# Informal Science Learning Environments:

# A Review of Research to Inform K-8 Schooling

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The purpose of this paper is to review what is known about informal science learning and to recommend areas for further research. The review is intended to support an examination of how children's science learning experiences in designed informal environments like science museums and zoos relate to science learning activities in K-8 schools.

A review of the literature led us to approach this task from a dual perspective that respects the context-specific focus of the existing literature but also problematizes this focus by arguing that we need to understand these activities across contexts. Specifically, the term "informal learning" has been used to refer to at least two distinct but overlapping areas of study. Some researchers use the phrase to refer to learning that happens in designed, non-school, public settings like science museums[1] and after-school clubs. Others use the phrase informal learning to focus attention on the largely emergent occasions of learning that occur in homes, on playgrounds, among peers, and in other situations where a designed and planned educational agenda is not authoritatively sustained over time. In this paper, we use the terms 'informal learning' and 'informal learning environments' to refer to experiences within designed settings such as museums. The paper focuses on learning in these designed, informal learning environments. We find it difficult, however, to discuss learning in museums without some reference to

[1] The term "science museum" is used here broadly to refer to science and nature centers, zoos, aquaria, botanic gardens, arboretums, planetariums, natural history and science museums, as well as science-rich children's museums.

emergent learning situations, so distinguish this by using the term ‘emergent’ or ‘everyday’ learning.

The first part of the paper provides an overview of the ongoing debate about the use of the term ‘informal learning,’ and the research that has built up around that term. The second part of the paper examines the kinds of activities engendered by informal learning environments, organized around three common themes in the literature: 1) discipline-specific knowledge, 2) talk as a medium for learning and experiencing science, and 3) identity development. The final section discusses possible directions for the design of out of school learning contexts that can positively impact the development of science knowledge, talk, and identity.

## Exploring the Field of Informal Science Learning Research

A distinguishing feature of children’s learning is that it often occurs in settings outside of school, focused on interactions with related adults rather than teachers. It has been argued, then, that science education cannot be based in school alone, but must also include the full range of learning environments, including home, museums, and community organizations (Schauble, Beane, Coates, Martin, & Sterling, 1996). Understanding children’s science education through a comprehensive effort that integrates the full range of learning environments has a great potential to increase the pervasiveness and improve the quality of children’s overall science learning experiences (Martin, 1996).

There are three common arguments for the existence and importance of informal science learning: (1) theory of human development (Schauble, Beane, Coates, Martin, & Sterling, 1996), (2) alternative avenues to success (McLaughlin, Irby, & Langman, 2001), and (3) time out-of-school (Sosniack, 2001). First, informal learning is considered to be the 'third leg' of human development that completes the educative triad of learning within the pre-school family environment and learning in school (Schauble, Beane, Coates, Martin, & Sterling, 1996). From this perspective, examinations of informal, designed, learning environments may both enrich our understanding of learning across environments and force a re-examination of the design of typical formal learning environments.

Second, some children who do poorly in formal educational environments may learn more effectively in informal contexts (e.g., McLaughlin et al., 2001). A combination of factors, including social arrangements, peer networks or mentors, and increases in motivation and interactivity appear to account for this contrast.

Third is time, perhaps the most compelling argument for the importance of informal learning environments. By the age of eighteen, a child will have spent, at most, nine percent of his or her lifetime in school (U.S. Department of Education, 2000). This conclusion is comparable to estimates made more than three decades earlier (Jackson, 1968). Jackson's argument is that if a child spends about six hours a day in school, and is present for each of the one hundred and eighty days required by most states, he will spend little over one thousand hours in school in a year. This is a low estimate of the time spent on schooling activities, as it does not consider time spent on homework. But it is a generous estimate as it assumes perfect attendance, and counts all of the time spent in school as a schooling activity, including activities such as lunch and recess.

Eight to nine percent of a childhood is a great deal of time for one single activity such as schooling. But from the perspective of examining all opportunities for learning, it must be understood as a weak intervention or low dose (Sosniak, 2001). It is, upon reflection, commendable that schools have such an impact after only taking up eight to nine percent of childhood. It is worth adding that in a life of seventy-five years, barely two percent of a person's time will have been spent in schooling. Other educational influences, such as home, community, media, and society must be considered in a complete survey of a person's learning experiences. Herein lies the importance of learning outside of school.

What are the learning possibilities of time-out-of-school? Examining the informal learning experiences of an eighteen-year-old requires the consideration of ninety one to ninety two percent of his or her time. Granted, the activities of playing and critical self-maintenance (e.g., sleeping, eating, and washing) take up a significant amount of time. But we are still left with an extensive educational infrastructure that includes non-school institutions (e.g., libraries and museums), organizations (e.g., community, church and scouting groups), and media (e.g., books, newspapers, magazines, television, film, radio, and the Web) (St. John & Perry, 1996). Although the existence of this infrastructure is contested (e.g., Luke, Camp, Dierking, & Pearce, 2001), significant evidence suggests that at the least, the groundwork has been laid for a series of connections across institutions, organizations, and communities that allows interaction, communication, and progress (Falk, Brooks, & Amin, 2001; Lewenstein, 2001; St. John & Perry, 1996). Although the definition and extent of the learning infrastructure is contested, it is more readily agreed that the functions of the infrastructure resources for learning outside of school and for connecting to school-based learning are not well understood.

## Defining Informal Learning

Efforts to define out-of-school learning have frequently resulted in lists of characteristics that compare informal and formal learning, for example: mandatory versus voluntary (Crane, 1994); de-contextualized versus embedded (Greenfield & Lave, 1982); and, individual versus shared cognition (Resnick, 1987). One of the most distinguishing characteristics to come to light from these lists is structure. In-school learning is described as mandatory, dictated by formal curriculum at local, state, and national levels, as part of a highly organized system of activity. Informal or out-of-school learning is described as voluntary, lacking curriculum and standards, and open-ended. These descriptions are based more on a traditional view of schools and museums than a research-based description of learning environments. Ironically, research on the design of museum exhibitions[2] (e.g., Vallance, 1995) and on the activities of children participating in day-to-day learning activities (e.g., Henze, 1992) points to a "hidden curriculum" that intentionally or unintentionally structures informal learning environments.

