service teachers and their students. These programs, many with major corporate and government funding, focused on a variety of important topics such as gender equity, physics, and science and technology. Bailey (1988, p. 52) pointed out, however, that implementing the program has "not all been smooth sailing. Some teachers have found their schools won't let them implement the interactive teaching techniques they have learned in museum workshops. [As a result of this] museums are working more and more closely with school principals and administrators. A Lawrence Hall [of Science] seminar for principals—planned for 40—had to shift to a new location when 120 registered." Kyle et al. (1990) concurred with this outcome, noting that the factor that had the greatest effect on educational innovations and success of staff development was administrative support.

Grinell (1988) noted that science museums are well positioned to address some inadequacies in science education by providing innovative programs where teachers learn to use hands-on methods to enhance science teaching. Museums can provide even more than field trips and supplementary programs because museums have accumulated science teaching resources such as materials, skilled staff, and knowledge of local educational settings. In fact, the most promising area of growth for science centers is in their relationship to teachers and schools (Grinell, 1988). For several years the Franklin Institute Science Museum in Philadelphia has invited teachers to spend an evening at the museum to learn about its resources, sign up for workshops, and exchange information with their colleagues. The museum also offers programs to inform administrators about the requirements for presenting hands-on science. A joint school district-museum curricular project has put four interactive science lesson museum kits in every elementary classroom in Philadelphia (Grinell, 1988).

Seidman (1989) described how a museum-based monthly teacher in-service program relieved science anxiety among teachers by increasing their confidence and competence in presenting science as an active, enjoyable part of the curriculum. Kyle et al. (1990) noted that teacher participants in their program displayed a newfound enthusiasm for teaching science that was reflected in the classroom and made science fun, interesting, and exciting for students. One goal of informal science education programs is to promote teachers' enjoyment of investigation so that teachers will encourage their students to conduct more science explorations.

Implications

Enhancing Science Learning

Project 2061: Science for All Americans (Rutherford & Ahlgren, 1990) and subsequent documents presenting models for national and state science education provide a starting point for discussion and redesign of the way in which science is taught. Much of what needs to take place is a radical rethinking of what society and schools in the United States have traditionally thought of as science. Science education reform documents call for the elimination of the so-called layer cake approach to the science disciplines—chemistry, physics, geology, biology—in favor of a more integrated, conceptual teaching approach. Reforms also advocate use of the scientific process skills, such as observation, prediction, data collection, and so on as the basis for hands-on science activities. For many, this new way of thinking about science teaching does not seem feasible; it requires too much time and money while providing too little factual content. Realistically, if the mission of schools is to educate children to succeed in the future, the vital questions *should* be, How do children learn science best? and What are the best methods for teaching science effectively? Change, even for the better, is often uncomfortable and difficult.

While policy makers discuss reform issues and administrators wrestle with budget constraints, classroom teachers and teacher preparation programs are held responsible for implementing reforms. How do teacher educators ensure that teachers provide their students with science experiences that foster learning? And can preservice teachers be helped to overcome any fears they may have about science and science teaching? Throughout this article I have tried to show how the answers to these questions lie partly in cooperative efforts between schools and museums, which can reduce the burden on teachers to create science activities.

Haney and Lumpe (1995) concluded that teachers are the key to school change. State and local reform will encounter classroom-level resistance, resulting in short-term, minimal change, if reformers do not consider teachers' beliefs and attitudes. Thus, involving teachers in the change process, curriculum development, and professional development will increase the likelihood of successful implementation of hands-on science. David (1991) indicated that, "in the past, reforms have tried to change one piece at a time, in a system of many interlocking pieces" (p. 11). Understanding the pivotal role of the teacher is an important piece of the change implementation puzzle, starting with teacher preparation programs and professional development of in-service teachers.

As I discussed earlier, administrators need to know how to implement an effective hands-on science program and should support teachers who try to make their students' classroom experiences more like science center "discoveries." Although some science teachers simply need additional release time to plan, others may need guidance and support to continue to grow (Ramey-Gassert, Shroyer, & Staver, 1996). For example, principals can encourage science-shy teachers to incorporate more science into their classrooms by having them sign up for a workshop on integrating science with other subjects. Providing teachers with support and continuing professional development is essential for enhanced science teaching.

