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Augmented hands-on: an evaluation of the impact of augmented reality technology on informal science learning behavior

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AUGMENTED HANDS-ON:

AN EVALUATION OF THE IMPACT OF AUGMENTED REALITY TECHNOLOGY ON INFORMAL SCIENCE LEARNING BEHAVIOR

A dissertation submitted in partial satisfaction

of the requirements for the degree of

Doctor of Education in Educational Technology

by

Karen J. Elinich

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This dissertation, written by

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DEDICATION

This dissertation is dedicated to my mother, Regina Elinich, who did not live to see me complete my journey. She was, is, and forever shall be my guiding light.

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ABSTRACT

This evaluative comparison study was designed to determine the extent to which the application of augmented reality technology increases realization of a hands-on exhibit device's intent and how augmented reality technology might influence family learning behaviors and facilitate the integration of the experiential and interpretive aspects of an informal science learning experience. The study was conducted at The Franklin Institute Science Museum during the summer of 2010. Twenty families interacted with an exhibit device called "Be the Path" in both its traditional hands-on condition and a novel augmented condition. While the sample size was too small to generate statistically significant differences between conditions, the resultant qualitative analysis of the family learning behaviors suggested that the families who encountered "Be the Path" in its augmented hands-on condition played longer and at a higher level of quality than those who encountered the hands-on device without augmentation. All of the families who experienced "Be the Path" in its augmented condition surpassed the families who experienced the non-augmented device on at least one measure. Furthermore, many of the families who encountered the augmented reality surpassed their counterparts in the non-augmented device group on two or more measures. These positive findings suggest that additional investigation is warranted in order to deepen understanding of augmented reality technology's potential to influence family learning behaviors around hands-on exhibit devices in ways that could create and support the development of skills needed to maximize the impact of informal learning—in science museums and elsewhere.

Chapter 1: A Scientific Future at Risk

America needs scientists, engineers, and technology professionals in order to remain competitive in a global economy and in order to address the critical challenges that accompany globalization, yet science education in America is in a state of steady decline. Recent news (OECD, 2010) that 22 countries ranked higher than the United States on the 2009 international science assessment—and especially that Shanghai-China ranked first—has fueled the flames of fear for the future. President Obama, in his 2011 State of the Union address, joined the editorial columnists, news anchors, and late-night television personalities who have been rallying ordinary Americans to act in response to the troubling news. The President's plan to "win the future" positions science and technology education as the bedrock for future innovation.

America's past is a history filled with stories of innovation and progress and its present remains populated with creative and collaborative individuals who strive to lead the way with scientific and technological change. Can America maintain its scientific leadership in the global future? Unfortunately, current data suggests that the next generation is not sufficiently prepared and that formal educational systems—as they currently exist—are not sufficiently equipped to respond, lacking the capacity to mount the necessary response to the challenge. Informal science education, therefore, has become more important than ever and has the opportunity to contribute innovative solutions.

As out-of-school venues for engagement with science and technology content and resources, informal science learning institutions are positioned to help confront the pressing challenges. Informal science institutions have long existed as part of the "invisible infrastructure" (St. John, 1996) that supports learning beyond the classroom. That existing infrastructure can be leveraged to support science education in new ways in response to the critical needs of society. However, informal science education has its own longstanding shortfalls which need to be acknowledged and addressed. For example, informal science education positions hands-on experiential encounters with scientific phenomena—usually in the form of a kiosk or free-standing device—at the forefront of learning activities. Designed location-based interpretative support—usually in the form of a printed graphic panel—exists alongside the experiential space, intended for careful consideration. When engaged thoughtfully in tandem, the experiential (device) and the interpretive (graphic panel) combine for meaningful and impactful learning experiences. What informal science education research currently reveals, however, is that the thoughtful engagement of the two occurs far too infrequently, with the interpretive components more commonly left unconsidered. This shortfall is endemic within informal family learning behavior and needs to be addressed if informal science venues hope to demonstrate their value and influence the future of science in America.

Families need scaffolds and support for their learning behavior around science exhibit devices such that both adults and children engage with both the experiential and the interpretive components. This behavior—in which both adults and children model experiencing and interpreting for each other—is not innate. It requires practice. Families who visit science museums frequently may develop the skills on their own, but the far more common mainstream families who visit on less frequent occasions need help in order to maximize the impact of their effort. Might new technologies hold the solution? Can augmented reality technology influence family learning behavior in order to bridge the gap between the experiential and the interpretive aspects of the informal science learning experience? If technology can succeed in merging the experiential with the interpretive, the potential for informal science learning impact increases.

Calls to Action

Over recent years, the issue of America's science, technology, and engineering competitiveness has drawn attention and calls to action from both the private and public sectors (Business Roundtable, 2005; Domestic Policy Council, 2006; U.S. Department of Education, 2007). In 2007, for example, the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine jointly authored "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future" (National Academy of Science, 2007). The strategic report details an urgent agenda for science and technology and its importance in preserving America's leadership in those areas. The report boldly calls for an "increase [in] America's talent pool by vastly improving K-12 science and mathematics education" (National Academy of Science, 2007, p. 5). The proposed efforts are familiar elements of the school reform movement that has existed over the past two decades, yet have failed to produce real change. While these calls have not directly involved the informal science learning community, the concerns are widely shared and the informal science community has been struggling to develop its own response. It is within this context that informal science educators work simultaneously to identify innovative solutions to the problems at hand and to remain relevant for science learning in future generations.

Also in 2007, the Chairman of the Microsoft Corporation, Bill Gates, stepped forward to articulate a plan for "How to Keep America Competitive" (Gates, 2007) in a global innovation economy. He expressed his belief that in order for America to compete, Americans must

> …commit to an ambitious national agenda for education [in which] government and businesses can both play a role. Companies must advocate for strong education policies and work with schools to foster interest in science and mathematics and to provide an education that is relevant to the needs of business. Government must work with educators to reform schools and improve educational excellence. (Gates, 2007, para. 9)

Informal science educators are well-positioned to respond, having a long history of fostering interest in science and mathematics. In fact, a survey of 1400 scientists showed that 76% of them reported that their early interest in science was cultivated by visits to science museums (Bayer Facts of Science Education Survey, 1998).

In 2008, the State Educational Technology Directors Association (SETDA) issued "Science, Technology, Engineering, and Mathematics Education: Achievement and Innovation" (SETDA, 2008), a report that includes a strategic plan to unify state efforts to counteract the alarming decline in achievement. In particular, SETDA recognized that "In K-12, high-quality [science] education is hindered by a number of factors, including a dearth of qualified teachers, lack of funding to promote [science] education, inadequate recruitment and retention policies, and certification issues for [science]-trained professionals who want to move into teaching" (Nagel, 2008, para. 5). These problems are not new. For many years, informal science learning institutions have worked to serve their communities by supporting the formal school system by providing professional development events and curricular resources (St. John, 1996) in attempts to help overcome these systemic shortfalls. Furthermore, informal science learning institutions have worked steadfastly to demonstrate the value of hands-on engagement with scientific phenomena accompanied by reflective consideration of interpretative content. The impact of those efforts, however, has not been rigorously or systematically evaluated.

Gathering Evidence

Understanding the urgency of these calls for action requires an appreciation of the data that partially inspired them. The 2003 Trends in International Mathematics and Science Study (TIMSS), for example, presented alarming statistics (Institute of Education Statistics, 2003). The data showed that American science students were among the best in the world at grade 4, ranking fourth. However, at the eighth-grade level, American science students ranked only eighth, being outperformed by their peers in Chinese Taipei, Hong Kong, Japan, Korea, Singapore, Estonia, and Hungary.

Likewise, the 2006 Programme for International Student Assessment (PISA) provided evidence that American science students were being left behind in the global economy. PISA 2006 (OECD, 2007) looked specifically at student preparation and readiness for scientific careers in the future. The results were very troubling; of the 30 participating countries, only nine ranked below the United States. 20 countries have students who are better prepared to succeed in a challenging future. There was some good news; when top performing students were placed side-by-side, the U.S. students performed on par with the best in the world. At the highest levels, therefore, America is prepared to lead. The challenge arises, however, when one looks more broadly for participants in the scientific enterprise. For every talented lead researcher, a team of collaborators, colleagues, and contributors is needed to help fulfill the promises of new innovations. In America, today, it seems that average students who might contribute simply do not care about science and that decline in interest happens significantly between fourth and eighth grade. Coincidentally, that grade band aligns directly with the typical audience targeted and served by informal science institutions. Whether visiting with their families or classmates, students in grades 4 through 8 can and do encounter interesting informal science learning experiences. Yet a gap persists between the experiential pleasure of science exhibits and the deeper interpretive contemplation of science phenomena that might influence future career pursuits.

Meeting the Challenge

The more that formal K-12 education systems attempt to “fix” science education, the more broken it seems to be. The need for radical approaches may be at hand. The National Science Foundation (National Science Foundation, 2006) estimates that, by 2012, the number of career positions in science and engineering will outpace the number of qualified individuals by 26% and 15%, respectively. Industry leaders, as described above, are concerned that even the educated entrants into the workforce lack the skills needed to innovate. As new scientific and technological developments continue to transform the way that people live and work, the need for scientific and technological literacy increases.

The challenge is great. In fact, the challenge is greater than the capacity of formal K-12 science education. Even if the calls for reform are fully embraced, the need exceeds the available resources. It has become clear that formal education is no longer a sufficient mechanism for producing scientifically and technologically literate citizens. Children spend only 21% of their waking hours annually with teachers in classrooms. Parents select and provide the out-of-school learning experiences that occupy the largest majority of a child's life. Informal science education is properly positioned to help families invest their time wisely. However, the return on that investment is dependent upon parents learning good practical strategies for translating the natural curiosity of children into effective science learning behavior.

It is in this context that the role of informal science education becomes essential. Informal science institutions have the capacity to help overcome the systemic shortfalls. The recent National Research Council report on learning science in informal environments (Bell, Lewenstein, Shouse, & Feder, 2009) notes that No Child Left Behind (NCLB) legislation has actually limited the amount of in-school instructional time for science, further exacerbating the problem. Given the pressures associated with NCLB, formal K-12 science education is shrinking, just as the need for it is exploding. Informal science education has always sought to supplement and support the formal K-12 learning experience. Now, however, it has become vital and must demonstrate the validity of its contributions.

There is a need, as documented by the National Research Council report (Bell et al., 2009) as well as others (Rennie, Feher, Dierking, & Falk, 2003), for systematic and rigorous studies of learning designs in informal science education settings in order to understand the real potential for impacting science education. This research study responds to that call for data, as America's scientific future depends on it. In particular, this study considers how augmented reality technology may impact traditional family learning behavior in order to maximize the potential impact of a science museum exhibit.

Life—in Science

The vibrant passionate life of a scientist is a worthy pursuit for any young American who seeks a dynamic life of intellectual stimulation and service. Every participant in the scientific enterprise makes a difference in the world—not by balancing equations and factoring derivatives, but by asking questions, seeking answers, and attempting to create new knowledge for generations to come. Students need to understand the nature of science as a fundamentally collaborative human endeavor. And, instinctively, students seem to know this. The NetDay/Project for Tomorrow survey (NetDay, 2005) asked students what might increase their interest in science. Their responses included field trips to museums, nature sites, and laboratories. They mentioned meeting scientists and seeing what they actually do. They seemed to know that the interesting part of science happens "out there" beyond the classroom, out where real human beings are. Their instincts appropriately lead them to suspect that perhaps what they do in their classroom is artificial.

The problems are systemic, where standardized curriculum preferences breadth over depth and where textbook purchasing decisions are made far from the classroom (Michaels, Shouse, & Schweingruber, 2007). Science textbooks and resource materials are nearly universal in their presentation of lifeless, sanitized accounts of the real dramatic events of scientific discovery (Clough & Olson, 2004; Lederman & Lederman, 2004). Additionally, many teachers are products of the same system, such that they too perceive science as a body of knowledge to be absorbed rather than as a dynamic human endeavor. Given this convergence of circumstances it is perhaps logical that mainstream formal science education fails to inspire students and lacks the structural capacity to respond quickly and sufficiently to the calls for action.

In informal science education, however, learners can find freedom and inspiration. Asking questions, seeking answers, playing with materials, and making sense are the standards to be met. Informal science education functions best when learners are having fun. Yet, informal science education itself currently exists in a world of challenging conditions and may need to prove its worth. In years gone by, it may have been sufficient to report that visitors were engaged and enjoyed learning about science during a museum visit, even without knowing if they understood what they encountered. Satisfaction surveys were the instrument of standard measure. Now, and for the future, new strategies are needed—both for informal science education exhibit design and research—to make sure that the educational intent is fully realized.

This research study considers how a new technology—augmented reality—may ensure that it will be. To what extent does the application of augmented reality technology achieve its goal of increasing realization of an exhibit device's intent? To what extent can augmented reality technology facilitate the integration of the experiential and interpretive aspects of the informal science learning experience? How might augmented reality technology impact family behavior around exhibit devices?

Augmented reality technology refers to the application of digital computer-generated imagery within a live real-world physical encounter. The augmentations are layered directly onto the real experience. In many instances, augmented reality technology involves specialized gear such as goggles, head-mounted displays, or handheld devices. For the purposes of this research study, however, the emphasis is on fixed-position augmented reality that seamlessly responds to an individual's real-time movement within a defined learning space around an exhibit device with no need for specialized gear. In particular, the study considers the impact of augmentation on a hands-on exhibit device called "Be the Path" which invites learners to complete an electrical circuit and consider the scientific phenomenon of conductivity.

Summary

At a time when America most needs its educational system to encourage students to pursue science-related careers, student interest and competence in science is shrinking. Despite decades of reform efforts, formal science education lacks the structural capacity to respond sufficiently to the need for future innovators in American industry. Informal science education, therefore, can no longer exist on the margins. It must deliberately and strategically evaluate itself in an attempt to maximize its contribution. Studies are needed to understand how best to engage families who visit science museum exhibits. This research study looks at one well-known problem—the lack of integration of the experiential and interpretive aspects of learning around a single exhibit device—and analyzes how new augmented reality technologies may help to solve it. In doing so, it examines patterns of family learning behavior and role-playing prompted by museum exhibit devices.