Scribner and Cole (1973) argue that the distinction between formal and informal education is marked by whether it is organized systematically. Specifically, education is formal if it is culturally organized. For example, an apprenticeship, with its specific stages and roles is a formal educational experience. Likewise, ritualistic coming of age ceremonies are formal educational experiences. Even some elements of day-to-day activities have been shown to be a ritualized (Henze, 1992), and therefore could be considered a formal educational experience. It would be difficult, then, to argue that learning from museums is not, at least in part, a formal educational activity.

<u>Development of Research on Informal Learning</u>

The origins of the field of research on informal learning are diverse. Distinctions between formal, informal, and nonformal were first developed in the 1950s (see review in Henze, 1992). The terms were borrowed in the 1970s by museum professionals and environmental educators in an effort to distinguish their activities from schools (Falk & Dierking, 1998). Although studies of informal learning have at times been positioned to be critical of the traditional school learning environment, the outcome has been an understanding of the school as a context with its own culture, history, politics, and

[2] In this paper, the term "exhibition' is used to refer a related set of exhibits. The term 'exhibit' refers to an individual component of an exhibition or a stand-alone piece.

agendas (Bransford, et. al, in press). The use of the term informal learning has flourished in both cultural psychology studies of everyday learning (e.g., Cole, 1996; Scribner, 1984) and educational studies of the museum learning experience (e.g., Hein, 1998). (See Bransford, et.al., in press, for a review of the development of research on everyday learning experiences.)

In the 1980s, a few researchers began to argue that it might be more appropriate to describe informal learning in designed environments as free-choice learning (Dierking, 1987; Koran, Longino, & Shafer, 1983). The intention was to introduce clarity about the nature of the learning, rather than over generalize about the wide variety of learning experiences that take place within a single learning environment such as a museum or even a school. Free-choice learning is voluntary and self-placed. Although it is most commonly used to describe learning outside of school, it is specific to the learning, not the environment, and therefore could be used to describe learning experiences within schools also.

A common concern among those who use the term informal learning and the term free choice learning is the belief that it is important to examine learning over time and across environments (Dierking et. al., 2003). Experiences in schools, museums and after-school clubs, watching television and films, listening to the radio or audio recordings, playing games, reading books, magazines, newspapers, blogs, and other Web resources, participating in community or religion-based organizations, and talking to colleagues, friends, family, and strangers all cumulatively contribute over time to an individual's learning experience. Historically, what we know about this sort of learning is limited to studies within museums (e.g., Falk & Dierking, 2000) and research on everyday learning from an anthropological or cultural psychology perspective (e.g., Rogoff & Lave, 1984). An interesting middle ground between the two is the highly designed media of television and the Web that is viewed or used within highly unconstrained environments such as the home. There is less published data about the impact of these media experiences, but evidence suggests that access to technology outside of home provides students, particularly boys, with a head start in schooling (see review in Kafi, Fishman, Bruckman, Rockman, 2002). Learning media such as television is even less understood in relation to overall impact on school success. Despite extensive studies on the impact of specific episodes of television shows, most cross-program studies focus on attitudes more so than learning (e.g., Potts & Martines, 1994). Increasingly, there is an interest in examining learning across types of media and mediation, beyond constrained learning environments, and extended through time. The result would be a more holistic understanding of the learning process that measures a scale and scope not yet attempted.

## What We Know About Informal Learning

This overview of research on informal science learning environments was designed with an eye toward highlighting findings that can inform K-8 schooling. The number of studies of informal learning pale in comparison to the number of studies of formal learning. But a range of insights and principles nonetheless distinguish informal learning research and suggest important links to the K-8 school environment.

Psychologists have typically viewed learning changes in terms of concepts or mental processes. Informal learning researchers have described other, though not necessarily incompatible, dimensions of change when people learn. Research on informal and everyday science education has described learning in terms of changing participation and activity within a community (Lave, 1988). This understanding of learning points to the importance of not only concepts or disciplinary knowledge, but also science talk, and identity.

Some researchers have emphasized the importance of developing disciplinary-specific knowledge, such as the big ideas and processes of science (Ash, 2003; Crowley & Jacobs, 2002; Tunnicliffe, 2000). Other researchers have described informal science learning as an opportunity to appropriate the language of science (Borun, et al., 1998; Crowley & Callanan, 1998; Ellenbogen, 2003) Still others have highlighted that learning involves changes in identities, specifically how people view themselves, how they present themselves, and how others see them (Holland, Lachicotte, Skinner, & Cain, 1998; Wenger, 1999). No single definition of learning unites informal learning research. However these three characteristics—disciplinary knowledge, science talk, and identity—provide a multi-faceted view of learning that (a) accommodates the need for a nuanced definition of learning; (b) highlights characteristics of learning that are strongly supported by informal learning environments; and (c) draws upon an understanding of science as a human endeavor (Kuhn, 1970; Latour, 1987; Longino, 1990). Although the three concepts of disciplinary knowledge, science talk, and identity overlap in powerful and productive ways, we describe each concept in turn here.

<u>Discipline-Specific Knowledge</u>

Individuals do make discipline-specific cognitive gains as a result of their museum visits (Allen, 1997; Anderson, Lucas, & Ginns, 20037; Falk & Dierking, 1997; Stevens & Hall, 1997). Studies of cognitive learning in museums have included unguided visits as well as structured programs or tours, but they are all concerned with the disciplinary knowledge gained from a particular exhibition or program.

Much of the work on the development of discipline-specific knowledge in informal learning environments relates to field trips. Numerous studies show that field trips to museums have a positive impact on cognitive gains when students are well prepared with the curriculum, when they participate actively during the trip, and when the field trip experience is reinforced following the visit (Bitgood, 1993; Koran, Lehman, Shafer, and Koran, 1983; Orion, 1993; Ramey-Gassert et al., 1994; Rennie and McClafferty, 1995). Recent reviews of the literature (Anderson, Kisiel, & Storksdieck, in press; Griffin, 2004) describe a series of critical factors that influence the cognitive impact of a field trip, including students' preexisting knowledge, pre- and post-visit activities, orientation to the learning, environment, teachers' perceptions about curriculum fit, and obstacles to field trip planning. Two of these—teachers' perceptions about curriculum fit and pre- and post-visit activities—emerge as the most frequently cited factors to impact the development of disciplinary specific knowledge from field trips.

Teachers' perceptions of informal science learning environments profoundly influence the kind of visit their students' experience. Perceptions about the rationale for field trips vary widely. A study by Jamison (1998) considered the perceptions of elementary and middle school teachers regarding field-trips a history center and a science museum. The investigation revealed that the location, the quality of the exhibits and programs, the safety and security of students, and relevance of the field trip experiences to the school curriculum were all key factors in teachers planning visits to these sites.