In the next section I present a vision for restructuring science education that integrates informal science experiences with classroom curriculum. In a review of the literature, Smylie (1994) discussed the redesign of teachers' roles and the school as a workplace. He indicated that, in order to promote change and increase effectiveness of teachers and schools, "professional communities" need to be created. The Professional Development School (PDS) model (see Fig. 1) enriches the classroom learning community by bringing in university resources, preservice interns and faculty, as well as resources and personnel from the community such as museums and science centers. These additional resources not only enrich the teaching environment, they also provide additional ideas, as well as "another pair of hands and eyes" of people interested in students. Shroyer, Wright, and Ramey-Gassert (1996) documented that such learning communities, or PDSs, enhance the science learning environment for students and the teaching environment for teachers. Professional Development Schools also provide a continuum of growth experiences, from novice to student teaching, for preservice teachers.

Another concern in implementing science education reform is cost. School districts, universities, and other public and private educational agencies are operating on dwindling financial resources. It makes sense for schools and science centers to collaborate, to pool resources, to seek additional outside funding, and to capitalize on what is already available within the community. With this line of thinking, what are the implications for policy change? What would a school district's plan for implementation of science education reform look like based on the collaborative PDS model I have described?

Implementing Change

In considering the policy changes needed to bring science museums and

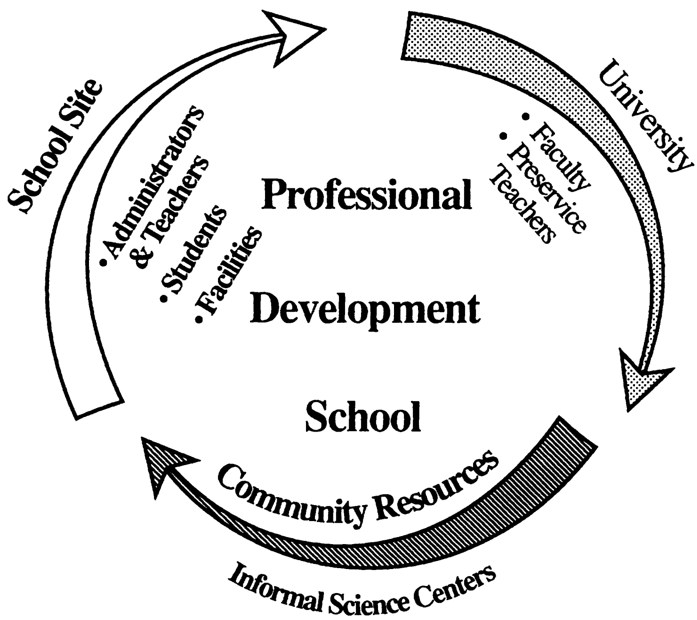

FIG. 1.—A model for developing a professional development school

schools together to improve science teaching and learning, it may be helpful to think of local implementation based on state and national science education reform guidelines. Decisions on budgets, teacher professional development, and procurement of science teaching resources should be made at the district or, better yet, school level after a carefully selected committee has reviewed the reform documents. This committee should be composed of an administrator, science lead teachers from various grade levels, a university representative, and interested others, including a parent and a community resource/science center person. The charge of such a committee would be to develop a comprehensive, collaborative plan to improve science education based on the guidelines but unique to the school community. The committee would consider questions such as, What science teaching expertise and resources are already present within the school? What else is available in the area? What could be developed collaboratively with available funds or readily obtainable "seed grants"?

Time is an important factor relevant to the committee's uncovering resources and developing a plan as well as for implementing the plan in classrooms. Time is also a critical factor in the change process. It takes time to investigate what science materials and curricula exist, to learn new teaching methods, to develop and/or integrate science activities into the existing curriculum, and to develop a science framework that is comprehensive and provides continuity across grade levels. Time is necessary to develop an interdisciplinary, concept-driven program for science teaching advocated in reform documents. Change requires planning; thoughtful planning takes considerable time.