Chapter 2: Problem Discussion

What is Informal Science Education?

Every year, around the world, millions of people visit science museums. Innate human curiosity about the natural and physical worlds compels learners of all ages to visit museum spaces filled with devices designed deliberately to engage and reward that curiosity. Every day, visitors line up in hopes of experiencing awesome moments of discovery. During 2009, for example, the Association of Science-Technology Centers (Association of Science-Technology Centers, 2009) estimated that 82 million people visited its member organizations.

The science museum visit experience is fundamentally about first-person encounters with phenomena (Allen, 2004; Eberbach & Crowley, 2005) that satisfy the human urge to understand the world. Informal science educators facilitate learning by providing "dynamic information spaces for knowledge building" (Knipfer, Mayr, Zahn, Schwan, & Hesse, 2009, p. 197) wherein learners encounter the exhibition content but are also expected to participate in the social construction of knowledge.

Given that expectation, what, then, makes a science learning experience "informal?" The National Science Foundation (2005) has used this definition for informal science education:

> Informal learning happens throughout people's lives in a highly personalized manner based on their particular needs, interests, and past

> experiences. This type of multi-faceted learning is voluntary, self-directed, and often mediated within a social context (Crane, Nicholson, Chen, & Bitgood, 1994; Dierking, Ellenbogen, & Falk, 2004; Falk, 2001); it provides an experiential base and motivation for further activity and subsequent learning. (p. 4)

In this context, science museums are certainly not the only venues for informal science learning. In fact, informal science institutions exist in a wide variety of circumstances—even some for-profit ventures are classified as such. For the sake of this analysis, however, the context for informal science education will be the kind of experience that occurs during a visit to a science museum.

Furthermore, this analysis aligns with the "strands of science learning" framework suggested by Bell et al. (2009). The framework identifies six distinct strands of science-specific capabilities that are supported by informal learning environments, providing an organizational mechanism for recognizing and identifying the characteristics of effective science learning in informal settings. The strands "illustrate how schools and informal environments can pursue complementary goals" (p. 4). The six strands are:

- Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.
- Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.
- Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.

- Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own process of learning about phenomena.
- Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.
- Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.

The framework's intention is not to suggest that every activity in a science exhibition must—or even can—reflect all six strands. Rather, the purpose is that "the strands serve as an important resource from which to develop tools for practice and research. They should play a central role in refining assessments for evaluating science learning in informal environments" (Bell et al., 2009, p. 5). This study's findings, therefore, will be discussed within the strands framework.

The learning that takes place in science museums also reflects principles of life-long, life-wide, life-deep learning as articulated by the LIFE Diversity Consensus Panel (Banks et al., 2007). Science museums especially demonstrate principles two and three:

2. Learning takes place not only in school but also in the multiple contexts and valued practices of everyday lives across the life span.
3. All learners need multiple sources of support from a variety of institutions to promote their personal and intellectual development.

Science museums, therefore, clearly support the long, wide, and deep learning that ebbs and flows throughout the lifetime of most citizens. Precisely how and how well science museums do so, however, remains beyond quantification.

Origins of the 21st Century Science Museum

The exhibition of artifacts that invoke curiosity has been in practice for centuries. Curiosity cabinets and the display of medical specimens have long been recreational diversions, many dating to the mid-18th Century. In many cases, science museum collections originated in medical schools which collected preserved specimens—both normal and odd—for teaching purposes. In other cases, international expositions or "World's Fairs" became the foundation for science museum collections. The most notable example is the magnificent Science Museum in London which opened in 1857 in South Kensington as the permanent home of the 1851 Crystal Palace Great Exhibition.

The modern conception of an interactive science museum, however, dates only to the early Twentieth Century. The Deutsches Museum in Munich is considered the pioneer, as it was the first to feature exhibits that encouraged hands-on interaction with buttons that caused a response. In America, The Franklin Institute Science Museum in Philadelphia, the Museum of Science in Boston, and the Museum of Science and Industry in Chicago were early leaders in the field, becoming popular destinations that celebrated the innovations of the Industrial Revolution. (Like the Science Museum in London, the Chicago Museum of Science and Industry can trace its origins to a World's Fair. It opened in 1933 in a building which first housed the Palace of Fine Arts during the 1893 World's Columbian Exhibition.)

By mid-twentieth century, a new model arrived in San Francisco at the Exploratorium, with its lack of historical collections and its avant-garde approach to exhibition that grouped devices in curiously random ways rather than within discipline areas. Since then, the norm for science museums has become the hybrid exhibition of artifacts in concert with interactive devices for hands-on encounters with related scientific phenomenon. For example, at The Franklin Institute, an 18th-Century lightning rod that belonged to Benjamin Franklin is on display in a glass case beside an interactive kiosk where visitors can make their own hair stand on end by grasping a van de Graaff static electricity generator and allowing its electric current to flow through them.

The Current Challenge

Society needs informal science education to help prepare the next generation of science and technology professionals. Formal K-12 science education currently lacks the capacity to expand its offerings (Bell et al., 2009). It is within this context that it has become imperative for informal science education to think carefully and analyze rigorously (Bell et al., 2009) the quality and impact of the informal learning experiences it offers for families who opt to engage in out-of-school science learning experiences (Falk, 2001).

While families are not the only audience informal science education serves, family groups consistently represent the largest percentage of a science museum's visitor base (Dierking & Falk, 1994), typically more than half (Ash, 2003). Therefore, it is important for museum educators to ensure that they are carefully considering the impact of their exhibit design on family learning behaviors. It is also important for museum educators to recognize that parents are their partners in informal science learning. Parents shape and support their children's scientific thinking before, during, and after their museum visit. Crowley et al. (2001) compared children who visited the science museum with parents against those who visited without their parents (e.g. with a school class or other peer group). He found that when children had parents with them, their exploration of evidence was longer, broader, and more focused on relevant comparisons (Crowley et al., 2001). Parents are trusted intermediaries who play an important role in the informal science learning experience.

Much is known about how families use science museums (Ash, 2003; Bertschi, Benne, & Elkins, 2008; Borun et al., 1998; Crowley & Callanan, 1998; Crowley et al., 2001; Diamond, 1986; Dierking & Falk, 1994; McManus, 1989, 1994). Unfortunately, research has shown that families often neglect to take full advantage of the resources at hand (Ash, 2003; Bertschi et al., 2008) during their exhibit visits. For example, instructive graphic panel displays placed beside hands-on devices are often ignored or misread, minimizing the device’s impact. With rare exception, an exhibit device’s intent presumes that the learner will engage fully, incorporating the graphic display into the hands-on experience. Unfortunately, learners rarely read instructions when they approach a device, instead engaging in fun play and more creative—occasionally counterproductive—use of the exhibit (Ayres & Melear, 1998; Fleck et al., 2002). When only this hands-on play occurs, the intent is unfulfilled. (Likewise, if a learner opts to only read the display without experiencing the hands-on portion, the intent is lost. This is uncommonly observed, however.) While the hands-on encounter with the scientific phenomena may have some intrinsic value, its lack of integration with the interpretive context minimizes its potential impact.

Families like to talk to museum educators and frequently rate those conversational interactions as the highlight of their visit (Dierking & Holland, 1995). The challenge is to help visitors recognize that content of stationary graphic panels positioned beside devices represents the voice of the museum educator and are the primary mechanism for the museum-to-visitor pathway of knowledge communication as defined by Knipfer et al. (2009). By reading the interpretive panel text aloud and discussing illustrations, it is as if the family invites the museum educator to be present in their conversation. And, it is within that conversation that the knowledge communication shifts to the second pathway: visitor-to-visitor (Knipfer et al., 2009).

How can science museums increase the likelihood that families take full advantage of the science learning opportunities within an exhibit? Knipfer et al. (2009) undertook a thorough review of existing advanced media applications that support knowledge communication within science exhibitions. In particular, their survey looked at how science museums were currently using technology to facilitate and strengthen the pathway for visitor-to-visitor knowledge communication (Knipfer et al., 2009). They found that media applications can and do support knowledge communication, although the extent to which the applications were purposefully designed with that goal in mind remains unclear. As a result, the existing applications lack consistent features that would enable a systematic comparison. Still, the study reveals that there is a real potential for computer-supported knowledge communication within science museum exhibits.

None of the applications considered by Knipfer et al. (2009) featured augmented reality technologies, as they are only just emerging and being considered for use in informal science education. Augmented reality technologies provide the opportunity to merge hands-on physical device interaction with use of the graphic panel display, ensuring that the museum educator's voice (the museum-to-visitor pathway) is present in the family learning experience (the visitor-to-visitor pathway). In effect, augmented reality offers the potential to intersect the museum-to-visitor pathway for knowledge communication with the visitor-to-visitor pathway (Knipfer et al., 2009).

The ideal exhibit device provides a meaningful primary and sensory involvement with scientific phenomena. To move beyond the primary experience, secondary support—graphic panels, explanatory text, videos, and animations—assists the learner in reflecting on the experience. However, this secondary "interpretive" learning is necessarily removed from the actual, hands-on interaction. Once the device has been used, the learner must make the decision to invest further time and effort to read the graphic panel, make sense of the panel's content, and then return to the primary experience to connect the hands-on and interpretive experiences (Falk, 2001). Coupled with reticence to read graphic panels at all (Ayres & Melear, 1998; Fleck et al., 2002), this structure makes the interpretation of the hands-on experience a primary challenge when designing experiential interactive exhibit devices. Through augmented reality technologies, the primary encounter and secondary interpretation can merge and generate a singular integrated experience. This research study considers how that merger impacts family behavior around a single exhibit device.

Augmented reality technologies integrate the experiential, interpretive, and social dynamics of the family learning experience. Essentially, science museums are constructivist learning environments (Knipfer et al., 2009). Within science museums, intentional learners have countless opportunities to construct knowledge. In contrast, most formal science learning environments—especially K-12 science classrooms—represent science as a discipline for objectivists by presenting science as a body of facts to be known and remembered. Most learners who visit museums are products of those classrooms. Science museums, therefore, need to find the points of intersection between prior objective experience and the invitation to construct new knowledge.

Perhaps more so than classrooms, exhibit halls at science museums honor the learner's prior knowledge. As a theory of knowing, constructivism provides an architectural foundation for the design of museum exhibits and especially for augmented reality usage. If "people construct new knowledge and understandings based on what they already know and believe," (Bransford, Brown, & Cocking, 2000, p. 10) then prior knowledge is always a key consideration. No matter *how* the learner came to understand electricity, for example, in the past, (Bransford et al., 2000) some previous encounter has left a cognitive imprint.

Computers in Science Museums

Although some computer-based interactive platforms have improved the potential for social interaction and overcome the isolation of individuals who are not co-located (Heath, vom Lehn, & Osborne, 2005; vom Lehn, Heath, & Hindmarsh, 2002), research (e.g. Heath et al., 2005; Sandifer, 2003) has shown that computer interactives, particularly in the science museum field, can often limit social interaction in the real world, thus eliminating the opportunities for discussion and communication that research has shown to be essential for effective learning (Bransford et al., 2000; Knipfer et al., 2009). Even computer-based devices designed to encourage use by more than one person at a time show a reduced level of visitor conversation. A digital interface can be designed to lead users through specific instructions and actions on sequential screens to guide them towards a more directed learning goal (Ayres & Melear, 1998; Fleck et al., 2002). However, aversion to reading graphic panels also extends to these computer-based display screens, which are passed over just as frequently as graphic panels (Sandifer, 2003). Regardless of the technology, interface design plays a key role in educational efficacy; unfamiliar computer navigation or unintended physical actions that obscure the phenomenon are all too common (Allen, 2004; Fleck et al., 2002; Gammon, 1999a, 1999b). Finally, for all the novel experiences only possible on a computer screen, these opportunities are removed from the direct, first-hand interactive experiences that are one of the singular strengths of a science museum visit. It is within this context, then, that the successful implementation of augmented reality technologies for use in informal science learning institutions represents a recent and important innovation for the field.

Augmented Reality in Science Museums

While augmented reality has yet to gain ground in K-12 or informal science education, it has increased its footprint in higher education and other knowledge domains including medicine and defense (John & Lim, 2007; Klopfer & Squire, 2008). At the university level, for example, learning experiences are being enhanced through augmented reality to offer real-world scenarios and visualization of unseen phenomena. Research has found that these tools can produce positive learning gains (Klopfer &

Squire, 2008), challenge misconceptions (Tasker & Dalton, 2008), and concretize abstract theories (Dori & Belcher, 2005). In all of these studies, however, the augmented reality experience existed in concert with formal classroom instruction. The evidence for the affect of augmented reality in K-12 or in a free-choice informal science family learning experience is scant. While limited, the following review presents existing implementations and evidence.

One recent approach to the problem of more firmly connecting primary experience and interpretation has been to use augmented reality in handheld devices. Augmented reality is a field of computer research that works to merge the real world and computer-generated data. By using live video imagery, digitally processed to include computer-generated graphics, it augments the real world with digital enhancements. As this technology has advanced, the use of an array of different sensor technologies—including motion tracking and machine vision—have added to the power of the experience and the seamlessness with which the two worlds can be combined. Augmented reality systems based in handheld devices are already in regular use in some science museums (Klopfer, 2008), notably in Austria and Japan. For example, The Graz University of Technology in Vienna has developed an innovative handheld system called the Museum Augmented Reality Quest (MARQ), which developed and provided an electronic tour guide for museums based on a self-contained, inexpensive, handheld device that delivers an interactive 3D augmented reality experience (Schmalstieg & Wagner, 2005).

Augmented reality research (Kondo et al., 2007) is also underway at the National Science Museum in Tokyo, Japan where a dinosaur gallery is augmented with virtual creatures accessed using a handheld device. Like the MARQ project, however, the dependence upon handheld devices limits the widespread, practical applicability for science museums.

CONNECT is a European project that has been using augmented reality as a means of augmenting existing interactive stations with digital visualizations (CONNECT, 2010). By projecting force diagrams and controlled explanatory videos, this system allows visitors to enhance their experience to positive effect. The system was developed specifically for use with visitors from the formal education system. Students strap on a backpack holding the computing platform and wear head-mounted displays. Initial findings from this project demonstrate a definite potential for the approach to improve learning in the science museum setting. Improvements were seen in CONNECT student motivation and learning. While the researchers could not credit this fully to the augmented reality system, the early success indicated that further development of interfaces for hands-on devices in the science center would be a potentially fruitful area for exploration.