A recent study (Kisiel, 2005), however, demonstrated the dominance of the curriculum fit in teachers' perceptions of field trips. Fully 90% of participating teachers stated that a connection to the curriculum was an important rationale for a field trip. Teachers gain legitimacy for their field trip by showing that it fits the curriculum. The importance of curriculum fit is not surprising, given the increased emphasis on standards and accountability. Although there is much evidence to suggest that teachers justify field trip experiences in terms of curriculum fit in an effort to secure the legitimacy and administrative approval needed to conduct a field trip, there is little evidence that teachers actually integrate the field trip experiences into their curriculum. Anderson, Kisiel, & Storksdieck (in press) found that despite the perceived importance of connecting the field trip to the curriculum, it is less influential within the reality of planning and conducting the actual excursion. Their data suggest that making a connection to the curriculum, while a desirable outcome, is difficult due to the constraints of the school system. This does not pose a problem to teachers whose perceptions of field trips include a range of rationales and multiple outcomes unrelated to the curriculum, as long as they can prove that the field trip is designed to fit the curriculum.

Several studies have shown that pre- and post-visit activities support students' orientation, understanding, and the development of a context for future experiences (Anderson, Lucas, Ginns, Dierking, 2000; Falk and Dierking, 2000; Gennaro, 1981; Orion and Hofstein, 1994; Storksdieck and Falk, 2003). Anderson (1999) found that post-visit activities were significant catalysts for later development of knowledge in and beyond the classroom and museum settings. Gennaro (1981) reported that a treatment group who participated in pre-visit activities showed greater overall knowledge acquisition from a field trip than a control group that went on the trip without the pre-visit instruction. Orion and Hofstein (1994) noted that students who participated in a 10-hour preparation unit designed to support both orientation to the site and conceptual development prior to a geology field trip outperformed the control group who received no preparation other than completion of a traditional school unit on geology. Storksdieck and Falk (2003) have found evidence that pre- and post-visit activities support not only the field trip itself, but also subsequent learning experiences that provide evidence for the long-term impact of a science museum visit.

There are an increasing number of studies that demonstrate the long-term impact of informal learning environment experiences on the development of the learners' disciplinary knowledge (e.g., Adelman, Falk, & James, 2000; Anderson, 2003; Ellenbogen, 2002). These studies and others (Moussouri, 1997; Falk, Moussouri, & Coulson, 1998) reveal that the impact of the museum visit is directly related to people's motivations or agendas. For example, on a content knowledge test given to museum visitors before and after they went through an exhibition, those with a high education agenda scored significantly higher than those with a low education agenda (Falk, Moussouri, & Coulson, 1998). More interestingly, education and entertainment agendas proved to be highly independent dimensions: people with a high education agenda, regardless of their entertainment agenda, showed significant conceptual learning. Likewise, people with a high entertainment agenda, regardless of their education agenda, showed significant vocabulary development and overall mastery of the topic. Therefore, the effects of a person's entertainment agenda are independent of the same person's education agenda. These results reinforce the belief that education and entertainment are not two ends of a single continuum. It suggests that people do not distinguish between the worth of education and entertainment and that both are effective motivations in informal learning environments.

Despite this evidence that people make cognitive gains as a result of their experiences in informal learning environments, the developmental trajectory of people's discipline-specific learning in these environments is not well documented. Much of the learning takes place in brief moments, unexpected episodes, and occasional experiences that lack significance when measured with traditional approaches common in formal learning environments. Crowley & Jacobs (2002) propose the notion of "islands of expertise" as an alternative schema for the development of disciplinary knowledge in informal and emergent learning experiences. An island of expertise is a topic-specific area of proficiency developed by a child as a result of multiple, interconnected learning experiences. Typically, an island emerges over time, through social interactions that are a part of the many activities of a social group, such as a family. An island can support extended investigations and conversations among parents and children in a manner that would not be possible with a subject matter that was not driven as strongly by interest and maintained by family activities.

Informal learning environments have proven to be ideal environments to foster and better understand the nature of building islands of expertise. The authentic objects of museums, the many scaffolding tools of the environment (such as labels and interactive devices), and the memorability of the infrequent museum visit all make it particularly powerful in creating shared parent-child learning experiences. Studies have shown that parents' participation in museum-based activities deepen children's engagement (Crowley & Callanan, 2002). But the focus of parents' mediating activities, in informal and emergent learning environments alike, tends to underestimate the cognitive skills of children (Callanan, Jipson, & Soennichsen, 2002; Gelman, Coley, Rosengren, Hartman, & Pappas, 1998; Gleason & Schauble, 2000). Parents tend to assume the most difficult conceptual tasks, delegating manual tasks to the children. Parents encourage their children to physically participate, but miss opportunities to encourage children to participate in discipline-specific science activities.

Science Talk

The presentation of science in museums has traditionally focused on scientific facts, or what we know (Arnold, 1996). The factual focus has led to a image of science as verification, i.e., collecting data and making observations at one end and pre-set explanations at the other with little conversation about the middle ground of science (Duschl, 1990; Kelly & Duschl, 2002), i.e., how data and observations are transformed into explanations. Increasingly, however, museum exhibitions are being designed to support social mediation and conversation (Schauble & Bartlett, 1997). The nature and extent of parents' mediating techniques in informal science learning environments are better understood through examinations of their conversations and engagement in science talk. When talk is viewed as an activity in which children come to understand what it is to "do science," socially driven informal learning environments such as museums gain more potential as powerful places for learning.

Although there has been research on families' conversations in museums for more than a decade (e.g., Hensel, 1987; McManus, 1987; Taylor, 1986), this research has frequently been limited to descriptions of how adults and children interact around and talk about content presented in exhibitions and programs. Extensive observations of families' interactions and conversations show that parents take on teacher-like roles during museum visits (Diamond, 1986; Hensel, 1987). Diamond's (1986) observations revealed five categories of exhibit-mediating behavior in family groups. She found that parents 'teach' by verbal and non-verbal methods that most commonly fall into the categories of 'show' and 'tell'. These two behaviors can function in a variety of ways, but telling tends to involve giving commands like "look at this" or "come see." Other mediating activities include 'name exhibit,' 'look at graphics,' and 'read'. Additionally, Hensel (1987) found that much of the physical behavior observed in museums is a result of specific conversational rules. For example, reading labels interrupts conversations, and staying at an exhibition for an extended period of time may be uncomfortable because it requires extended conversation material. Exhibits can actually inhibit learning interactions.