In the remainder of this section I present an example of one school's plan to illustrate how schools and science centers ideally should work together to enhance science education. In this scenario the school district called for each school to create a committee to develop a science teaching enhancement plan. Release time and common planning time were provided for the committee to review the state's newly released K–8 science model that was based on national reform documents. After a presentation for the entire school faculty, the committee formulated a comprehensive science scope and sequence plan for their school and held several working discussions with the entire teaching staff to discuss implementation across grade levels. The committee then drafted a detailed implementation plan. The resources, including external sources of funding and community/university expertise needed for implementing the plan, were clearly articulated for the program.

First, a series of science-related professional development institutes were held both at the school and at the science center. The initial summer institute lasted 2 weeks, but other meetings occurred throughout the year. Each participant—teacher, university faculty member, preservice intern, science center staff member, and others—was encouraged to contribute expertise and to conduct at least one session with a partner. These teacher-friendly institutes focused on promoting positive attitudes toward science, learning of science content and conducting effective field trips, exploring local natural resources (parks, science museums, nature centers, etc.), and investigating available resources to create an integrated science plan for each classroom. Teachers were encouraged to use existing school and community science resources as well as to identify additional ones that they would need. Then the committee sought input from students to refine the program further. The overall goal was to create a problem-solving K–8 science curriculum based on broad conceptual themes, such as patterns and cycles, and systems and interactions, and on the idea that students would revisit these concepts in more depth every 2–3 years.

After a yearlong science enhancement initiative of curriculum coordination, resource gathering, and in-depth planning, the students, teachers, principal, preservice interns, university faculty, and science center education staff held an open house for district administrators and personnel, parents, and the community. Science activities created and displayed by students are described next.

Kindergartners collected plant specimens, comparing similarities and differences between ones at the nature center/botanic garden and those in the school yard. A zoo naturalist helped students learn about native and exotic animals, and they compared these animals' bodies and lifestyles (families, communities) to their own. The third graders at the school assisted the kindergartners with several of their schoolyard investigations. The first-grade teachers and students researched and developed a "museum" displaying science activities and content over a wide range of topics (see Wallach & Callahan, 1994). The fourth graders shared their reading, listening, and writing expertise with the first-grade "museum" developers.

Second-grade students and teachers obtained funding to set up a weather station on one corner of the school grounds, similar to the one at the nature center. They collected and compiled weather data throughout the year and compared it to weather conditions 3 miles away at the center. With the help of the fifth graders, they presented this information to the whole school in the form of weekly and monthly charts and, eventually, a 1-year chart displayed in the front hall. They also visited a local TV station to see the weather forecasting equipment and hosted periodic visits to their classroom by the TV weathercaster.

Third-grade students and teachers, with the help of a landscaping company and the county extension service, developed a backyard habitat area around the second graders' weather station. This project called for research on the "needs for living" of native flora and fauna. Following extensive research, the students determined appropriate school yard plantings and the habitat required to provide adequate food, water, and shelter for the wildlife they wanted to attract. Sixth graders from the neighboring middle school helped build and maintain this project by locating and collecting donations (monetary and products) and by assisting with data collection (e.g., the number and types of birds and other species present and frequency of their visits).

Fourth-grade students and teachers developed an extensive "body systems" collection of activities to accompany the first graders' museum. With assistance from computer technology students in seventh grade, they researched topics of interest by becoming partners with a local hospital and going on-line to communicate with medical personnel, such as nutritionists, medical technologists, cardiologists, and practitioners in sports medicine. Students not only collected, analyzed, and displayed results of their own "tests," they also developed interactive exhibits to collect data from visitors for analysis.

Students and teachers on the fifth-grade level went into the community to learn more about recycling. They researched products that could be recycled, various types of plastics, the recycling process, products that could be made from recycled materials, and what was being recycled in their town. They contacted local government officials and recycling companies in the area to discuss issues and possible solutions. They pursued several worthwhile recycling projects and made over $100.00, which they donated to the school science club. Using the science-related community efforts of the eighth graders, and the expertise of the media resource teacher and university communications department, the fifth graders produced a video, "Helps and Hurts of Recycling Efforts in Our Community."

Students and teachers from the nearby middle school are planning an experimental courtyard garden and successional land lab (to document vegetation changes over time in an old-field area) for use by students at both schools. Teachers in various disciplines, including the arts, continue to work on integrated teaching units related to the many science themes and projects.