In Boston, the Museum of Science piloted an augmented reality project developed with the Massachusetts Institute of Technology. The experience, which also used handheld devices, layered a murder mystery over the museum gallery space, challenging participants to locate clues and attempt to solve the mystery. MIT’s Teacher Education Program also offers the Developing Public Opinions on Science Using Information

Technologies (POSIT) project model, which, again, is handheld-based (Klopfer, 2010). These projects both offer important models, but raise the question of how practical they are for family learning.

Handheld augmented reality may be effective for individualized learning, but as a mechanism for family learning they fail to exhibit the characteristics of family-friendly devices. Informal science education research has determined that family-friendly devices are multi-sided, multi-user, accessible, multi-outcome, multi-modal, readable, and relevant (Borun & Dritsas, 1997). While the augmented reality experience enabled through the handheld display may indeed reflect some of these characteristics, the fundamental inability for a multi-generational family group to engage simultaneously with the content and with one another effectively marginalizes the experience. Rather, museum educators must seek to find the intersection between augmented reality technologies and devices that are already known to be family-friendly. For this reason, this research study focused on the evaluation of an augmented reality model that builds upon an existing exhibit device (called “Be the Path” and described fully in Chapter 3) that is already known to reflect the seven family-friendly characteristics.

Summary

Science museums have long known that family learning happens around exhibit devices. The challenge has always been to ensure the quality and accuracy of that learning. Now, as formal education has turned its focus elsewhere, informal education has an even greater role to play in order to inspire the next generation of scientists. The tradition of placing graphic panels with directive and interpretive text can be effective, but only when families actually read and discuss the text. Informal science educators have attempted to employ computer-based solutions to the problem but have met with little to no success. New augmented reality technologies may succeed in influencing behavior where those other technologies have fallen short; augmented reality may finally merge the dynamic experiential hands-on play with the static interpretative support.

Chapter 3: Research Methods

Purpose Statement

The purpose of this research study was to evaluate the impact of augmented reality technology on informal science learning behavior within the context of a science museum exhibit. In particular, the study attempted to understand how digital augmentation of a hands-on exhibit device may facilitate satisfaction of the device's intent and impact family learning behaviors around it (Ash, 2003; Diamond, 1986; McManus, 1989, 1994) by bringing the primary experiential and secondary interpretive aspects of the experience closer together. The evaluative comparison study considered a single hands-on exhibit device offered for use in two conditions: non-augmented and augmented. The study involved two cohorts of families, distinguished by the condition of the hands-on device they encountered: non-augmented (n=10) and augmented (n=10). Ultimately, the comparison study sought to inform the informal science learning community about augmented reality technology's potential to influence the way families interact with hands-on devices and interpretive content during science museum visits.

Research Questions

The study sought to answer the following questions:

1. To what extent does the application of augmented reality technology increase realization of a hands-on exhibit device's intent for learning?
2. To what extent can augmented reality facilitate integration of the experiential and interpretive aspects of the informal science learning experience?

Logic Model

The following figure illustrates the study's logic model.

ASSUMPTIONS:
Science education in America is in steady decline.
Formal education system lacks the structural capacity to respond sufficiently.
Informal science education can help, but has its own problems.
Informal educators need ways to ensure that learning experiences are as effective as they intend.
Informal educators need to identify ways to overcome the gap between the experiential and interpretive aspects of informal science education experiences.

RESOURCES/ INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
Science Museum. Be the Path exhibit device. Augmented Reality (AR) technology. Family groups visiting during summer.	Use AR to enhance Be the Path. Evaluate AR to determine if it impacts engagement & understanding of device's intent. Observe and compare the behavior and response of learners who engage the device without augmentations against those who encounter augmentations. Interview them about the experience.	An enhanced Be the Path exhibit device. Data about the use of AR in informal science learning exhibits. New knowledge about AR technology. New strategies for use in exhibit design.	Informal science education is better positioned to support the need for expanded science education in America. Exhibit developers can apply AR strategies in new exhibits.	Informal science education better supports improvement of science education in America.

Figure 1. Research logic model, including inputs, activities, outputs, outcomes, and impacts.

Methodology

McManus (1989, 1994) offers a model for evaluating and understanding family communication and behavior around museum exhibit devices. Her seminal work showed that visitors who attend museum exhibits as groups function as social units (1989). Through the placement of graphic panels and label copy, museum educators engage these social units in asynchronous conversation (see also Bertschi et al., 2008). In effect, the museum educators make their side of the conversation accessible on demand by creating mounted graphic displays, most often featuring text and images. McManus (1989) suggests that those graphic panels should be designed to facilitate further conversation within the social units. Ideally, the museum educators post topical content that sparks discussion within the visitor groups. All too often, however, visitors overlook or ignore the graphic panels, sabotaging their potential contribution to the conversation and silencing the museum educator’s voice.

McManus’ (1994) seminal research provided the communication models which were analyzed in this study. For decades, science museum educators have attempted to design exhibit devices so that social units (especially families) can interact with the hands-on portion of the exhibit device while incorporating the graphic panel content that is presented nearby. For example, consider the Bernoulli Ball—a classic device that appears in some form in nearly every science center. A kiosk houses a wind machine which, when activated, causes a strong burst of air to flow upward. Above the kiosk, an inflated plastic beach ball begins to ride the air current. It seems to be magically floating on air. Visitors of all ages are drawn to the ball and playfully try to alter its movement.

Traditionally, a printed graphic panel is mounted nearby to explain Bernoulli's Principle and some elementary fluid mechanics. The museum educator hopes that the social unit will read the interpretive panel, experience hands-on play with the ball, and then discuss the two parts—experiential and interpretive—in an attempt to make sense of the whole experience. In reality, many visitors ignore the panel and little sense-making occurs, although the experience of playing with the ball in the airstream is pleasant and memorable.

The advent of desktop multimedia and computer technology provided an appealing opportunity to offer on-screen simulations which museum educators found enticing as they would compel visitors to read. An on-screen simulation of the beach ball floating in the air added visualizations of the currents and a multimedia presentation of Bernoulli's principle. Without the direct hands-on play with the beach ball, however, the experience is merely tolerable and forgettable.

Now, augmented reality technology has the potential to bridge the two extremes. The hands-on experiential play with the beach ball can be accompanied by augmented reality projections that show the air currents and how they change in response to the ball's movement. In essence, the augmented reality projection can layer the traditional interpretive graphic panel copy directly onto the physical phenomenon, forcing visitors to notice it and make sense of it within their social units.

This research study was premised on this suspicion that augmented reality technology might influence conversation and sense-making behavior within the social unit by combining the experiential and interpretive aspects of the experience. Likewise, the belief was that the digital enhancement might positively impact engagement as the learners would be compelled to consider a more proper and thorough interpretation of the experience by actually paying attention to the interpretive explanation provided by the museum educators.

The researcher tested these hypotheses and provided answers to the research questions within the context of The Franklin Institute Science Museum. First founded in 1824 as an organization for the promotion of the mechanical arts, The Franklin Institute later opened its "Wonderland of Science" in 1934. While it was the height of The Great Depression, crowds lined up to pay the five-cent price of admission for the delight of encountering the amazing sights and sounds of science and technology. Informal science learning today looks much different, but has at its foundation the same implied agreement to deliver extraordinary science and technology experiences for ordinary people.

In particular, the researcher engaged the study participants with a device called "Be the Path" which was available for use in traditional, hands-on, non-augmented form as well as with the digital augmentation enabled. (See Figure 2.) "Be the Path" is a hands-on exhibit device that invites learners to complete an electrical circuit and discover that the human body acts like a wire as a conductor of electricity. A three-foot square kiosk features a flat tabletop on which there are two light bulbs, two batteries, and four metal spheres. (The spheres are approximately the size of baseballs.) Additionally, thin wires run from the spheres to the battery and bulb. When learners grasp the two metal spheres, they complete the circuit and the bulb lights. It is a quick and easy experience with instant gratification. Most learners smile and run away, satisfied that they lit the bulb. The intent of the device, however, is to invite learners to think about the human body as a conductor and to think about the components of electrical circuits. The mounted graphic panel invites experimentation and collaborative play in an attempt to demonstrate the need for a complete circuit of conductors. For example, the label copy invites learners to try extending the circuit by linking hands with peers or others nearby. When learners ignore the graphic panel, as they often do, they enjoy the instant gratification of the lit bulb, but they miss the point of the device and derive only partial benefit from the experience. Augmented reality technology may facilitate the integration of the hands-on experiential delight with its important interpretive counterpart.

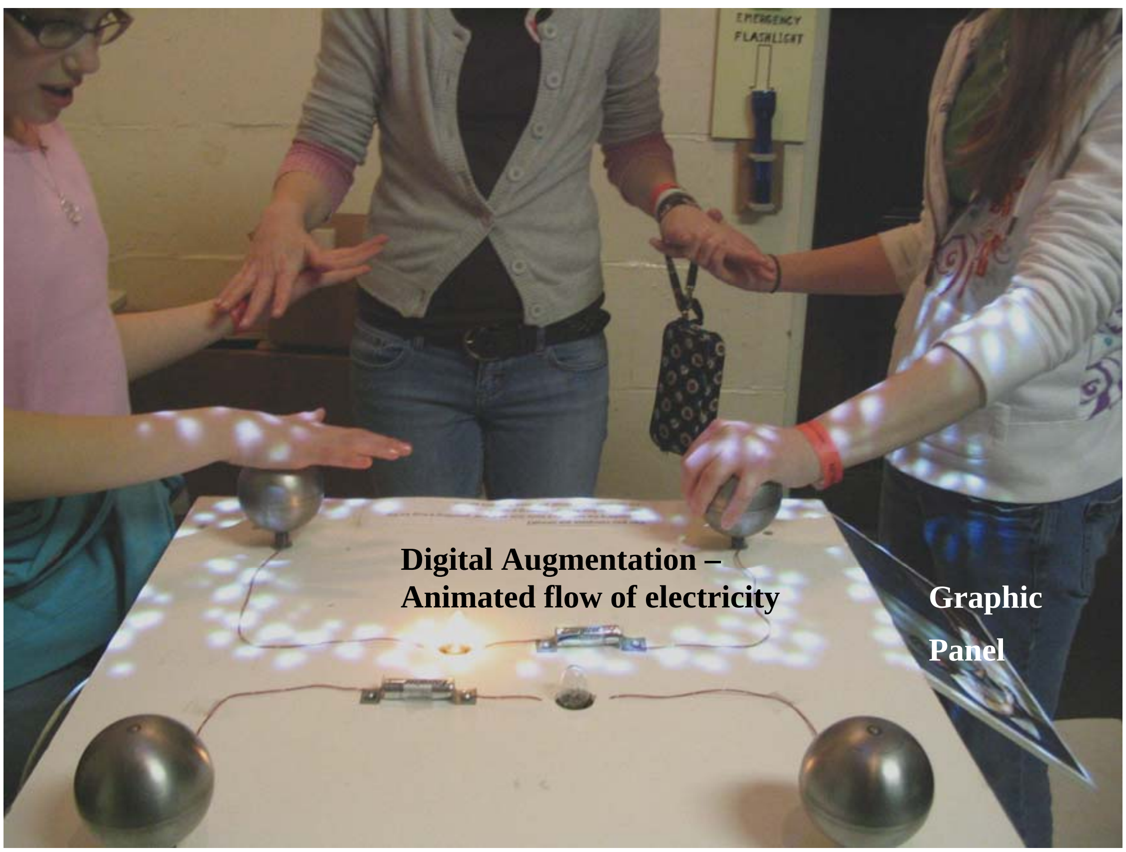

Figure 1. "Be the Path" device shown in its augmented condition. Copyright 2010 by The Franklin Institute.

Using augmented reality technology (specifically, EyesWeb software and background differencing techniques), “Be the Path” has been enhanced with a digital projection to overlay a digital visualization of a current of flowing electrons onto the body of the learner when the bulb lights. So, the learner grasps the two metal spheres, the bulb lights, and, in the same instant, a projection appears on the learner’s arms, shoulders, and head. If the learner lets go of the spheres, the projection vanishes. Grasp the spheres, and the projection reappears as the bulb lights. The augmentation appears whenever the circuit is completed properly. The intent of the digital augmentation is to draw the learner more fully into interaction with the device. Literally, the projection shows the learners “being the path” for the flow of current through the circuit. At this point, the visitors often begin talking about the projection, reading the graphic panel, experimenting with their hand placements, discussing the device within their social units, and making sense of the experience.

The intent of this research study was to observe, measure, and compare the extent and quality of this behavior between the device’s two conditions—non-augmented and augmented. The hypothesis was that the families who used the augmented device would display characteristics of higher quality behavior and sense-making, resulting in a higher-level of realization of the device’s intent as indicated by the quality of their responses to interview questions.

In “Be the Path,” the primary role of augmented reality technology is to make the invisible visible. The projected animation of a current of flowing electricity falls upon the learner’s body so as to reveal the fact that the human body is capable of conducting electricity. The projection expands and contracts along with the size of the circuit. When multiple people join hands to expand the circuit, the projection reveals that electrical charges can indeed pass from one person to the next. In many science exhibit devices, the gap between the experiential and the interpretive is often due to the invisibility of physical phenomena. Augmented reality has the potential to make the unseen seen and narrow that gap. It also has the potential to influence family learning behavior around the device as it draws the group more fully into the experience.

"Be the Path" was designed in consideration of the seven characteristics of family-friendly exhibit devices. These are: multi-sided—family can cluster around exhibit; multi-user—interaction allows for several sets of hands (or bodies); accessible—comfortably used by children and adults; multi-outcome—observation and interaction are sufficiently complex to foster group discussion; multi-modal—appeals to different learning styles and levels of knowledge; readable—text is arranged in easily understood segments; and relevant—provides cognitive links to visitors' existing knowledge and experience (Borun & Dritsas, 1997). These device characteristics existed whether the augmented reality technology was enabled or not, so the device was equally family-friendly for each cohort.