A multi-city, multi-museum study on exhibit characteristics, family behaviors, and family conversations was developed in an effort to identify design characteristics of exhibits that would support learning interactions and conversations (Borun, et al., 1998). The first phase of the project (Borun, Chambers & Cleghorn, 1996) examined the correlation between families' physical and verbal interactions and learning measured through a post-visit interview process. Borun and her colleagues developed a set of three learning levels based on a list of learning goals related to the exhibits: (1) identifying, (2) describing, and (3) interpreting and applying.

Borun and her colleagues proposed that the three levels of learning reflect increasing complexity and richness. One-word statements that make few associations to the exhibition content, or make connections to content that miss the point of the exhibition indicate the first level of learning, identifying. Multiple-word statements that connect visible exhibit characteristics (not concepts) to personal experiences or to other correct topics indicate the second level of learning, describing. Multiple-word statements correctly making connections to exhibition concepts through science topics or through personal connections indicate the third and highest level of learning, interpreting and applying. This framework was used to show that families are learning in science museums. Only twelve percent of the families participating in this multi-institution project demonstrated learning at the level of interpreting and applying. This was in contrast the other levels of learning which were present in the conversations of more than forty percent of the families.

Conversations have increasingly been used to reveal the nature of learning in museums. A series of studies conducted under a common effort to adopt a sociocultural approach to understanding learning in museums (Leinhardt, Crowley, & Knutson, 2002) pointed to extensive evidence for the meaning making that is revealed through conversations in museums. A range of methodologies, including diary studies, interviews, audio and video taping, as well as ethnographic case studies revealed the powerful understanding that emerges when you examine museum experiences as learning within a social context, rather than simply social interactions. One of these studies (Allen, 2002) showed that more than 83% of the conversation occurring in a science exhibition was related to learning. Other studies included an examination of the ways in which families integrate museum experiences into their lives (Ellenbogen, 2002; Leinhardt, Title, & Knutson, 2002) and the impact of people's personal narrative upon the extent and analytic content of their conversations (Abu-Shumays & Leinhardt, 2002).

The adoption of sociocultural perspectives on museum learning has not only brought about an increase in research on conversations in museums but also afforded opportunities for more in-depth investigation of the mediating techniques used in these interactions and the meanings created from them (c.f., Stevens & Hall, 1997; Borun et. al., 1998; Leinhardt & Knutson, 2004). Studies of parent-child interactions around science objects in museums frame explanatory conversations in different ways (Callanan & Jipson, 2001; Crowley, et al., 2001; Hilke & Balling, 1985). Families create their own interpretations of the content and experiences they find in museums, making explicit connections to their prior experiences (Hilke, 1989). Conversations that make connections to prior experiences account for as much as five percent of all of the family interactions (Hilke & Balling, 1985). Or, when examined strictly within the explanatory context, explanations that make connections to prior experiences account for as much as twenty-five percent of the explanatory conversations occurring in parent-child interactions (Callanan & Jipson, 2001).

Callanan and Jipson (2001) argue that this type of explanatory conversation may be particularly effective in engaging children in science topics. Parents' explanations help children interpret what they are seeing and doing in science museums. Parents' explanations tend to focus on functions and mechanics of using the interactive exhibit, connecting the exhibit with real phenomena, and making connections to formal science ideas (Crowley & Callanan, 1998). When parents explain a feature in an exhibit, children are more likely to talk about their experiences. By adding questions, they are able to optimize the learning even more.

Recent studies of families' conversations indicate that families do construct meaning through their conversations (Ash, 2003; Crowley et al., 2001; Ellenbogen, Luke, & Dierking, 2002). These studies emphasize the processes families engage in to construct meaning and build identity, and the role of the museum experience in the family's larger social and cultural context.

Findings suggested that none of these interactions take precedence over the group's ability to enjoy and maintain social relationships. Family members talk about what they know from previous experiences, discussing what they see, hear, read, and do in relation to their family experiences and memories. This research also demonstrated that these discussions provide opportunities for family members to reinforce past experiences, family history, and to develop shared understandings. However, this research did not pursue an in depth of understanding of the role of conversations in identity building and other social and cultural aspects.

Identity Development

Museums, like all educational institutions (Bruner, 1996), can be seen as a place of enculturation (Pearce, 1994). Enculturation is about developing identity as a part of a community, and the museum are one of many types of informal science learning environments that influence that activity. From this perspective, (e.g., Ivanova, 2003) we can begin to examine museums and other institutions in the learning infrastructure as places for building and affirming identity.

A child's identity as a learner is contested and influenced by different practices in everyday interactions, as well as in the cultural institutions he uses (Bruner, 1996; Ogbu, 1995). Museums tend to represent the dominant culture, which presents a conflict for these in the minority or marginalized cultures (Ivanova, 2003). In order to manage these differences, a child from a marginalized culture may temporarily adopt an identity for science learning experiences (Heath, 1982). If we can better understand how children come to integrate science into their existing culture, rather than temporarily adopt an identity, we can use this knowledge to create informal science learning environments that are more accessible and meaningful.

We do know that identity greatly shapes learning experiences within museums (Ellenbogen, Luke, & Dierking, 2004; Leinhardt & Gregg, 2002). Parents who want to develop a particular family identity are able to quickly adapt the general museum experience, as well as specific content, to reinforce the desired identity. Identity highly influences museum visitors' conversations (Feinberg & Leinhardt, 2002). Everything from behavior modification ('We don't bang on the computer screen like that.') to personal narrative episodes ('Do you remember the last time we saw one like that?') can quickly be used to reinforce the identity of the family. At times, this effort to reinforce family identity comes at the expense of the museum's intended experience or content goals.

Museums intentionally choose content and create experiences to support a specific agenda or learning goals that may or may not be consistent with the agenda and goals of the visitor (Hilke, 1987). If visitors' efforts to develop their family identity do not coincide with the museum's intended goals, they may hijack the museum messages and reshape them to support identity building (Ellenbogen, 2003). The flexibility of the museum learning environments, supported by a lack of accountability, overt curriculum, and enforcement makes the variation from the intended agenda the rule rather than the exception.