This science enhancement program, of course, is an ideal, a model of what science educators who are familiar with reform efforts and pedagogy on effective science teaching recommend. It is doable, but such a program requires a commitment by policy makers and school administrators to provide funding for sufficient release time for planning and teacher professional development.

Conclusion

In this article I have perhaps generated more questions than answers while summarizing what informal science learning environments have to offer. Museums are nonevaluative, stimulating places to explore knowledge about the world that science and technology have generated. Collaboration between schools and informal science centers would enable both to contribute more effectively to science literacy. Professional Development Schools provide collegial extended learning environments, bringing together the elements needed to improve science learning opportunities. These schools can facilitate growth and change, bringing together a powerful continuum of learners—school students and their families, teacher education students, classroom teachers, school staff and administrators, university faculty, other educational institutions including science museums, science-related business and industry, and other community people and resources. There is a vast amount of fertile ground to be broken as staff of informal science centers, PDS teachers and students, science educators, and university faculty discuss possibilities for change. Partnerships between schools and community resources can also increase students' and teachers' motivation to learn and teach science and provide means for engaging hard-to-reach-students using relevant, realistic museum materials and settings.

Finally, I hope that my overview of the role of informal science experiences in enhancing science education and my recommendations for policy change will spark discussion and questions. I also hope that my recommendations will facilitate rethinking of classroom science teaching to include more community resources, differential school building use, changes in scheduling, and so on. This rethinking requires creativity, flexibility, acceptance of change, and a willingness to do things in an unconventional manner. Could students and teachers work with museum staff to research and create exhibits? Could these exhibits travel to schools with the student designers serving as facilitators? Could school buildings be used in off-hours to house family science exploration events? What about expanding students' view of science by involving community members—naturalists, medical practitioners, master gardeners, and so on—in science education? The possibilities for enhancing school science are limitless. Encouraging teachers, students, and the science museum community to collaborate and pool resources to address science education problems will, over time, result in productive changes in science teaching and learning.

References

Ames, P. (1988). To realize museums' educational potential. *Curator*, **31**(1), 20–25.

Bailey, A. L. (1988, May/June). Ending science illiteracy: Teaching teachers to teach science. *Museum News*, pp. 50–53.

Beer, V. (1987). Do museums have "curriculum"? *Journal of Museum Education*, **12**(3), 10–13.

Birney, B. A. (1988). Criteria for successful museum and zoo visits: Children offer guidance. *Curator*, **31**(4), 292–316.

Bitgood, S. (1991, January/February). What do we know about school field trips? What research says. *ASTC Newsletter*, **19**(1), 5–6, 8.

Boykie, T. S. (1986). Stars in the schools: Teacher training at the New York Hall of Science. *Journal of Museum Education*, **11**(2), 10–11.

Bresler, C. A. (1991). Museums and environmental education. *NAPEC Quarterly*, **2**(1), 6.

Carr, D. (1989, May/June). "Live up" to learners. *Museum News*, pp. 54–55.

Chambers, M. (1990). Beyond "aha": Motivating museum visitors. In B. Serrell (Ed.), *What research says about learning in science museums* (pp. 10–11). Washington, DC: Association of Science-Technology Centers.

Chesebrough, D. E. (1994). Informal science teacher preparation. *Science Education International*, **5**(2), 28–34.

Crane, V. (1994). *Informal science learning: What the research says about television, science museums, and community-based projects*. Dedham, MA: Research Communications.

Csikszentmihalyi, M. (1987). Human behavior and the science center. In P. G. Heltne & L. A. Marquardt (Eds.), *Science learning in the informal setting*. Proceedings of the Symposium of the Chicago Academy of Sciences (pp. 79–87). Chicago: University of Chicago Press.

David, J. L. (1991). What it takes to restructure education. *Educational Leadership*, **49**(8), 11–15.

Dierking, L. D. (1991). Learning theory and learning styles: An overview. *Journal of Museum Education*, **16**(1), 4–6.

Doris, E. (1993). Keeping wonder alive. In C. Flake (Ed.), *Holistic education: Principles, perspectives and practices* (pp. 56–62). Brandon, VT: Holistic Education Press.