Design

This qualitative research study employed an evaluation design in an attempt to answer the central research questions. The study evaluated the use of augmented reality technology to determine its effect within a group of informal science learners. In particular, the study analyzed family group behaviors. As its name suggests, evaluation research evaluates organizational programs or interventions (Bryman & Bell, 2003). Through program evaluation design, a target population is isolated and the immediate effects of an intervention within that group shown (Denzin & Lincoln, 2005). Given the purpose of the study, program evaluation was selected as the research design so as to best determine the impact of augmented reality technology on behavior during an informal science learning experience.

Two samples were compared in this study. One sample included participants who encountered the "Be the Path" device in its non-augmented hands-on condition. The other sample encountered the device in its augmented hands-on condition. The same observational protocol and interview instrument were used with each sample in order to collect data related to the influence of the augmented reality technology on realization of the device's intent for learning and merger of the experiential and interpretive aspects.

Study Sample Composition

The study's target population was families who visit The Franklin Institute Science Museum of their own free choice. Every day, multi-generational family groups choose of their own free-will to visit the science museum. The researcher intercepted 26 families in the museum over the course of three weeks during the summer of 2010 and invited them to participate in the survey. 20 of them agreed to participate, with the other six citing time constraints as their reason for declining the invitation. The intercepts took place in an area of the museum known as the Testing Zone. The researcher applied some preliminary screening protocols when making the decision about which family to intercept. First, the researcher looked for groups that included one, two, or three adults with one, two, or three children between the ages of seven and 17. This is a highly representative multi-generational family group structure within the museum's visitor base. For example, 88% of The Franklin Institute's Membership holders reflect this profile. The researcher also listened to determine that the family was speaking English before intercepting the group, as the researcher lacks fluency in any other languages. Otherwise, any family that fit the profile was approached.

Environmental Description

Located along a colorful hallway, between two popular exhibits, The Testing Zone is both an evaluation space and a functional workshop where exhibit designers construct new devices for testing. On this study's data collection days, for example, the exhibit team was building prototype devices for a new exhibit about the brain that is in development for 2013. So, in the rear sections of the Zone, designers could be seen at workbenches, constructing interactive heads that open to reveal the human brain. The evaluation area is set apart at the front of the space, nearest to the entrance. It was within this context that 20 families agreed to participate in the study.

The researcher used this intercept protocol.

1. Researcher is wearing staff identification badge and carrying a clipboard.
2. Researcher observes family group that fits the profile.
3. Researcher pauses to determine that the family is conversing in English.
4. Researcher steps toward the family, smiling, and delivers the invitation.

5. "Hello! My name is Karen Elinich and I work here at The Franklin Institute. We're doing research on something new for our exhibits and we're looking for families to try it and answer a few questions for us. It will take about 20 minutes and you'll receive a 20 dollar gift certificate for the gift shop. Would you be able to help us with our research?"
6. If any family member says no, the researcher thanks them and moves on.
7. If family agrees, researcher begins the informed consent process.
8. If any member of the family hesitates to give consent, the researcher thanks them and moves on.
9. If all family members agree, researcher escorts the family into the Testing Zone and continues.

The first family encountered the device in its non-augmented hands-on condition; the second family encountered the augmented device. This alternating strategy enabled the quick identification of any issues with the testing protocol. Also, this strategy enabled equitable treatment in the study; when the first family (who used the non-augmented hands-on device) was finished, they were invited to stay for a moment while the digital augmentations were enabled so that they could see the device's augmented condition. Their reactions to it, however, were not recorded. Then, the device was ready for the recruitment of the second family to begin. This rotating pattern was repeated 10 times so that 20 families encountered the device—10 in its non-augmented state and 10 in its augmented state.

This sample composition methodology reflected the principles of non-probability sampling (Bryman & Bell, 2003) as its strategy for assembling the samples. The study participants who were more likely to be selected than others (Bryman & Bell, 2003) were those English-speaking families that opted to visit the museum in groups of three to six people. Furthermore, the study utilized principles of convenience sampling (Bryman & Bell, 2003). While the easy accessibility of family groups within the museum during the summer necessarily characterized them as a convenience population, it should be noted that they were highly representative of the national population of informal science learners. The purpose of the study was to produce knowledge for other informal science learning institutions who serve this same population. The study sought to understand the influence of a new technology on the behavior of a population that already visits science museums. Therefore, it was appropriate to use convenience sampling.

Human Subjects Consideration

Participation in the study presented no more than minimal risk to human subjects. It involved only procedures listed in categories six (collection of data from voice, video, digital, or image recordings) and seven (research employing survey, interview, or program evaluation methodologies). Each participating family received no direct benefit from participation beyond a small token of appreciation valued at 20 dollars. Participation was entirely voluntary. All responses are reported anonymously. For these reasons, the study qualified for an Expedited Research Review according to federal guidelines. An appropriate application to Pepperdine University's Institutional Review

Board was submitted accordingly and the study was formally approved and authorized on July 20, 2010.

When the researcher intercepted a family, the informed consent process commenced. Each member of the family was asked to confirm willingness to participate. If one member of the family declined, the entire family was excused from participation. Parents signed consent forms for children under the age of 18.

All study participants are being identified generically in the presentation of data. Only the researcher knows the subjects' actual identities. The code which associates the pseudonym to the consent form will be destroyed 12 months after publication of this report. The video and audio recordings will likewise be destroyed in 12 months.

Data Collection

The researcher intercepted families for participation in the study, as described above. Once the informed consent process concluded, the data collection began. The family was escorted to the Testing Zone space where the "Be the Path" device was located. The family was invited to begin interacting with the device as they normally would by saying, "Please approach the device and begin to interact with it as a family, just as if you might have come across this device out in the exhibit areas." At that point, the researcher stepped to the side and began to observe their behavior, recording notes on a clipboard using the observational protocol. In particular, the researcher listened for discourse acts (e.g., telling someone to do something, describing something, raising questions) and looked for signs of experimentation (i.e., deviations from the simple prescribed play). The interactions were video-recorded for subsequent review and analysis. The observation continued until the family looked for guidance or expressed that they had finished. Then, the family members participated in a brief interview to determine if the intent of the device was realized (through either the graphic display panel or the digital augmentation) and if the learners accessed any prior knowledge of electricity and circuits while they engaged with the device. All individual members of the family group were expected and directly invited to respond. However, if someone was shy or struggling with an answer, the researcher did not force a response. This rarely occurred; very nearly all of the individuals responded enthusiastically and positively to the interview questions. The interviews were audio-recorded for subsequent transcription and data analysis.

The entire experience in the Testing Zone lasted from 20 to 25 minutes per family. In exchange for their time, each family received a gift certificate valued at 20 dollars for use in the museum's gift shop.

Instruments

The study required an observational instrument (see Appendix A) and an interview instrument (see Appendix B) for use in data collection.

The observational protocol derived from McManus' (1989, 1994) and Diamond's (1986) seminal analyses of communication and behavior within social units at a science museum. They based their analyses on the frequency of categorized discourse acts and behaviors. For this study, three categories of discourse acts were relevant: telling someone to do something; describing something; and raising questions (Diamond, 1986).

For the observational protocol, the researcher drew from those categorizations, noting the frequency and nature of those acts within each cohort and then comparing the two.

Time on task was also measured. As described above, each family's engagement with the device was timed. McManus (1994) suggests that families are likely to spend very little time with a device if they do not read the graphic panels and incorporate the content into their discourse. Therefore, the participants who encountered the device in its non-augmented condition would have been likely (on average) to have a shorter time on task than those who encountered the augmentation.

Finally, experimentation with the device was a key indicator of whether or not the participants understood its intent. For "Be the Path," experimentation was likely to be more rewarding for the participants who encountered its augmented condition than for those who did not experience the augmentation. While it was likely that everyone would experiment playfully, those who encountered the augmented reality projections adapting to their play, would have their desire to try new combinations reinforced. For example, two or more people can hold hands to expand the circuit. At the non-augmented hands-on device, the incentive was to light the bulb. At the augmented device, the incentive was both to light the bulb and to see how the projections merge and expand. In fact, the entire family could form a circuit and the augmentation would grow with it.

Neither Diamond nor McManus featured an evaluation of a technology or intervention by comparison between samples in their work, so no follow-up interviews with the families are described in their reports. Therefore, an original interview protocol was needed. The goal of the interview was to probe for key words that would reveal understanding of the device's intent. For example, the words *circuit*, *conductor*, and *electricity* were essential. Without them, it was reasonable to conclude that the device's intent was not fully realized.

Internal Reliability

The study's internal reliability derived from its use of convenience sampling. All of the study participants were free-choice informal science learners who had chosen on their own to visit The Franklin Institute. Their commonality within the community suggested a comparable readiness for participation in the study. They were likely to have been exposed to comparable external influences.

No protocol training was necessary as the researcher conducted all of the observations and interviews personally, increasing the study's internal reliability. For coding and data analysis, the researcher developed and used the code manual (see Appendix C) to train a colleague who volunteered to support the research study. Each analyst independently reviewed the transcript excerpts (for the interview scoring) and the video recordings (for the experimentation scoring). Then, the two analysts met and compared their results in order to determine the inter-rater reliability of the analysis. There were 80 items coded for analysis, with agreement on 70 items, indicating an inter-rater reliability of 88%.

External Validity and Pilot Study

The proposed study's external validity derived primarily from its reliance upon Ash (2003) and McManus' (1989, 2004) existing observational protocols. In order to establish the adapted instruments' reliability, the researcher piloted their use with two families for each condition.

For the pilot study, the researcher followed the testing protocols and intercepted two families who fit the study's profile. Each family included one, two, or three adults accompanied by one, two, or three children. All subjects were between ages seven and 77. The purpose of the pilot study was to exercise the protocols and to test to make sure that the instruments were effective. The observational worksheet was used to capture field notes while the families were using the device. When they finished, the researcher switched to the interview protocol sheet and asked the questions, eliciting responses and taking notes. Afterwards, the researcher asked the participants if they felt that they understood what they were doing. All of them agreed that they were comfortable and not at all confused. The researcher asked if the interview questions were clear; the participants all responded positively. When asked if there was anything else they would have wanted to say but were not asked, no one could think of anything. Based on these results, the researcher decided that the instruments were effective and ready for use in the data collection phase of the study. Since the purpose of the pilot was to exercise the protocols and instruments, the actual data collected during the pilot was set aside as the researcher's focus was on the instrumentation and not directly on the participant interaction.

Data Analysis

The six-step data analysis plan for qualitative research was followed (Creswell, 2003). First, the data was organized and prepared for analysis. Field notes and interview recordings were transcribed. Then, the researcher read through all of the data in order to obtain a general sense of the information it provided. It was a reflective task, allowing an opportunity for thinking about the entire data collection experience at once and as a whole.

Next, the coding process began with the identification of significant themes in preparation for applying meaning to those segments of the data. For example, McManus' (1989) model suggested that the data be coded for the broadcasting behavior. The researcher processed the data looking for discourse acts where an individual (child or adult) within the family announced or declared something for the group. Other discourse act coding related to questioning and instructing.

The researcher next applied the thick description techniques (Bryman & Bell, 2003; Creswell, 2003; Lincoln & Guba, 1985) for each family in order to render the setting and the information it provided. Findings are conveyed in rich, descriptive accounts (see, especially, Appendix D) in order to portray the social circumstances in depth, giving the analysis an element of shared experience that reflects the details of the particular science museum culture. Thick description (Lincoln & Guba, 1985) will provide peer institutions with the database they need for judging the possible transferability of the study's findings related to the use of augmented reality technology.

Through this descriptive phase, the primary themes emerged to provide evidence for the comparison between the families who encountered the device in its non-augmented hands-on condition and those families who encountered the augmented condition. During this phase of the analysis, the researcher also interpreted the interview data to see how the addition of augmented reality to a traditional hands-on science exhibit interactive device may or may not have influenced family behavior, realization of the device's intent, and the merger of the experiential and interpretive aspects.

Summary

This study evaluated the use of augmented reality technology within the context of The Franklin Institute Science Museum to determine the technology's impact on the realization of a hands-on device's intent and its potential for merging the experiential and interpretive aspects of the experience. In particular, the study sought to understand the influence of digital augmentations on family behaviors during an informal science learning experience around an exhibit device. Twenty families participated in the study. Ten encountered the "Be the Path" device in its non-augmented state and 10 encountered it with its augmentation enabled. The researcher used observational protocols and interviews to collect data in order to detect, compare, and analyze differences in those family behaviors. The qualitative data analysis used thick description techniques in an attempt to offer a detailed portrayal of the cultural circumstances so that peer institutions can determine the transferability of the study's findings.

Chapter 4: Results

Research Questions

The study sought to determine the extent to which the application of augmented reality technology increases realization of an exhibit device's intent and also the extent to which augmented reality technology might facilitate the integration of the experiential and interpretive aspects of the informal science learning experience. The study's participants reflect the characteristics of the informal science learning community. They are representative of the unpredictable population of families who voluntarily choose to visit science museums on any given day.

Sample Composition

The study considered each family as a distinct social unit of analysis. Twenty families participated in the study. Tables 1 and 2 present the individuals who populated those 20 families in order to provide context for the data that follows. The first table is an overview, while the second provides individual family detail.