One of the most common underlying agenda's of informal science learning environments like museums is to not only interest people in science, but also to propel children into science careers. Although there are compelling, apocryphal stories from Nobel prize winning scientists who point to museums as a critical influence on their lifelong science passion, there is little data to support the notion of the museum as a catalyst that leads children to take up science careers. There is some promising evidence, however, that informal science learning experiences do impact children's motivation and identity with regards to science careers (Jarvis & Pell, 2005). Follow up interviews conducted with middle school students two months after their visit to a space center found that 20% of them were more interested in science careers. This increased interest virtually disappeared after five months.

More intensive informal science programming has been shown to have a longer-lasting impact of children's science identities. A longitudinal study of young women from urban, low-income, single-parent families who participated in an after-school informal science program found that more than 90% went on to attend college (Fadigan & Hammrich, 2004). For those young women, careers in the medical field, followed by SMET-related careers were the highest-ranking chosen career paths four to nine years after initial participation in the program. The young women pointed to three characteristics—having staff to talk to, job skills learned, and having the museum as a safe place to go—as most influential on their chosen educational and career paths.

## Promising Directions for Informal Learning Research

Learning in designed informal science learning environments can be measured and shaped (Martin, 2001). The agenda of the learners, the form of the exhibition, the relationships among group members, and the physical and dialogic interactions can all be documented. Still, research on measuring the impact of these environments and the extent of everyday learning lacks a sustained focus and impact. Just as the last two decades of research on learning in school environments have reshaped our understanding of human cognition and influenced educational practice (Bransford, Brown, & Cocking, 2000), there is reason to hope that sustained research focused on learning in informal learning environments can be similarly transformative in the coming decades.

<u>Across Context Studies</u>

Learning is no longer viewed as a singular event in response to a specific stimulus. Instead, interrelated experiences across time and environments have a combined impact that make it difficult to pinpoint exactly when experiences culminate in learning. Studying this more organic understanding of learning requires an understanding of how one event or experience fits into the overall scheme. The implication is that we need to reframe our research to ask not “What did the child learn and when?” but instead “How did this experience contribute to what the child has already experienced?”

This suggests that the sum total of the child’s educational experience is not just what happens inside the walls of the school. Few contest that external factors such as parental involvement (e.g., Beals & Snow, 1994), everyday learning events (e.g., Cole, 1996) and experiences in informal learning environments (e.g., Falk & Dierking, 2000) have an impact on school success. We need to follow the child across learning environments and events, rather than constrain certain types of learning to certain types of environments. Tracking these external factors across environments, however, is not well understood. Only by extending our observational boundaries and broadening our measurement approaches will we profitably determine the true impact of informal science learning environments.

Taking a more longitudinal approach to research design provides a more holistic understanding of the affordances of a particular environments. It also sheds light on the transition moments between environments. As a field, we need to improve our understanding of the range of possible impacts of informal learning experiences, situating outcomes within larger frames of time, culture, and space.

A better understanding of what people bring to, take from, and adapt across different environments also has important implications for the design the next generation of learning environments. To mediate and facilitate extended meaningful disciplinary-specific knowledge, science talk, or identity development, we need to better understand the specific resources that children bring to school from their informal activities as well as how school-based knowledge is utilized to further non-school based learning.

References

Abu-Shumays, M. & Leinhardt, G. (2002). In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 45-80). Mahwah, NJ: Erlbaum.

Adelman, L., Falk, J.H., & James, S. (2000). Assessing the National Aquarium in Baltimore's impact on visitors' conservation knowledge, attitudes and behaviors. *Curator, 43*(1), 33-61.

Allen, S. (1997). Using scientific inquiry activities in exhibit explanations. *Science Education, 81*(6), 715-734.

Allen, S. (2002). Looking for learning in visitor talk: A methodological exploration. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 259-303). Mahwah, NJ: Erlbaum.

Allen, S. (2004). Designs for learning: Studying science museum exhibits that do more than entertain. *Science Education, 88*(Supplement 1), S17-S33.

American Association of Museums. 1984. *Museums for a new century*. Washington, DC: Author.

Anderson, D. (2003). Visitors' long-term memories of World Expositions. *Curator, 46*(4), 400-420.

Anderson, D., Kisiel, J., & Storksdieck, M. (in press). School field trip visits: understanding the teacher's world through the lens of three international studies. *Curator*.

Anderson, D., Lucas, K.B., & Ginns, I.S. (2003). Theoretical perspectives on learning in an informal setting. *Journal of Research in Science Teaching, 40*(2), 177-199.

Anderson, D., Lucas, K.B., Ginns, I.S., Dierking, L.D. (2000). Development of knowledge about electricity and magnetism during a visit to a science museum and related post-visit activities. *Science Education*, *84*(5), 658-679.

Arnold, K. (1996). Presenting science as a product or as process: Museums and the making of science. In S.M. Pearce (Ed.), *Exploring science in museums.* London: Athlone.

Ash, D. (2003). Dialogic inquiry in life science conversations of family groups in a museum*. Journal of Research in Science Teaching, 40*(2), 138-162.

Ash, D. & Klein, K. (2000). Inquiry in the informal learning environment, In J. Minstrell & E. Van Zee (Eds.),*Teaching and learning in an inquiry-based classroom* (pp. 216-240). Washington DC: AAAS.

Bain, R. & Ellenbogen, K.M. (2002). Placing objects within disciplinary perspectives: Examples from history and science. In S.G. Paris (Ed.), *Perspectives on object-centered learning in museums*, pp. 153-169. Mahwah: New Jersey: Erlbaum.

Beals, D.E. & Snow, C.E. (1994). "Thunder is when angels are upstairs bowling": Narratives and explanations at the dinner table. <u>Journal of Narrative and Life History, 4</u>(4), 331-352.

Becker, H. S. (1972). A school is a lousy place to learn anything in. *American Behavioral Scientist, 16*, 85-105.

Bitgood, S. (1993). What do we know about school field trips? In R. J. Hannapel (Ed.), *What research says about learning in science museums* (Vol. 2, pp. 12-16). Washington, DC: Association of Science Technology Centers.

Borun, M., Chambers, M., & Cleghorn, A. (1996). Families are learning in science museums. *Curator, 39*(2), 124-138.

Borun, M., Flexer, B. K., Casey, A. F., & Baum, L. R. (1983). Planets and pulleys: Studies of class visits to a science museum. Washington, DC: Association of Science-Technology Centers.