Downs, L. (1989, May/June). Search for solutions. *Museum News*, pp. 45–47.

Edeiken, L. R. (1992). Children's museums: The serious business of wonder, play, and learning. *Curator*, **35**(1), 21–27.

Eratuuli, M., & Sneider, C. (1990). The experiences of visitors in a physics discovery room. *Science Education*, **74**(4), 481–493.

Falk, J. H., & Dierking, L. D. (1992). *The museum experience*. Washington, DC: Whalesback Books.

Falk, J. H., Koran, J. J., Jr., & Dierking, L. D. (1986). The things of science: Assessing the learning potential of science museums. *Science Education*, **70**(5), 503–508.

Falk, J. H., Martin, W. W., & Balling, J. D. (1978). The novel field-trip phenomenon: Adjustment to novel settings interferes with task learning. *Journal of Research in Science Teaching*, **15**(2), 127–134.

Feber, S. (1987). New approaches to science: In the museum or out with the museum? In T. Ambrose (Ed.), *Education in museums, museums in education* (pp. 85–93). Edinburgh: Her Majesty's Stationery Office.

Feher, E., & Diamond, J. (1990). Science centers as research laboratories. In B. Serrell (Ed.), *What research says about learning in science museums* (pp. 26–28). Washington, DC: Association of Science-Technology Centers.

Feher, E., & Rice, K. (1988). Shadows and anti-images: Children's conceptions of light and vision. *Science Education*, **72**(5), 637–649.

Gardner, H. (1991). Making schools more like museums. *Education Week*, **11**(5), 10.

Gartenhaus, A. (1991). *Minds in motion: Using museums to expand creative thinking*. Davis, CA: Caddo Gap Press.

Grinell, S. (1988). Science centers come of age. *Issues in Science and Technology*, **4**(3), 70–75.

Haney, J. J., & Lumpe, A. T. (1995). A teacher professional development framework guided by reform policies, teachers' needs and research. *Journal of Science Teacher Education*, **6**(4), 187–196.

Harrison, M., & Neaf, B. (1985). Toward a partnership: Developing the museum-school relationship. *Journal of Museum Education*, **10**(4), 9–12.

Harte, D. V. (1989). Fine tuning the learning experience: An information age model for excellence. *NASSP Bulletin*, **73**(517), 96–101.

Hornung, G. S. (1987). Making connections. *Educational Perspectives*, **24**(2), 2–5.

Kremer, K. B., & Mullins, G. W. (1992). Children's gender behavior at science museum exhibits. *Curator*, **35**(1), 39–48.

Kubota, C. A., & Olstad, R. G. (1991). Effects of novelty-reducing preparation on exploratory behavior and cognitive learning in a science museum setting. *Journal of Research in Science Teaching*, **28**(3), 225–234.

Kyle, W. C., Jr., Bonnstetter, R. J., Sedotti, M. A., & Dvarskas, D. (1990). ScienceQuest: A program that works. *Science and Children*, **27**(8), 20–21.

Leroux, J. A. (1989). Teacher training in a science museum. *Curator*, **32**(1), 70–80.

Linn, M. C., & Hyde, J. S. (1989). Gender, mathematics, and science. *Educational Researcher*, **18**(8), 17–19, 22–27.

Madden, J. C. (1985). To realize our museums' full potential. *Journal of Museum Education*, **10**(4), 3–5.

Martin, W. W., Falk, J. H., & Balling, J. D. (1981). Environmental effects on learning: The outdoor field trip. *Science Education*, **65**(3), 301–309.

Martinello, M. L., & Gonzalez, M. (1987). The university gallery as a field setting for teacher education. *Journal of Museum Education*, **12**(3), 16–19.

Martinello, M. L., & Kromer, M. E. (1990). Developing and assessing lower-SES Hispanic children's inferential thinking through a museum-school program. *Journal of Elementary Science Education*, **2**(2), 21–36.

Miller, J. D. (1987). The roots of scientific literacy: The role of informal learning. In P. G. Heltne & L. A. Marquardt (Eds.), *Science learning in the informal setting*. Proceedings of the Symposium of the Chicago Academy of Sciences (pp. 172–182). Chicago: University of Chicago Press.