Table 1

Study Sample Composition Overview of Adults and Minors

	NON-AUGMENTED HANDS-ON ELECTRICITY DEVICE *n=10 families*	AUGMENTED HANDS-ON ELECTRICITY DEVICE *n=10 families*	
ADULTS	19	17	36
Female Adult	*13*	*12*	
Male Adult	*6*	*5*	

(continued)

	NON-AUGMENTED HANDS-ON ELECTRICITY DEVICE *n=10 families*	AUGMENTED HANDS-ON ELECTRICITY DEVICE *n=10 families*	
MINORS	20	19	39
Female Minor	*4*	*8*	
Male Minor	*16*	*11*	
	39	36	75

Table 2

Study Sample Composition with Individual Family Details for Non-Augmented (NA) Group and Augmented (A) Goup

	FEMALE ADULT	*MALE ADULT*	*FEMALE MINOR*	*MALE MINOR*	
NON-AUGMENTED HANDS-ON ELECTRICITY DEVICE					
FAMILY NA1	2			2	
FAMILY NA2	1	1		2	
FAMILY NA3	1	1		3	
FAMILY NA4	1	1	1	1	
FAMILY NA5	1	1		2	
FAMILY NA6	1	1		2	
FAMILY NA7	2		1	1	
FAMILY NA8	1	1	1	1	
FAMILY NA9	2		1		
FAMILY NA10	1			2	
TOTALS	13	6	4	16	39
AUGMENTED HANDS-ON ELECTRICITY DEVICE					
FAMILY A1	2			2	
FAMILY A2	1	1	1	2	
FAMILY A3	1	1		1	
FAMILY A4	1		1	1	
FAMILY A5	1	1	1	1	
FAMILY A6	1		2		
FAMILY A7	2		1	2	
FAMILY A8	1	1	1		
FAMILY A9	1		1	1	
FAMILY A10	1	1		1	
TOTALS	12	5	8	11	36

As discussed in Chapter 3, the study's target population was families who visit The Franklin Institute Science Museum of their own free choice. Furthermore, the study's sample included 20 families composed of one, two, or three adults accompanied by one, two, or three minors between the ages of seven and 17. Ten families encountered the hands-on device in its non-augmented condition, while 10 families encountered it in its augmented condition. The 10 families in the non-augmented group included 39 individuals, while the 10 families in the augmented group included 36 individuals.

All 20 families had at least three individuals, including at least one adult and at least one child. Appendix D provides full narrative ethnographic descriptions of the families' interactions and behaviors. Each family was considered as a distinct unit of analysis. While there were certainly differences among the families, they collectively served as a representative sample of the population that visits science museums on a voluntary basis. The unpredictable nature of who will be present and attending to the exhibit devices is a continual challenge for the informal science educator. This study's participants perfectly reflected that profile.

Description of Play

The playful interaction around the hands-on device allowed informal science learning behaviors to reveal themselves. The characteristics of playful experimentation varied from family to family, but were largely predictable. In fact, the opening invitation to approach the device as if they had come across it in any of the exhibits carried with it an underlying assumption that this was not the first time that any of these families had seen a hands-on science exhibit device. This was a function of the convenience population used for the study. The study was premised upon an assumption that families who visit a science museum have a basic knowledge of how to approach and engage a device. That basic behavioral foundation enabled the collection of data that would allow an evaluative comparison between families who encountered the hands-on device in either its non-augmented or augmented condition. The first simple comparative measure was time spent interacting with the device. The amount of time that the family spent interacting with the device was considered time on task. The expectation was that those who encountered the device in its augmented condition might spend more time on task as the augmentation might alter their behavior as they interacted around the device.

Time on task. Time on task was measured using the video recording. A fixed-position device captured the moment when family members entered the frame surrounding the hands-on device, "Be the Path." Likewise, the moment when the family left the frame was captured. The difference between the two timestamps was used to calculate the time on task. In general, the expectation was that families who experienced the device with its augmented reality enabled would spend more time on task.

Table 3

A Comparison of the Number of Minutes Each Family Spent Interacting with the Hands-On Device, Whether in its Non-Augmented (NA) or Augmented (A) Condition

FAMILY	NON-AUGMENTED HANDS-ON ELECTRICITY DEVICE	FAMILY	AUGMENTED HANDS-ON ELECTRICITY DEVICE
NA1	01:15	A1	02:06
NA2	01:50	A2	02:07
NA3	01:13	A3	01:23
NA4	01:14	A4	02:18

(continued)

FAMILY	NON-AUGMENTED HANDS-ON ELECTRICITY DEVICE	FAMILY	AUGMENTED HANDS-ON ELECTRICITY DEVICE
NA5	01:55	A5	02:08
NA6	02:30	A6	01:59
NA7	01:23	A7	01:21
NA8	01:58	A8	02:06
NA9	03:00	A9	01:38
NA10	01:50	A10	01:55
Mean:	01:46.8		01:54.1
Median:	01:50		02:02.5

In order for any technology to impact the informal science learning experience and influence behaviors, it must capture and hold attention. The augmented reality tested in this study did capture and engage the participants. In general, the families who experienced the “Be the Path” hands-on device in its augmented condition spent more time on task with the device. However, on average, the difference is only 7 seconds. Still, within the context of an informal science learning experience, 7 extra seconds is a noteworthy improvement, particularly if those extra seconds are spent closing the gap between the experiential and interpretive aspects of the hands-on experience. The 12 second improvement in the median is even more compelling. Informal science educators would wholeheartedly welcome an additional 7 to 12 seconds of engagement with a device. So while small in magnitude, the increase in time spent with the device suggests that augmented reality technology does merit additional consideration and experimentation for use within the informal science learning community.

Quality of play. Beyond time on task, the next question is about the quality of interaction around the hands-on device. Did the families who encountered the device in its augmented condition have a different quality of experience? Based on watching a family's interaction with the hands-on device and with one another, a quality of play score was assigned according to the following coding scheme. The three-level categorization—basic play, advanced play, and experimentation—emerged during analysis of the video recordings. While analyzing the recordings, it became evident that some families' behavior was very simplistic or basic. Likewise, some families' behavior was more sophisticated. Others fell in the middle. Analysis of each group revealed the distinct individual acts—turn-taking, hand-linking, configurations, questioning, etc.—that were used to develop this three-point quality of experimentation rubric.

- Basic Play = 1 point

  Each individual grasps the balls and lights the bulb. Turn-taking occurs. Conversation focuses on the task at hand, rather than on questioning. No hand-linking occurs.

- Advanced Play = 2 points

  All of the basic play characteristics plus hand-linking and at least one person questions how the device works. At least one person proposes using other body parts, such as using elbows or fingertips.

- Experimentation = 3 points

  All of the advanced play characteristics plus someone organizes sophisticated linking configurations that include more than two people around the device. Conversation focuses on the design of the circuit.

Table 4

A Comparison of Quality of Play during Interaction with the Hands-On Device using a 3-Point Scale

NON-AUGMENTED HANDS-ON ELECTRICITY DEVICE		AUGMENTED HANDS-ON ELECTRICITY DEVICE	
FAMILY NA1	1	FAMILY A1	3
FAMILY NA2	2	FAMILY A2	3
FAMILY NA3	3	FAMILY A3	3
FAMILY NA4	2	FAMILY A4	3
FAMILY NA5	1	FAMILY A5	3
FAMILY NA6	3	FAMILY A6	1
FAMILY NA7	2	FAMILY A7	3
FAMILY NA8	2	FAMILY A8	3
FAMILY NA9	1	FAMILY A9	2
FAMILY NA10	1	FAMILY A10	3
Mean:	1.8	Mean:	2.7
Median:	2	Median:	3

As Table 4 shows, the families who encountered “Be the Path” in its augmented condition exhibited, on average, a higher quality of play and level of experimentation around the device. While their time on task (as described above) was only modestly longer, the quality of play and experimentation during that time was higher for families who encountered the augmented reality. Given that the families were all of a similar profile and randomly assigned conditions, this finding suggests that the augmented reality technology played a role in improving the quality of their play and experimentation.

Role-playing. In addition to time on task and quality of play, the study found that observed role-playing behavior within the families contributed to the overall informal learning experience. Each member of the family often seemed prepared to play a particular role when he or she approached the hands-on device. This role-playing behavior also seemed to differ depending upon whether the participant was an adult or a child. After studying the video recordings of the interactions, the role-playing behavior appeared to be classifiable as either experiencing or interpreting. Each participant's behavior was coded for these two types. The experiential role was characterized by placing hands on the device and by varying those hand placements in an attempt to manipulate the device or extend its functionality. (The absence of any actual physical contact with the device was distinct and clear evidence that the experiential role was not played by an individual.) The interpretive role was characterized by spoken and unspoken attempts to understand the device and make meaning for others in the group. Reading the graphic panel aloud was a clear instance of the behavior. Instructing others to read the graphic panel was also considered indicative. References to prior knowledge or attempts to "explain" the device were also noted as interpretive behavior.

Table 5 summarizes the role-playing behaviors observed within both groups. The observation of role-playing was an entirely qualitative measure, but, for the purposes of comparing and ranking families within both groups, a numerical scoring system has been used. For the adults, the role of interpreter was anticipated. Therefore, evidence of it was weighted with one point. Since playing the experiential role was considered a positive behavioral shift, evidence of it was weighted with two points. For the children, the opposite scoring applied: one point for experiencing, two points for interpreting. Zero points were assigned when the complete absence of a role was detected. This scoring rubric was intended only as a mechanism for ranking and comparing role-playing behaviors. It was not intended to suggest that the roles were in any way quantifiable.

Table 5

Accounting of Role-Play Behaviors Exhibited by Families Who Encountered the Device in its Non-Augmented (NA) and Augmented (A) Conditions

	Adult Role Play		Minor Role Play		
	Interpreting	Experiencing	Interpreting	Experiencing	TOTALS
NA1	1	2	0	1	4
NA2	1	2	0	1	4
NA3	1	2	0	1	4
NA4	1	0	0	1	2
NA5	1	0	0	1	2
NA6	1	2	0	1	4
NA7	1	2	2	1	6
NA8	1	2	2	1	6
NA9	1	2	0	1	4
NA10	1	2	2	1	6
A1	0	2	2	1	5
A2	1	2	2	1	6
A3	1	2	2	1	6
A4	0	2	0	1	3
A5	1	0	0	1	2
A6	1	0	0	1	2
A7	1	2	2	1	6
A8	1	2	0	1	4
A9	1	2	0	1	4
A10	1	2	2	1	6

The weighted scoring suggests that the families who encountered the augmented hands-on condition were more likely to adjust their behavior and alternate roles so that the entire family worked together throughout their engagement with the device.

Children consistently tended to made first contact with the device, leading the way for experience, play, and experimentation. The adults, however, did most of the talking. (Adults were collectively responsible for 71% of the discourse acts.) For some of the family groups, it appeared that a rigid (although likely unconscious) division of effort existed, with the children focused on the experiential behavior and the parents focused on the interpretive behavior. Informal science educators have long observed a lack of integration between the experiential and interpretive aspects of hands-on exhibit experiences and have routinely considered it a design challenge. Through the video analysis of role-playing, it became clear that some adults never exhibited experiential behavior and some children never exhibited interpretive behavior, suggesting that it may in fact be a fundamental behavioral posture. If adults are deliberately inattentive to the experiential because they are focused on their perceived role as interpreters, it may not be possible to integrate the two behaviors and, consequently, the experiential and interpretive aspects of the informal science experience. Likewise, if the children persist in their reliance upon the adults to provide the interpretation, they may consistently ignore the presentation of interpretive content and continue their hit-and-run behavior, dashing from device to device.

While the persistent division of effort may have been unconscious, some families in both cohorts clearly and definitively acknowledged during the interview following their interaction with the device that the children did not pay attention to any of the interpretive panel content. So, while the adoption of the children's persistent experiential role-playing behavior may not have been consciously considered, it was consciously observed and noted during the interview. To illustrate this point, consider the following excerpts from the family interviews conducted during the data collection in the summer of 2010.

- Non-Augmented Device – Family NA2: *Adult female said, "No way did the boys read directions. Have you read anything all day?" The boys smile and shake their heads from side to side.*
- Non-Augmented Device – Family NA4: *9-year-old girl boasted, "I didn't read anything!"*
- Augmented Device – Family A2: *12-year-old boy asserted, "I have no idea what it said!"*
- Augmented Device – Family A5: *9-year-old boy said. "I didn't read anything."*

Likewise, there were adults in both cohorts who were so focused on their role as interpreters that they actually never engaged directly with the experience of the hands-on device, personally treating it as a "hands-off" device. To illustrate this point, consider the following excerpts from the ethnographic descriptions (see Appendix D) prepared during data collection in the summer of 2010.

- Non-Augmented Device – Family NA4: *The grandfather suddenly figures it out and takes control of the situation. He announces that "it's a current thing" and begins telling everyone what to do. He never actually touches the device himself.*

- Non-Augmented Device – Family NA5: *The grandmother stands back, telling the boys what to do. The grandfather makes a playful buzzing noise when the boys complete the circuit. Both grandparents describe what they see happening for the boys. The grandmother tries to explain how it works. The grandfather asks questions. Both grandparents are reading the directions, following along, describing, and noticing. The grandmother is focused on the boys, rather than on doing it herself.*

- Augmented Device – Family A5: *The father stands aside, watching, and then announces what he has figured out about the two circuits. He explains what he sees happening.*

- Augmented Device – Family A8: *Before he even touches the device, the father announces that "it's going to show you how electricity passes through your body."*

While the explanations that these adults provided for their families may have been effectively accurate, the interpretations might have been stronger and more meaningful if they derived from actual direct experiential encounters with the hands-on device. There was a great deal of pre-supposition in their discourse as they "jumped to conclusions" about the device, predicting what would happen and attempting to explain how it worked rather than actually engaging directly.

Did rigidly held role-playing behaviors necessarily prevent a quality informal learning experience? No. It was clearly possible for the quality of play and experimentation to be high while the family members held fast to their preconceived roles. The third family that encountered the device in its non-augmented condition, for example, scored three out of three points in their quality of play assessment. Yet the rigid role-playing behaviors were evident. To illustrate this point, consider the following excerpts from the ethnographic descriptions (see Appendix D) prepared during data collection in the summer of 2010.

- Non-Augmented Device – Family NA3: *The parents approached the device first, each taking a position on opposite sides. The mother clearly paused to read the directions before doing anything. The father also appeared to read the graphic panel. The 13 and 14 year-olds waited for their parents, looking at the directions from the sides. The youngest boy was standing off to the side a bit, furthest away from the device. The parents then invite the kids to try it, and the mother says "we got this." The mother and the 14-year-old boy immediately hold hands and succeed in completing the circuit. There is a lot of smiling and laughing. The father and the 13-year-old work on the other side, completing that circuit. The father begins to direct the hand placements, so that the whole family is working together.*

The parents began by deliberately assuming the role of interpreters by reading the directions thoroughly in order to make sense of the device. The children waited to experience the device, opting not to participate in the interpretive tasks, suggesting that they knew their role. This role-playing continued during the interview.