Borun, M., Dritsas, J., Johnson, J.I., Peter, N.E., Wagner, K.F., Fadigan, K., Jangaard, A., Stroup, E., & Wenger, A. (1998). *Family learning in museums: The PISEC perspective.* Philadelphia, PA: The Franklin Institute.

Bransford, J.D., Brown, A.L., & Cocking, R.R. (2000). *How people learn: Brain, mind, experience, and school.* Washington DC: National Academy Press.

Bransford, J., Vye, N., Stevens, R., Kuhl, P. Schwartz, D. Bell, P., Meltzoff, A., Barron, B., Pea, R., Reeves, B., Roschelle, J., & Sabelli, N. (in press). Learning theories and education: Toward a decade of synergy. In P. Alexander & P. Winne (Eds.), Handbook of Educational Psychology (Second Edition).  Mahwah, NJ: Erlbaum.

Bruner, J. (1996) *The Culture of Education*, Cambridge, MA: Harvard University Press.

Callanan, M. A. & Jipson, J. L. (2001). Explanatory conversations and young children's developing scientific literacy. In K. Crowley, C. Schunn, & T. Okada (Eds.), <u>Designing for science: Implications from everyday, classroom, and professional</u>

science (pp. 21-49). Mahwah, NJ: Erlbaum.

Callanan, M.A., Jipson, J.L., & Soennichsen, M.S. (2002). Maps, globes, and videos: Parent-child conversations about representational objects. In S.G. Paris (Ed.), Perspectives on object-centered learning in museums, pp. 261-283. Mahwah: New Jersey: Erlbaum.

Callanan, M., & Oakes, L. (1992). Preschoolers' questions and parents' explanations: Causal thinking in everyday activity. *Cognitive Development*, *7*, 213-233.

Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge, MA: Harvard University Press.

Crane, V. (1994). An introduction to informal science learning and research. In V. Crane, H. Nicholson, M. Chen, & S. Bitgood *Informal science learning: What research says about television, science museums, and community-based projects.* (pp. 1-14). Dedham, MA: Research Communications, Ltd.

Cronbach, L. J. (1975). Beyond the two disciplines of scientific psychology. *American Psychologist*, *30*, 116-127.

Cronbach, L. J., & Meehl, P.E. (1955). Construct validity in psychological tests. *Psychological Bulletin*, *52*, 281-302.

Crowley, K., & Callanan, M. (1998). Describing and supporting collaborative scientific thinking in parent-child interactions. *Journal of Museum Education, 23*(1), 12-17.

Crowley, K., Callanan, M.A., Tenenbaum, H.R., & Allen, E. (2001). Parents explain more often to boys than to girls during shared scientific thinking. *Psychological*

*Science, 12* (3), 258-261.

Crowley, K., Callanan, M.A., Jipson, J., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent-child activity. *Science Education. 85*(6), 712-732.

Crowley, K. & Galco, J. (2001). An explanation gap in everyday conversations about science. In K. Crowley, C. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional science* (pp. 393-413). Mahwah, NJ: Erlbaum.

Crowley, K. & Jacobs, M. (2002). Islands of expertise and the development of family scientific literacy. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.) *Learning conversations in museums* (pp. 333-356). Mahwah, NJ: Lawrence Erlbaum Associates.

Dhingra, K. Thinking about television science: How students understand the nature of science from different program genres*. Journal of Research in Science Teaching, 40*(2), 234-256.

Diamond, J. (1986). The behavior of family groups in science museums. *Curator, 29*(2), 139-154.

Dierking, L.D. (1987). Parent-child interactions in free-choice learning settings: An examination of attention-directing behaviors. *Dissertation Abstracts International, 49*(04), 778A.

Dierking, L.D., Falk, J.H., Rennie, L., Anderson, D., & Ellenbogen, K. (2003). Policy statement of the “informal science education” ad hoc committee. *Journal of Research in Science Teaching, 40*(2), 108-111.

Duschl, R.A. (1990). Restructuring science education: The importance of theories and their development. New York: Teachers College Press.

Ellenbogen. K.M. (2002). Museums in family life: An ethnographic case study. In Leinhardt, G. & Crowley, K. (Eds.), Learning conversations: Explanation and identity in museums (pp. 81-101). Mahwah, NJ: Erlbaum.

Ellenbogen, K.M. (2003). From dioramas to the dinner table: An ethnographic case study of the role of science museums in family life. Dissertation Abstracts International, 64(03), 846A. (University Microfilms No. AAT30-85758).

Ellenbogen, K.M., Luke, J. J., & Dierking, L.D. (2004). Family learning research in museums: An emerging disciplinary matrix? *Science Education, 88*(Supplement 1), S48-58.

Fadigan, K.A. & Hammrich, P.L. (2004). A longitudinal study of the educational and career trajectories of female participants of an urban informal science education program. *Journal of Research in Science Teaching, 41*(8), 835-860.

Falk, J.H., Brooks, P. & Amin, R. (2001). Investigating the role of free-choice learning on public understanding of science: The California Science Center L.A.S.E.R. Project. In Falk, J.H. (Ed.), *Free-choice science education: How we learn science outside of school* (pp. 115-132). New York: Teachers College Press.

Falk, J.H., & Dierking, L.D. (1997). School field trips: Assessing their long-term impact.

*Curator, 40*(3), 211-218.

Falk, J.H. & Dierking, L.D., (1998). Free-choice learning: An alternative term to informal learning. In Ellenbogen (Ed.), *Informal learning environments research newsletter 2*(1), 2.

Falk, J.H., & Dierking, L.D. (2000). Learning from museums: Visitor experiences and the making of meaning. Walnut Creek, CA: Alta Mira Press.

Falk, J.H., Moussouri, T., & Coulson, D. (1998). The effect of visitors' agendas on museum learning. Curator, 41(2), 107-120.

Fienberg, J. & Leinhardt, G. (2002). Looking through the glass: Reflections of identity in conversations at a history museum. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 167-211). Mahwah, NJ: Erlbaum.

Fyfe, G. & Ross, M. (1996). Decoding the visitor's gaze: Rethinking museum visiting. In S. Macdonald & G. Fyfe (Eds.). *Theorizing museums: Representing identity and diversity in a changing world* (pp. 127-152). London: Blackwell Publishers.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Palgrave.