Oppenheimer, F. (1975). The Exploratorium and other ways of teaching physics. *Physics Today*, **28**(9), 9–13.

Prather, J. P. (1989). Review of the value of field trips in science instruction. *Journal of Elementary Science Education*, **1**(1), 10–17.

Price, S., & Hein, G. E. (1991). More than a field trip: Science programs for elementary school groups at museums. *International Journal of Science Education*, **13**(5), 505–519.

Ramey-Gassert, L., & Prather, J. P. (1994, January). Planning productive field trips: Enhancing student learning. Workshop presented at the annual meeting of the Association of Educators of Teachers of Science, El Paso, TX.

Ramey-Gassert, L., Shroyer, M. G., & Staver, J. (1996). A qualitative study of factors influencing science teaching self-efficacy of elementary level teachers. *Science Education*, **80**(3), 283–315.

Ramey-Gassert, L., Walberg, H. J., III, & Walberg, H. J. (1994). Museums as science learning environments: Reexamining connections. *Science Education*, **78**(4), 345–363.

Resnick, L. B. (1987, December). The 1987 Presidential Address: Learning in and out of school. *Educational Researcher*, **16**(9), 13–19.

Rice, K., & Feher, E. (1987). Pinholes and images: Children's conceptions of light and vision. *Science Education*, **71**(4), 629–639.

Rutherford, F. J., & Ahlgren, A. (1990). *Project 2061: Science for all Americans*. New York: Oxford University Press.

Sakofs, M. (1985). Structuring a museum in-service for teachers. *Journal of Museum Education*, **10**(2), 16–17.

Schibeci, R. A. (1993). Evaluation of the educational benefit of a special exhibition at an interactive science center. *Science Education International*, **4**(1), 22–25.

Seidman, C. M. (1989). A community centered on learning. *Science and Children*, **26**(5), 25–26.

Seletsky, A. (1990). The mark in the brick and other museum matters. *Journal of Museum Education*, **15**(1), 15–17.

Semper, R. J. (1990). Science museums as environments for learning. *Physics Today*, **43**, 2–8.

Serrell, B. (1990). Introduction. In B. Serrell (Ed.), *What research says about learning in science museums* (pp. ii–iv). Washington, DC: Association of Science-Technology Centers.

Shroyer, M. G., Ramey-Gassert, L., Hancock, M., Walker, M., & Moore, P. (1995). Math, science and technology after-school clubs and summer magnet schools: Collaborative professional development opportunities for science educators. *Journal of Science Teacher Education*, **6**(2), 112–119.

Shroyer, M. G., Wright, E. L., & Ramey-Gassert, L. (1996). Science education reform: The role of professional development schools. *Journal of Science Teacher Education*, **7**(3), 151–168.

Smylie, M. (1994). Redesigning teachers' work: Connections to the classroom. In L. Darling-Hammond (Ed.), *Review of research in education* (Vol. **20**, pp. 129–178). Washington, DC: American Educational Research Association.

Stevenson, J. (1991). The long-term impact of interactive exhibits. *International Journal of Science Education*, **13**(5), 521–531.

St. John, M. (1990). *First hand learning: Teaching education in science museums* (Vols. **1** & **2**). Washington, DC: Association of Science-Technology Centers.

Tuckey, C. J. (1992). School children's reactions to an interactive science center. *Curator*, **35**(1), 28–38.

Wallach, C., & Callahan, S. (1994). The 1st grade plant museum. *Educational Leadership*, **52**(3), 32–34.

Wellington, J. (1990). Formal and informal learning in science: The role of the interactive science centres. *Physics Education*, **25**(5), 247–252.

Williams, D. (1993). The outdoor school: Reverence and connectedness. In C. Flake (Ed.), *Holistic education: Principles, perspectives and practices* (pp. 97–103). Brandon, VT: Holistic Education Press.

Wolf, R. L. (1986). The missing link: A look at the role of orientation in enriching the museum experience. *Journal of Museum Education*, **11**(1), 17–21.

Wright, E. W. (1980). Analysis of the effect of a museum experience on the biology achievement of sixth graders. *Journal of Research in Science Teaching*, **17**(2), 99–104.