- *The parents answered the questions first before inviting the children to respond. The mother excuses the children's silence by saying, "They're teenagers." When asked about the interpretive panel, the 7-year-old announces, "I didn't read it." The 14-year-old admits to only looking at the picture.*

For this family, the persistent role-playing behavior enabled a high quality of play and level of experimentation, suggesting that the experiential and interpretive may not necessarily need to be integrated in order to achieve an effective experience. Still, the role-playing data (see Table 5 above) does tend to suggest that augmented reality may help to facilitate shared role-playing behaviors. When that happens, the experiential and interpretive aspects of a designed informal learning experience are more likely to be integrated, reinforcing the effect and potential impact of both.

Discourse acts. In addition to the observed role-playing behaviors, distinct discourse patterns were noted throughout the interactions. With rare exception, all family members spoke to one another during their encounter with "Be the Path." However, the nature of the conversation varied widely. An analysis of the recordings enabled the categorization of conversational moments that represented instruction, description, or inquiry. These three categories derived from the discourse analysis conducted by McManus (1994). Table 6 presents the frequency of occurrences within each group.

Table 6

Accounting of Discourse Acts by Adults and Minors Who Encountered the Device in Both Conditions, Grouped by Category

	Discourse Act Categories						
	Instructing		Describing		Questioning		
Family	Adults	Minors	Adults	Minors	Adults	Minors	
NA1	1		2			1	
NA2	1		2		1		
NA3	1						
NA4	1		1	1			
NA5	2		2		1		
NA6	2		2		1		
NA7	1	1	1	1	1		
NA8	2	1	1	1	1		
NA9	1	1	1	1			
NA10	1	1	1	1	1		
	13	4	13	5	6	1	42
A1	1	1	1	2	1		
A2	2	2	2		1	1	
A3	2	1	2	1	1		
A4	1	1	1	1	1		
A5	2		2		2	1	
A6	1		1		1		
A7	2		2	1	1		
A8	2		2		1		
A9		1	1	1			
A10		1	1	1		1	
	13	7	15	7	9	3	54

The families in the non-augmented hands-on device group collectively accounted for 42 discourse acts as characterized by McManus (1994). The families in the augmented hands-on device group accounted for 54 discourse acts. Furthermore, the children who encountered the device in its augmented condition contributed 17 discourse acts while those in the non-augmented group contributed only 10. This finding suggests that the addition of augmented reality technology to a hands-on device may influence role-playing behavior by sparking an increase in discursive activity, with more multi-generational instructing, describing, and questioning around the device being evident.

Aggregated description of play. Table 7 presents aggregated indicators for the description of play measures including time-on-task, quality of play, role-playing, and discourse acts. It is important to note that the aggregation was solely for the purpose of ranking the families within the two groups. The aggregation was not intended to suggest that the individual qualitative measures are in any way mathematically-based.

Table 7

Presentation of Aggregated Indicators for the Description of Play Measures for Families Who Encountered the Device in Both Non-Augmented (NA) and Augmented (A) Conditions

	Time on Task	Quality of Play (1-3)	Adult Role Play		Minor Role Play		Discourse Acts		Aggregated Description of Play
			I	E	I	E	A	M	
NA8	01:58	2	1	2	2	1	4	2	14
NA7	01:23	2	1	2	2	1	3	2	13
NA10	01:50	1	1	2	2	1	3	2	12
NA6	02:30	3	1	2	0	1	5	0	12
NA2	01:50	2	1	2	0	1	4	0	10
NA1	01:15	1	1	2	0	1	3	1	9
NA9	03:00	1	1	2	0	1	2	2	9
NA3	01:13	3	1	2	0	1	1	0	8
NA5	01:55	1	1	0	0	1	5	0	8
NA4	01:14	2	1	0	0	1	2	1	7
Mean	01:46.8	1.8							10.2
A2	02:07	3	1	2	2	1	5	3	17
A3	01:23	3	1	2	2	1	5	2	16

(continued)

	Time on Task	Quality of Play (1-3)	Adult Role Play		Minor Role Play		Discourse Acts		Aggregated Description of Play
			I	E	I	E	A	M	
A7	01:21	3	1	2	2	1	5	1	15
A1	02:06	3	0	2	2	1	3	3	14
A10	01:55	3	1	2	2	1	1	3	13
A5	02:08	3	1	0	0	1	6	1	12
A8	02:06	3	1	2	0	1	5	0	12
A4	02:18	3	0	2	0	1	3	2	11
A9	01:38	2	1	2	0	1	1	2	9
A6	01:59	1	1	0	0	1	3	0	6
Mean	01:54.1	2.7							12.5

As described above, the role-playing scores are weighted such that adults who played the predictable role of interpreter received one point, while those who shifted their behavior to play the experiencing role received two points. The opposite rubric applied for children, with one point assigned for experiencing and two points assigned for interpreting. On average, the families who encountered the augmented hands-on condition scored 12.5 points, while those in the non-augmented group scored 10.2. This data suggests that the overall quality of play and interaction around the device was higher when families encountered the augmented hands-on device.

Experiential Outcomes

After interaction with the device, each family was seated in a semi-circle such that their view of the device was impeded. The researcher read each interview question aloud, waited for someone to respond, and then polled the other individuals. Each person was directly asked to contribute to the collective response. The researcher made sure that each person responded in some way, either by contributing additional information, agreeing with the previous respondent, or expressing that they could not think of anything else. Since the family was the unit of analysis, repetition of a response was treated holistically. (For example, if two people said *conductor*, it counted as one utterance of *conductor* in the coding process.) Likewise, if any individual made a comment, it became part of the whole family's composite response. The interviews were transcribed and analyzed. The interview responses were analyzed to determine each family's interpretive content recall, realization of the hands-on device's intent for learning, and connection to prior experience.

Interpretive content recall. To determine the extent to which augmented reality technology might facilitate the integration of the experiential and interpretive aspects of the informal science learning experience, the participating families were asked to recall the content of the device's interpretive panel after the completion of their interaction with the hands-on device. During the interview, each family responded to this question: There was a printed graphic panel on the device. What did it say? The ideal answer would include the key phrases from the panel—try to complete the circuit and try with more than one person—as well as a description of the illustration of the flow of electricity through a body.

The ability to recall the content of the graphic panel a few minutes after seeing it, particularly its illustration, is an indication of the family's attention to the interpretive aspects of the device. The hypothesis was that the families who encountered the device in its augmented condition would be better able to recall the interpretive content after their experience, suggesting that the augmented reality technology had contributed to the merger of the experiential and interpretive aspects of the hands-on device. Tables 8 and 9 feature the relevant excerpts from the interview responses, captured using the study's interview instrument.

Table 8

Coded Composite Family Responses to Interview Question 3 from Non-Augmented (NA) Device Group on a 3-Point Scale

Interview Question 3: There was a printed graphic panel on the device. What did it say?	
NA1: Put your hands on each of the balls to complete the circuit and light the bulb.	1
NA2: No way did the boys read directions. Have you read anything all day?	0
NA3: Honestly, I read it but don't remember. Try to figure out how to complete a circuit?	1
NA4: It said to put your hands on the balls. Try to loop multiple people—it said that at the bottom.	1
NA5: Complete the circuit. It also said to try it with more than one person.	2
NA6: Place your hands on the metal balls and see if you can complete the circuit. It says to use hands, not elbows. I remember the diagram had red lines going around the body.	2
NA7: Put hands on both. To complete a circuit. It said to try it with more than one person.	2
NA8: Place both hands on two of the silver spheres. Complete the circuit.	1
NA9: Place hands on bulbs. Has to be more than one person. I remember the picture and the diagram with the red lines going through it.	2
NA10: I remember the picture of the body.	1
Mean:	1.3
Median:	1

Note. The ideal answer is: Try to complete the circuit. Try it with more than one person. Describe the diagram of the person acting as a wire. The coding rubric is: Score 1 point for each concept. Repetition of a concept should not be counted. Each concept should only be counted once, resulting in a score from 0-3.

Table 9

Coded Composite Family Responses to Interview Question 3 from Augmented (A) Device Group on a 3-Point Scale

Interview Question 3: There was a printed graphic panel on the device. What did it say?	
A1: Try to complete the circuit. And then try to complete it with more than one person.	2
A2: How to transmit the current. Put your hands on the bulbs to make a circuit. And try more than one person and try holding hands.	2
A3: Place hands on the balls to complete the circuit. How many people can make it light? Work together.	2
A4: See if you can complete the circuit. Use the balls to complete the circuit, using your body as a wire.	2
A5: Try to make the circuit go through bodies.	1
A6: Touch the balls to complete the circuit and make a loop so you can make electricity flow.	1
A7: Complete the circuit using one person and then try with more than one person. Like in the diagram of the man/woman/person where the red lines go through the body from one sphere to the other.	3
A8: Can you complete the circuit? I looked at the picture.	2
A9: See if you can connect the electrical current with two people.	2
A10: Touch both spheres to complete the circuit.	1
Mean:	1.8
Median:	2

Note. The ideal answer is: Try to complete the circuit. Try it with more than one person. Describe the diagram of the person acting as a wire. The coding rubric is: Score 1 point for each concept. Repetition of a concept should not be counted. Each concept should only be counted once, resulting in a score from 0-3.

Of the 20 participating families, only one—family A7—scored the full 3 points for their response. Likewise, only one—family NA2—was completely unable to recall any of the interpretive content. Partial recall was far more common within both groups, with most families in the non-augmented group scoring 1 point and most families in the augmented group scoring 2 points. As the tables show, the families who encountered the device in its augmented condition scored, on average, a half-point higher than their peers in the non-augmented group. While small, this increase does suggest that the technology positively impacted recall of the interpretive content.

Family A7, as the high scorer, deserves closer analysis. (The ethnographic description of their interaction follows at the end of this paragraph.) The family included two adult females, an 11-year-old girl, an 11-year-old boy, and an 8-year-old boy. Collectively, they were able to articulate this description of the graphic panel's content: *Complete the circuit using one person and then try with more than one person. Like in the diagram of the man/woman/person where the red lines go through the body from one sphere to the other.*

- Augmented Device – Family A7: *One mother read the entire interpretive panel aloud before they began to do anything. The girl jumped in first, making contact, completing the circuit, and triggering the augmentation. The first mother was clearly taking control, directing the hand placements, and explaining what was happening. The kids were all taking turns and succeeding individually. The second adult female suggested that they try to link three people together. The younger boy began to direct the action to accomplish that goal. The first mother continued to act as the leader or director, while the second mother was more involved hands-on, figuring out*

> *how they could all link themselves together to create one complete circuit successfully. They smiled and laughed when they succeeded. The digital projection adapted perfectly to their complex arrangement, yet the family never acknowledged it. As a final thought while walking away from the device, the second mother suggested that the Museum should add information to the graphic panel to explain that it's actually two circuits. Interestingly, her own playful discovery had allowed her to deduce the circuitry yet she wanted to preempt that discovery by revealing the information on the panel for others.*

For this family, the experiential and interpretive aspects of the experience clearly supported each other. The family made full use of both. Their combined behaviors resulted in a high level of experimentation, possibly enhanced by the augmentation, and an excellent response to the interview question. Whether facilitated by the augmented reality or not, the shared role-playing that occurred within the family and the family's willingness to teach one another and learn together were noteworthy. Every individual attended fully to the both the experiential and interpretive aspects of the hands-on experience, taking turns while playing the roles of interpreters, actors, and leaders.

Realization of device intent. In order to determine the extent to which the application of augmented reality technology achieved its goal of increasing realization of the hands-on device's intent, each family was asked to articulate the perceived intent of the device. In particular, the interview question asked, "What do you think is the intent of this device?"

For analyzing the responses to this question, the researcher consulted the designer of the original, non-augmented hands-on exhibit device who is a colleague on staff at The Franklin Institute. When the device was conceptualized, its primary goal was defined to be to show that the human body can conduct electricity, acting like a wire to complete a circuit and provide power needed to light a bulb. From this consultation, the researcher determined that the ideal response to interview question one should be: "To show that the body can act like a wire to conduct electricity through the circuit, supplying power to light the bulb." Within that response, six distinct conceptual elements were noted: "To show that the [body can act like a wire] to [conduct] [electricity] through the [circuit], supplying [power] [to light] the bulb." A six-point scoring rubric emerged, such that articulation of each element was awarded a point. Factually correct, but off-topic responses were set aside, as the purpose of the interview was to determine if the family realized the defined intent of the device. The hypothesis was that families who encountered the hands-on device in its augmented condition would be better able to articulate the intent of the hands-on device.

Table 10

Coded Composite Family Responses to Interview Question 1 from the Non-Augmented (NA) Hands-On Device Group using a 6-Point Scale

Interview Question 1: What do you think is this intent of this device?	
NA1: It's cool! It's fun and interesting. It took a few minutes for us to figure it out.	0
NA2: To put hands on balls. To make the bulb light up. To complete a circuit.	2
NA3: To show us that you can complete a circuit. Teamwork.	1
NA4: To show current and how it can go through people. To activate your mind and make you think.	2
NA5: To show electricity going through the body. But you didn't feel it. It's only a AA battery. It felt warm. So electricity causes heat. Yeah, electricity causes heat.	2
NA6: To show a complete circuit. To see if the body can be used to close a circuit. How electricity travels through bodies.	3
NA7: To teach kids about circuits. The body acts like a wire. To complete the circuit and conduct electricity. You acted like a conductor.	4
NA8: To show people how electricity can be conducted through their bodies. To complete the circuit. When electricity flows through the body you have to touch two to make it light. You need to complete the circuit to power an object.	6
NA9: How electricity goes across you. It doesn't work with three people or more. No, it only works certain ways.	1
NA10: The purpose is that it flows through you. Electricity goes through you to the light.	2
Mean	2.3
Median	2

Note. The ideal answer is: To show that the [body can act like a wire] to [conduct] [electricity] through the [circuit], supplying [power] to [light] the bulb. The coding rubric: 1 point for each [thought] to a possible total of 6 points. If the same [thought] is repeated within the excerpt, do not add additional points. The score should represent the range of [thoughts] expressed, from 0-6.