Gelman, S. A., Coley, J. D., Rosengren, K. S., Hartman, E., & Pappas, A. (1998). Beyond labeling: The role of parental input in the acquisition of rightly-structured categories. *Monographs of the Society for Research in Child Development* Serial No. 253, Vol. 63, No. 1.

Gennaro, E. A. (1981). The effectiveness of using pre-visit instructional materials on learning for a museum field trip experience. *Journal of Research in Science Teaching, 18*(3), 275-279.

Gleason, M.E. & Schauble, L. (2000). Parents' assistance of their children's scientific reasoning. *Cognition and Instruction, 17*(4), 343-378.

Gonzâlez, N., Moll, L. C., & Amanti, C. (2005). *Theorizing education practice: Funds of knowledge in households*. Mahwah, NJ: Erlbaum.

Gottfried, J. L. (1980). Do children learn on field trips? *Curator, 23*(3), 165-174.

Greenfield, G. & Lave, J. (1982). Cognitive aspects of informal education. In D. Wagner & H.W. Stevenson (Eds.) *Cultural perspectives on child development* (pp. 181-207). San Francisco: Freeman.

Griffin, J. (1994). Learning to learn in informal science settings. *Research in Science Education, 24*, 121-128.

Griffin, J. (1988). Learning science through practical experiences museums. *International Journal of Science Education, 20*(6), 655-663.

Hall, R., & Stevens, R. (1995). Making space: A comparison of mathematical work at school and in professional design practice. In S. L. Star (Ed.), *Cultures of computing* (pp. 118-145). London: Basil Blackwell.

Halliday, M.A.K. & Martin, J.R. (Eds.), *Writing science: Literacy and discursive power.* Pittsburgh, PA; University of Pittsburgh Press.

Harris, N. (1978). Museums, merchandising and popular taste: The struggle for influence. In I. Quimby, (Ed.), *Material Culture and the Study of American Life*, New York:

Norton.

Heath, S. B. (1983). *Ways with words: Language, life, and work in communities and classrooms*. New York: Cambridge University Press.

Heath, S. B. (1991). “It’s about winning!” The language of knowledge in baseball. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 101-124). Washington D.C.: American Psychological Association.

Heath, S.B. & McLaughlin, M., Eds. (1993). *Identity and inner-city youth: Beyond ethnicity and gender*. New York: Teachers College Press.

Hein, G.E. (1998). *Learning in the museum.* London: Routledge.

Hensel, K.A. (1987). Families in a museum: Interactions and conversations at displays. *Dissertation Abstracts International, 49-09.* University Microfilms No. 8824441.

Henze, R.C. (1992). Informal teaching and learning: A study of everyday cognition in a Greek community. Hillsdale, NJ: Erlbaum.

Hilke, D.D. (1987). Museums as resources for family learning: Turning the question around. *The Museologist, 50*(175), 14-15.

Hilke, D.D. (1989). The family as a learning system: An observational study of families in museums. In B.H. Butler & M.B. Sussman (Eds.), *Museum visits and activities for family life enrichment* (pp. 101-129). New York: Haworth Press.

Hilke, D.D. & Balling, J. (1985). *The family as a learning system: An observational study of families in museums.* Washington, DC: Smithsonian Institution Press.

Holland, D., Lachicotte, W., Skinner, D., & Cain, C. (1998). *Identity and agency in* *cultural worlds.* Cambridge, MA: Harvard University Press.

Ivanova, E. (2003). Changes in collective memory: The schematic narrative template of victimhood in Kharkiv museums. *Journal of Museum Education, 28* (1).

Jackson, P.W. (1968). *Life in classrooms.* New York: Holt, Rinehart & Winston.

Jarvis, T. & Pell, A. (2005). Factors influencing elementary school children's attitudes toward science before, during, and after a visit to the UK National Space Centre, *Journal of Research in Science Teaching, 42*(1), 53-83.

Jamison, E. (1998). Field trip qualitative research. Prepared for: Science Museum of Minnesota and Minnesota Historical Society. Unpublished Research Report. St Paul, MN: Infocus Marketing Research.

Jessor, R., Colby, A., & Shweder, R. A. (Eds.) (1996). *Ethnography and human development*. Chicago: University of Chicago Press.

Kafi, Y.B., Fishman, B.J., Bruckman, A.S., Rockman, S. (2002). Models of educational computing @ home: New frontiers for research on technology in learning. *Educational Technology Review, [Online Serial], 10*(2), 52-68.

Kelly, G.J. & Duschl, R.A. (2002, April). *Toward a research agenda for epistemological studies in science education.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Kisiel, J. (2005). Understanding elementary teacher motivations for science fieldtrips. *Science Education 89*(6), 936-955.

Korpan, C.A., Bisanz, G.L., Boehme, C. & Lynch, M.A. (1997). What did you learn outside of school today? Using structured interviews to document home and community activities related to science and technology. *Science Education 81*(6): 651-662.

Koran, J. J., Lehman, J. R., Shafer, L. D., & Koran, M. L. (1983). The relative effect of pre- and post-attention directing devices on learning from a "walk-through" museum exhibit. *Journal of Research in Science Teaching, 20*(4), 341-346.

Koran, J.J., Longino, S.J., & Shafer, L.D. (1983). A framework for conceptualizing research in natural history museums and science centers. *Journal of Research in Science Teaching, 20*(4), 325-339.

Kuhn, T.S. (1970). *The structure of scientific revolutions. Second edition.* Chicago: University of Chicago Press.

Latour, B. (1987*). Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

Lave, J. (1988). Cognition in practice: Mind, mathematics, and culture in everyday life. Cambridge: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Leinhardt, G. & Gregg, M. (2002). Burning buses, burning crosses: Student teachers see civil rights. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 167-211). Mahwah, NJ: Erlbaum.

Leinhardt, G. & Knutson, K. (2004). <u>Listening in on museum conversations.</u> Walnut

Creek, CA: AltaMira Press.

Leinhardt, G., Tittle, C., & Knutson, K. (2002). Talking to oneself: Diaries of museum visits. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 167-211). Mahwah, NJ: Erlbaum.

Lemke, J. L. (1990). Talking science: Language, learning and values. Norwood, NJ: Ablex.

Lewenstein, B. (2001). Who produces science information for the public? In J.H. Falk, (Ed.), *Free-choice science education: How we learn science outside of school* (pp. 21-43). New York: Teachers College Press of Columbia University.

LIFE Center. (n.d.). *The Center for LIFE: Learning in Informal and Formal Environments.* Proposal. Available online at life-slc.org/LIFEproposal.pdf.

Longino, H. (1990). *Science as social knowledge.* Princeton, NJ: Princeton University Press.

Luke, J.J., Camp, B.D., Dierking, L.D., Pearce, U.J., (2001). The first free-choice science learning conference: From issues to future directions. In Falk, J.H. (Ed.), *Free-choice science education: How we learn science outside of school* (pp. 151-162). New York, Teachers College Press.

Martin, L.M.W. (1996). Learning in context. Association of Science-Technology Centers Newsletter, 24(2), 2-5.

Martin, L.M.W. (2001). Free-choice science learning. In J.H. Falk (Ed.), *Free-choice science education: How we learn science outside of school* (pp. 186-198). New York:

Teachers College Press.

Mayer, R.E., Quilici, J., Moreno, R., Duran, R., Woodbridge, S., Simon, R., Sanchez, D. & Lavezzo, A. (1997). Cognitive consequences of participation in a "Fifth Dimension" after school computer club. *Journal of Educational Computing Research, 16*(4): 353-370.

McDermott, R. P., Goldman, S. V., & Varenne, H. (1984). When school goes home: Some problems in the organization of homework. *Teachers College Record*, *85*, 391-409.

McLaughlin, M., Irby, M.A. & Langman, J. (2001). Urban sanctuaries: Neighborhood organizations in the lives and futures of inner-city youth. San Francisco: Jossey Bass.

McManus, P.M. (1987). It's the company you keep . . . The social determination of learning-related behaviour in a science museum. *The International Journal of Museum Management & Curatorship, 6,* 263-270.

McManus, P.M. (1992). Topics in museums and science education. *Studies in Science Education, 20,* 157-182.

Norman, D.A., (1988). *The design of everyday things.* New York: Doubleday.

Ochs, E., Taylor, C., Rudolph, D., & Smith, R. (1992). Storytelling as a theory-building activity. *Discourse Processes, 15(1)*, 37-17.

Ogbu, J. (1995). The influence of culture on learning and behavior. In J.H. Falk & L. Dierking (Eds.). Public institutions for personal learning: Establishing a research agenda. (pp. 79-95). Washington: DC: American Association of Museums.

Orion, N. (1993). A model for the development and implementation of field trips as an integral part of the science curriculum. *School Science and Mathematics, 93*(6), 325-331.

Orion, N., & Hofstein, A. (1994). Factors that influence learning during a scientific field trip in a natural environment. *Journal of Research in Science Teaching, 29*(8), 1097-1119.

Pearce, S. (Ed.). (1994). <u>Interpreting objects and collections.</u> London: Routledge.

Potts, R. & Martinez, I. (1994). Television viewing and children's beliefs about scientists. *Journal of Developmental Psychology, 15*(2), 287-300.

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

Rennie, L., and McClafferty, T. (1995). Using visits to interactive science and technology centers, museums, aquaria, and zoos to promote learning in science. *Journal of Science Teacher Education, 6*(4), 175-185.

Resnick, L.B. (1987). Learning in school and out. *Educational Researcher, 16*(9) 13-20.

Roberts, L.C. 1997. *From knowledge to narrative: Educators and the changing museum.* Washington, DC: Smithsonian Institution Press.

Rogoff, B., & Lave, J. (1984). *Everyday cognition: Its development in social context*. Cambridge: Harvard University Press.

Rogoff, B., Paradise, R., Mejía Arauz, R., Correa-Chávez, M., & Angelillo, C. (2003). Firsthand learning by intent participation. *Annual Review of Psychology*, 54.

Schauble, L. & Bartlett, K. (1997). Constructing a science gallery for children and families: The role of research in an innovative design process. Science Education, 81(6), 782-793.

Schauble, L, Beane, D.B., Coates, G.D., Martin, L.W., & Sterling, P.V. (1996). Outside the classroom walls: Learning in informal environments. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education* (pp. 5-24). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Scribner, S. (1984). Studying working intelligence. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 9-40). Cambridge: Harvard University Press.

Scribner, S., & Cole, M. (1973, 9 November). Cognitive consequences of formal and informal education. *Science* 82, 553-559.

Snow, C.E. & Kurland, B. (1996). Sticking to the point: Talk about magnets as a preparation for literacy. In D. Hicks (Ed.), Child discourse and social learning: An interdisciplinary perspective (pp. 189-220). New York: Cambridge University Press.

Sosniak, L. (2001). The 9% Challenge: Educating in school and society. *Teachers College Record*, 103.

St. John, M. & Perry, D. (1996). *An invisible infrastructure: Institutions of informal science education, Volume I.* Washington, DC: Association of Science-Technology Centers.

Stevens, R. (2000a). Divisions of labor in school and in the workplace: Comparing computer and paper-supported activities across settings. *The Journal of the Learning Sciences, 9(4),* 373-401.

Stevens, R. (2000b). Who counts what as math: Emergent and assigned mathematical problems in a project-based classroom. In J. Boaler (Ed.), *Multiple perspectives on mathematics education* (pp. 105-144). New York: Elsivier.

Stevens, R. & Hall, R. (1997). Seeing Tornado: How Video Traces mediate visitor understanding of (natural) phenomena in a science museum. *Science Education, 81*(6), 735-749.

Stevens, R., Wineburg, S., Herrenkohl, L.R., & Bell, P. (in press). The comparative understanding of school subjects: Past, present and future. *Review of Educational Research.*

Storksdieck, M. and Falk, J.H. (2003). After 18 months: What determines self-perceived and measured long-term impact of a visit to a science exhibition? Visitor Studies Association Conference, Columbus, OH.

Taylor, S. M. (1986). Understanding processes of informal education: A naturalistic study of visitors to a public aquarium. *Unpublished doctoral dissertation*, University of California, Berkeley, CA.

Tunnicliffe, S. (2000). Conversations of family and primary school groups at robotic dinosaur exhibits in a museum: what do they talk about? *International Journal of Science Education 22*(7), 739-754.

U.S. Department of Education. (2000). *America 2000: An education strategy,* *Sourcebook.* Washington DC: Author.

Vallance, E. (1995). The public curriculum of orderly images. *Educational Researcher, 24*(2), 4-13.

Wenger, E. (1999) *Communities of practice: Learning, meaning and identity*. Cambridge: Cambridge University Press.

Wertsch, J. V. (1998). *Mind as action*. New York: Oxford University Press.