Table 11

Coded Composite Family Responses to Interview Question 1 from the Augmented (A) Hands-On Device Group using a 6-Point Scale

Interview Question 1: What do you think is this intent of this device?	
A1: It demonstrates that electricity can flow through the human body. It demonstrates completing a circuit.	3
A2: To have fun and learn. How light and electricity transmits through body. Conductivity. How electricity is going through my body. Body can act like a wire. It's like an idea! Light bulb going on!	4
A3: To get the light to light. To show people how electricity works. Human bodies can conduct electricity. We're just electric!	3
A4: To show how to complete a circuit. Using your body as a wire. If you're connected, it still works.	3
A5: To see how electricity flows.	1
A6: So you could get the bulb to light up.	1
A7: To show electricity is in you and can travel through you. Teamwork. Holding hands. Get everybody to do it at the same time.	2
A8: To show how electricity passes through the body. To show how to complete the circuit.	2
A9: To feel electricity going through you.	1
A10: To show that a current of electricity goes through the body.	2
Mean	2.2
Median	2

Note. The ideal answer is: To show that the [body can act like a wire] to [conduct] [electricity] through the [circuit], supplying [power] to [light] the bulb. The coding rubric: 1 point for each [thought] to a possible total of 6 points. If the same [thought] is repeated within the excerpt, do not add additional points. The score should represent the range of [thoughts] expressed, from 0-6.

Of the 20 participating families, only one—family NA8—scored the full six points for their response. Likewise, only one—family NA1—was completely unable to articulate any elements of the hands-on device's intent. Partial realization of the intent was far more common within both groups, with most families in both groups scoring two or three points. As the tables show, the families who encountered the device in its augmented condition scored, on average, one-tenth of a point below their peers in the non-augmented group, suggesting that the augmented reality technology essentially had no impact on realization of the hands-on device's intent for learning within this sample.

The fact that only one family was fully able to articulate the device's intent merits further consideration, particularly since they did not need augmented reality technology in order to do so. Was there something special about family NA8's interaction that contributed to their success? The family included a 7-year-old girl, her 10-year-old brother, and their grandparents. The following is the ethnographic description of their interaction.

- Non-Augmented Device – Family NA8: *After the family approached the device, the grandmother appeared to be reading the text to herself, but not aloud. The boy jumped right in, initiating contact, but the grandmother stopped to ask him if he had read "the directions." The girl was on the opposite side and both children had success right away, expressing delight through big smiles. The grandfather commented that they were acting like wires and described what was happening, despite not yet having tried it for himself. The grandfather figured out that they should try holding hands and then the grandparents took over, directing various configurations. The boy also suggested configurations, and the family followed his lead. The*

> *grandmother pointed out the picture on the interpretive panel to call their attention to what was happening. She asked the girl if she could feel the electricity flowing through her. The girl was very quiet, but her eyes and facial expression suggested keen interest and delight. She became more vocal during the interview, happily reporting that the experience reminded her of devices she had seen "downstairs" in the Electricity exhibit.*

In this family's encounter, all members experienced the device, and all paid attention to the interpretive content. The grandparents first made use of the interpretive content while the children first made contact with the experiential aspects; a key action, though, seems likely to have been the grandparents subsequently calling the children's attention to the graphic panel and choosing to become actively involved in the experiential, hands-on aspect of the experience. As a result, everyone switched back-and-forth, playing both roles, experiencing and processing the interpretive support. As a result, they were collectively able to articulate an excellent response to question 1: the intent of the device is…*to show people how electricity can be conducted through their bodies. To complete the circuit. When electricity flows through the body you have to touch two to make it light. You need to complete the circuit to power an object.*

As this family—NA8—did not encounter the device in its augmented condition, the quality of their response is attributable to something else. It seems more likely to have derived from the shared role-playing behavior that occurred within the family and the family members' willingness to teach one another and learn together. Every individual attended fully to the experiential and interpretive aspects, taking turns as interpreters, actors, and leaders. If that shared role-playing behavior is indeed the most significant characteristic, can augmented reality technology be used to support it? This study's findings include indicators that it might, which warrant further investigation.

Connection to prior experience. During the interviews, families were also asked what the experience made them think about in an attempt to reveal the connections that might have been made to prior experience.

For analyzing the responses to this question, the researcher again consulted the designer of the original, non-augmented hands-on exhibit device. When the device was conceptualized, its secondary goal was to provoke thoughtful connection between the device and everyday circumstances where conductivity and circuit completion are relevant such as, for example, when home electrical circuit breakers need to be reset in order to restore the flow of electricity throughout the entire house. From this consultation, the researcher determined that the ideal response to question 1 should include references to historical, household, classroom, and everyday encounters with electrical circuits. Any thoughtful connection merited a point, with no upper limit set.

Table 12

Coded Composite Family Responses to Interview Question 2 from Non-Augmented (NA) Hands-On Device Group with No Set Point Limit

Interview Question 2: What did the experience make you think about?	
NA1: Electricity. That we're all conductors. I think it's something about the positive and negative flow.	0
NA2: How about…electricity? And connecting things to make electricity flow?	0

(continued)

Interview Question 2: What did the experience make you think about?	
NA3: Looking for ways to work together to complete the circuit.	0
NA4: Light and electricity.	0
NA5: It made me think of Ben Franklin.	1
NA6: The potato clock experiment.	1
NA7: Wires. Us as a wire. It’s interesting that electricity can go through the body. How electrons can go in one side of the body and flow through and out the other side.	0
NA8: How lights go on in your house. Experiments in my classroom.	2
NA9: It reminds me of the potato clock experiment. If you could get zapped when you touch something electrical, but it depends on what part of it you hold.	2
NA10: Mainly electricity.	0
Mean:	0.6
Median:	0

Note. The ideal answer includes examples of circuits in everyday life or references to electricity in everyday situations. The coding rubric is: score 1 point for each example or reference. If an example/reference is mentioned more than once, just score it once. The score should not increase due to repetition.

Table 13

Coded Composite Family Responses to Interview Question 2 from Augmented (A) Hands-On Device Group with No Set Point Limit

Interview Question 2: What did the experience make you think about?	
A1: It made me think about how electricity can flow through the human body. It made me think about a project in fifth grade where I had to draw a circuit.	1
A2: Ding! I have an idea! How to complete a circuit. Hope the light bulb at home doesn't blow out.	1
A3: Different ways to make it light. School. Ben Franklin and the kite experiment.	2
A4: Think about wires. Made me feel like a wire.	0

(continued)

Interview Question 2: What did the experience make you think about?	
A5: Thinking about making connections. We had to use our hands, but it had to be connected.	0
A6: Christmas lights! Carnival rides. We had to work together to get it to light.	2
A7: Lightning. It looks like lightning. Electricity and how it travels. Electricity. Safety at home and grounding electricity.	3
A8: Electricity. Circuits and the flow of electricity. Problem-solving. Ways to complete the circuit.	0
A9: I didn't think about anything. I thought about the lights.	0
A10: Amusement. I was thinking that he was having a good time. The times I zapped myself fixing things.	1
Mean:	1
Median:	1

Note. The ideal answer includes examples of circuits in everyday life or references to electricity in everyday situations. The coding rubric is: score 1 point for each example or reference. If an example/reference is mentioned more than once, just score it once. The score should not increase due to repetition.

Of the 10 families who encountered "Be the Path" in its non-augmented condition, only four were able to articulate any connections whatsoever to prior experience. Meanwhile, six of the families who encountered the device with its augmentations were able to make the connection to prior experience. As Tables 12 and 13 show, the families who encountered the device in its augmented condition scored, on average, four-tenths of a point higher than their peers in the non-augmented group. While small, this increase does suggest that the technology positively impacted the ability to connect the hands-on interaction to prior experiences with electrical circuits.

Family A7 again outperformed all other families. (Recall that family A7 also scored highest on interpretive content recall, as discussed above.) The experience made them think about lightning, how electricity travels, and electrical safety at home. No other family was able to think of three distinct connections to prior experience or knowledge of electricity.

Aggregated experiential outcomes. Table 14 presents aggregated scores for the experiential outcome measures including interpretive content recall, realization of device intent, and connection to prior experience. It is important to note that the aggregation is solely for the purpose of ranking the families within the two groups. The aggregation is not intended to suggest that the three individual qualitative measures are mathematically equivalent.

Table 14

Presentation of Aggregated Scores on the Experiential Outcome Measures for Families Who Encountered the Device in Both Non-Augmented (NA) and Augmented (A) Conditions

	Interpretive Content Recall (0-3)	Realization of Device Intent (0-6)	Connection to Prior Experience (no limit)	Aggregated Learning Outcomes
NA8	1	6	2	9
NA6	2	3	1	6
NA7	2	4	0	6
NA5	2	2	1	5
NA9	2	1	2	5
NA4	1	2	0	3
NA10	1	2	0	3
NA3	1	1	0	2
NA2	0	2	0	2
NA1	1	0	0	1
Mean	1.3	2.3	0.6	4.2
A7	3	2	3	8
A2	2	4	1	7
A3	2	3	2	7
A1	2	3	1	6

(continued)

	Interpretive Content Recall (0-3)	Realization of Device Intent (0-6)	Connection to Prior Experience (no limit)	Aggregated Learning Outcomes
A4	2	3	0	5
A6	1	1	2	4
A10	1	2	1	4
A8	2	2	0	4
A9	2	1	0	3
A5	1	1	0	2
Mean	1.8	2.2	1.0	5.0

On average, the families who encountered the device in its augmented condition scored an aggregate 5.0 points for experiential outcome measures. For the non-augmented condition, the average was 4.2. From this perspective, therefore, the data suggests that the experiential outcomes were higher, overall, for the families who encountered the augmented hands-on condition.

How Families Learn: Informal Science Learning Behaviors

In this section, the Description of Play findings and the Experiential Outcomes findings are considered in tandem in an attempt to generate a holistic understanding of how the families in this study behaved as they learned together about electrical circuits around “Be the Path.” When considered holistically, several families emerged as bellwethers—within both cohorts—for interpreting the potential impact of augmented reality technology on the informal science learning behavior.

Table 15 enables a ranked side-by-side comparison of the two sets of measures: Description of Play and Experiential Outcomes.

Description of Play includes time on task, quality of play, role-playing, and discourse acts. These first four measures represent the characteristics of the families' informal science learning behavior during their exhibit experience.

Experiential Outcomes include interpretive content recall, realization of the device's intent, and connection to prior experiences. These final three measures represent the experiential outcomes—as captured during the interview—of the families' informal science learning behaviors.

The characteristics of the families' experience with the exhibit—as reflected by time spent, quality of play, role-playing, and discourse—should be predictive of related experiential outcomes as measured by the interview questions about the purpose, understanding, and extension of the content.

Table 15

Combined Presentation of All Measures for Families Who Encountered the Device in Both Non-Augmented (NA) and Augmented (A) Conditions, Ranked by Aggregated Description of Play Score

	Time on Task	Quality of Play (1-3)	Adult Role Play		Minor Role Play		Discourse Acts		Aggregated Description of Play	Interpretive Content Recall (0-3)	Realization of Device Intent (0-6)	Connection to Prior Experience (no limit)	Aggregated Experiential Outcomes
			I	E	I	E	A	M					
NA8	**01:58**	**2**	**1**	**2**	**2**	**1**	**4**	**2**	**14**	**1**	**6**	**2**	**9**
NA7	**01:23**	**2**	**1**	**2**	**2**	**1**	**3**	**2**	**13**	**2**	**4**	**0**	**6**
NA6	02:30	3	1	2	0	1	5	0	12	2	3	1	6
NA10	01:50	1	1	2	2	1	3	2	12	1	2	0	3
NA2	**01:50**	**2**	**1**	**2**	**0**	**1**	**4**	**0**	**10**	**0**	**2**	**0**	**2**
NA9	03:00	1	1	2	0	1	2	2	9	2	1	2	5
NA1	01:15	1	1	2	0	1	3	1	9	1	0	0	1
NA5	01:55	1	1	0	0	1	5	0	8	2	2	1	5
NA3	01:13	3	1	2	0	1	1	0	8	1	1	0	2
NA4	**01:14**	**2**	**1**	**0**	**0**	**1**	**2**	**1**	**7**	**1**	**2**	**0**	**3**
Mean	01:46.8	1.8							10.2	1.3	2.3	0.6	4.2

(continued)

	Time on Task	Quality of Play (1-3)	Adult Role Play		Minor Role Play		Discourse Acts		Aggregated Description of Play	Interpretive Content Recall (0-3)	Realization of Device Intent (0-6)	Connection to Prior Experience (no limit)	Aggregated Experiential Outcomes
			I	E	I	E	A	M					
A2	**02:07**	**3**	**1**	**2**	**2**	**1**	**5**	**3**	**17**	**2**	**4**	**1**	**7**
A3	01:23	3	1	2	2	1	5	2	16	2	3	2	7
A7	**01:21**	**3**	**1**	**2**	**2**	**1**	**5**	**1**	**15**	**3**	**2**	**3**	**8**
A1	02:06	3	0	2	2	1	3	3	14	2	3	1	6
A10	01:55	3	1	2	2	1	1	3	13	1	2	1	4
A8	02:06	3	1	2	0	1	5	0	12	2	2	0	4
A5	**02:08**	**3**	**1**	**0**	**0**	**1**	**6**	**1**	**12**	**1**	**1**	**0**	**2**
A4	02:18	3	0	2	0	1	3	2	11	2	3	0	5
A9	01:38	2	1	2	0	1	1	2	9	2	1	0	3
A6	**01:59**	**1**	**1**	**0**	**0**	**1**	**3**	**0**	**6**	**1**	**1**	**2**	**4**
Mean	01:54.1	2.7							12.5	1.8	2.2	1.0	5.0
I = Interpreting, E = Experiencing, A = Adults, M = Minors													

As detailed above, family NA8 and family A7 had the highest scores for realization of device intent and interpretive content recall. Family A7 also had the highest score for connections to prior experience. Family A2 and Family NA7 scored four points for realization of the device's intent—the second highest score recorded. Based on these outcome measures, these four families, therefore, exhibited exemplary informal science learning behavior and outcomes within the study's sample. Which behaviors did these four families—highlighted in reverse, white on black—have in common? Notably, all four of them featured role-switching, with both adults and minors playing both the experiential and interpretive roles. Also, all four families had both adults and minors responsible for discourse acts—including explaining, describing, and questioning. Looking at these four families together, however, it is also noteworthy that the two families who encountered the hands-on device in its non-augmented condition only scored two of three possible points for the quality of their play. Families A2 and A7 encountered the device in its augmented condition—and succeeded in scoring three points for the quality of their play. All behavioral and outcome measures were comparable. Only the quality of play seemed to be impacted by the augmented reality technology. Of course, that higher quality of play may also have influenced behavioral and outcome measures. Either way, the finding does suggest that augmented reality technology may have positively impacted the learning experience for these families.

When an imbalance exists in the role-playing and discourse behaviors within a family, the outcomes suffer. Consider, for example, families NA2, NA4, A5, and A6—outlined in boldface. In these four families, the family members played fixed and inflexible roles. The adults interpreted while the children experienced. The adults did most (if not all) of the talking. While the quality of their playful behavior may have been beyond basic, the outcome of their interaction—as reflected by their interview responses—was consistently low. At best, someone in the family was able to recall one element of the interpretive content and two elements of the device's intent for learning. Three of the four families were completely unable to make a connection to prior experience. This data suggests that the imbalanced role-playing behavior negatively impacted the outcomes of their activity.

Taken together, the two sub-groups—highlighted in reverse and in boldface—suggest that several factors contribute simultaneously to success of the hands-on learning experience. While the study's findings do suggest that augmented reality technology appears to have the potential for positive effect, it alone is not likely to make a substantive difference. However, if augmented reality technology could be used to facilitate role-switching and shared discursive practices within family groups, the potential may be realized. This idea is discussed fully in Chapter 5.

Interpretation

This evaluative comparison study's findings suggest that hands-on experiences with "Be the Path" were enhanced by the addition of augmented reality technology, with most indicators pointing favorably in the same direction. The exploratory findings suggest that an experimental study, with larger sample sizes, may be warranted in order to determine the statistical significance of the improvement.

As will be discussed in Chapter 5, there were qualitative differences between the two samples and those differences may also warrant full-scale experimental investigation. Also, the ethnographies presented in Appendix D offer qualitative portraits of family learning behaviors around a hands-on science exhibit device that may prove useful for peer informal science educators.

It is evident that the actual composition of the individual family groups may have influenced the outcomes of this comparison study. Some adults were simply stronger interpreters than others. Some children were more inquisitive and excited than others. As the focus of this study was an exploratory evaluation of a new technology, those issues of intra-family learning dynamics were not directly considered. However, they are presented in the ethnographic descriptions (see Appendix D).

The key reality for informal science learning, however, remains that very unpredictability of who will visit exhibits and how they will make use of them. In that regard, all 20 of these families perfectly fit the profile of the population served by informal science educators. This study did not directly attempt to understand the dynamics of family interaction; rather, the study evaluated the potential for a new technology to influence behavior and help all families—regardless of expertise—to make better use of an existing hands-on science exhibit device.

Summary

The study's findings include data that responds directly to the central research questions regarding the realization of the device's intent for learning and the integration of the experiential and interpretive aspects of the experience. While the sample size was too small to generate statistically significant differences between conditions, the analysis of the family learning behaviors does suggest that the families who encountered "Be the Path" in its augmented condition played longer and at a higher level of quality than those who encountered the hands-on device without augmentation. Within this study's small sample, all of the families who experienced "Be the Path" in its augmented condition surpassed the families who experienced the non-augmented device on at least one measure. Furthermore, many of the families who encountered the augmented reality surpassed their counterparts in the non-augmented device group on two or more measures. These positive findings suggest that additional investigation—perhaps with an experimental design—is warranted with a larger sample in order to deepen understanding of the impact of augmented reality technology on informal science learning behavior.

Chapter 5: Discussion

Introduction

For decades, informal science learning in science museums has been based on hands-on device interaction in thematic exhibit spaces. Meanwhile, the use of technology—in science, in education, in entertainment—has emerged during those same decades as a fact of daily life in modern society. Yet, informal science educators know that there is something fundamentally vital about hands-on experiences that facilitate direct, non-simulated encounters with scientific phenomena. So, science museums have clung to traditional devices accompanied by traditional graphic panel displays. Might augmented reality technology now offer an opportunity to intersect the two histories? Has the field reached the brink of transformation? This study points to the possibility that augmented reality technology is a tool that could be used to help transform the way exhibits are structured.

This study attempted to show that augmented reality technology could impact family learning behaviors and improve the outcome of an informal science experience. A traditional hands-on science exhibit device called "Be the Path" was made available for use in both non-augmented and augmented conditions. A total of 20 families interacted with the hands-on device, 10 families for each condition. Several indicators suggested that the technology may indeed have played a role in changing both family learning behavior and outcomes. Time on task and the quality of play were strengthened when families encountered the device in its augmented condition, as compared to families who encountered the same device without any augmentation. The ability to connect the device's scientific content—conductivity and circuitry—with prior experience was also improved. The ability to recall the device's interpretive content increased. While the differences between the two groups were small in this evaluative comparison study, their positive trend suggests that further investigation with larger sample sizes might reveal statistically significant differences.

Research Logic—Outputs, Outcomes, Impacts

The study succeeded in producing the intended outputs: an enhanced "Be the Path" exhibit device; data about the use of augmented reality in informal science learning exhibits; new knowledge about augmented reality technology; and new strategies for use in exhibit design. The "Be the Path" device augmentation was seamless. Virtually none of the study's participants who encountered the device in its augmented condition questioned the source of the projection, or even looked up to see where it originated. The digital enhancements behaved as programmed—expanding and contracting as the family linked hands and tried various placements—providing a new model for how it can be incorporated into exhibit design. The study's data represents new knowledge about augmented reality and about its use in informal science learning exhibits.

The study's logic model (see Figure 1) anticipated two outcomes: informal science education would be better positioned to support the need for expanded science education in America; and exhibit developers would be able to apply augmented reality strategies in new exhibits. The first outcome was only marginally supported. An incremental increase in knowledge about the discrepancy between the experiential and interpretive aspects of informal science learning did result from the study. The study's findings represent a contribution of new knowledge for the field, suggesting that augmented reality technology does merit further consideration. And, as a manifestation of the second anticipated outcome, the study did offer a successful augmented reality strategy for use in new exhibits—providing a practical model for an augmented hands-on modality.

Is informal science education better positioned to support improvement of science education in America as a result of this study? The research was premised on an optimistic belief that augmented reality technology would make a difference in the interpretive behavior surrounding an informal science learning experience in order to improve outcomes and move the field forward. In fact, the differences were clearly suggestive of positive improvement, although only incrementally, given the small sample size. The potential impact of augmented reality technology, therefore, has not yet been fully assessed but warrants further consideration.

Characteristics of Effective Informal Science Learning

Only two families who encountered the hands-on "Be the Path" device without augmentation scored three points on their quality of play assessment. By comparison, eight families who encountered the device in its augmented condition did so. This difference suggests that augmented reality technology has the potential to make a real difference for informal science learning by improving the quality of play and impacting behavior as a family interacts around a hands-on exhibit device. Along with the higher level of playful experimentation, the families who encountered the augmented reality spent more time on task and generated more discourse acts than the other group. In general, therefore, the augmented reality condition provoked more discussion, sparked more playful experimentation, and held interest longer. Further research is needed to determine if these patterns would repeat themselves in larger samples.

In articulating the characteristics of effective science learning in informal settings, two of the features that Bell et al. (2009) identified were that the exhibit “leads to an experience of excitement, interest, and motivation to learn about phenomena in the natural and physical world” (p. 4) and that it encourages the participants to “manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world” (p. 4). When the study’s families exhibited sustained playful experimentation and meaningful discourse, therefore, the experience was supportive of effective learning. Eight families exhibited the highest level of playful experimentation, demonstrating excitement, interest, and motivation to try to outwit the device through creative hand placements and group configurations. Likewise, the high level of playful experimentation showed that the families who experienced “Be the Path” in its augmented condition were manipulating, testing its limits, and exploring the physical properties of the device.

The families who encountered the device in its augmented condition were responsible for 54 discourse acts, with participants taking turns instructing, describing, and questioning during the experience. Their discursive activity was also an essential part of the sense-making process. Taken collectively, these clearly observed family learning behaviors around an augmented hands-on exhibit device are evidence of the potential for augmented reality technology to support effective science learning within informal science contexts as defined by Bell et al. (2009).

Within this small comparative study, however, the increase in quality of play was not sufficient to demonstrate a striking difference in the resultant experiential outcomes. So, while the study does suggest the potential for augmented reality technology to support effective informal science learning, further research is needed to determine an associated impact on experiential outcomes.

Understanding Family Learning Behaviors

Informal science learning behaviors seem to come more easily for some families. They arrive at the science museum, pick an exhibit, and easily figure out what to do and how to make the best of the devices they encounter. They work collaboratively as a team—taking turns, switching roles, and supporting one another. They articulate their observations, tell each other what to do, and ask questions. They experiment with the hands-on devices playfully. They take turns acting as leaders and celebrate when they succeed—as indicated by smiles, laughter, and "high fives." They all participate equally, experiencing the scientific phenomena and making use of the interpretive content.

Family NA6 is one of these families. The sixth family to encounter the hands-on device in its non-augmented state included an 8-year-old boy, his 9-year-old brother, and their parents. With no special attention, the family easily figured out what to do and enjoyed a quality informal science learning experience using "Be the Path"—which is, ultimately, a rather standard informal science hands-on exhibit device with no novel enhancements. They invested 2 minutes and 30 seconds on the task and succeeded in collaboratively making full use of the device, even going so far as to try completing the circuit with their feet. (See Appendix D for a full ethnographic description of this family's interaction.) All members of the family participated fully in the activity and the sense-making, although the adults did account for all of the instructing, explaining, and questioning. The adults used their discourse acts constructively to encourage creative exploration and celebrate their successes, especially after skin contact between the sandal-wearing family members enabled them to prove that they could indeed complete the circuit with their feet. They made use of the interpretive content. They figured out, for themselves, how to merge the experiential and interpretive aspects of the device. In essence, they augmented the hands-on device themselves—with prior knowledge, avid curiosity, and teamwork. Families like NA6, the ones for whom informal science learning behaviors come more easily, unfortunately, are exceptional. They are not a fair representation of the mainstream families who visit science museums.

Far more common are the families who have not yet developed effective strategies for informal science learning and are not quite sure how to behave in exhibits. They respect and value science museums and hope to get the best possible return on their investment—of both the price of admission and their time. They happily seek to try everything in an exhibit, in an attempt to do it all. They approach hands-on devices in exhibits with curiosity, open to the experiences they offer, but they lack the behavioral knowledge needed to maximize the impact of their experience.

Most of the families who participated in this study would fall into this category, exhibiting that imbalance in the role-playing and discourse behaviors. For example, the individuals in families NA2, NA4, A5, and A6 all played fixed and inflexible roles. The adults interpreted while the children experienced. While the quality of their playful behavior may have been acceptable, the outcome of their experience was consistently low. At best, someone in the family was able to recall one element of the interpretive content and two elements of the device's intent. While they may certainly have had a positive experience during their visit to The Franklin Institute Science Museum, they have not developed the interactive skills and behaviors that would help them to learn effectively as a family and maximize the impact of their visit to the science museum. These families need help knowing know how to act, what to do, and what to say at a device. They commonly began their interaction with the device by "reading the directions," but lacked the capacity to advance the experience beyond the prescription. They are likely to leave the museum with a sense of satisfaction, content that they made pleasant family memories, despite not really understanding the scientific phenomena they encountered.

For many years, that mixed result has been the norm for informal science education, with institutions measuring success according to satisfaction surveys. In light of the current science education crisis, however, that status quo can no longer be considered acceptable. Traditional static role-playing behaviors may enable a satisfying experience but, by failing to integrate the experiential with the interpretive, ultimately render the learning experience impotent.

Informal science educators need to consider providing scaffolds that deliberately support the development of family learning behaviors in order to help everyone understand the multiple roles that they need to play. Without such scaffolds, families revert to predictable roles, with adults acting as authorities and making sure that the children are satisfied and happy. The adults do most of the science talking while the children do most of the science doing. These are the families who are most in need of special attention—in the form of scaffolds—in order to demonstrate the contribution of informal science learning to the life-long, life-wide, and life-deep learning that is needed to safeguard America's scientific future.

The study's findings include evidence to suggest that augmented reality technology could be used to provide that needed scaffolding for influencing family behavior. With just a simple projection of the flow of electricity, the technology succeeded in influencing role-playing behaviors. The families who encountered the augmented hands-on device were more likely to discuss the experience, experiment more playfully, and stay engaged longer than those who encountered it in its non-augmented condition. That NA6 family mentioned above, for whom informal science learning seemed to come somewhat more easily, needed no scaffolding to know that they should take turns experiencing the device and that they should ask questions, comment on their actions, and challenge one another. Most everyone else, however, failed to step outside of familiar age-related roles so that they could both experience the phenomena and simultaneously make use of the interpretive content. The simple digital augmentation of the hands-on device—the augmented hands-on state—did enable an incremental improvement in those role-playing behaviors (as presented in Chapter 4), helping families to behave more productively as informal science learning teams. Adults made modest strides to move from the sidelines of play to center field wherein their active engagement with "Be the Path" modeled playful learning for their children. Children accustomed to playing alone while their parents watched and commented from a few steps away readily made room at the device to include their parents as co-learners. The children willingly accepted new roles as commentators and interpreters as they relinquished their monopoly on the experiential aspects of the engagement. The result was a new behavioral profile for the entire family unit—one in which both adults and children became comfortable as collaborative learners.

Much more is needed, however. As discussed in Chapter 4, the study's highest level outcomes seemed to suggest that a balanced, shared role-playing behavior—where adults model play at the device and prompt children to join them—may be critical to integrating the experiential and interpretive aspects of informal science learning. The highest level responses seemed not to have been influenced solely by the augmented reality technology. Rather, the quality was more complexly intertwined with the shared role-playing that occurred within the families. In the families that provided the highest level responses, every individual attended fully to the experiential and interpretive aspects, taking turns as interpreters, actors, and leaders. If that shared role-playing is indeed the most significant characteristic, can augmented reality technology be used to support this function in innovative ways? Is it possible that augmented reality technology could be used strategically to support shared role-playing? The augmentations could deliberately target and encourage turn-taking and rotation in the roles. For example, an augmentation could invite each member of the family to assume the leadership role for a time. The fact that the families who encountered the augmented reality in this study expressed no surprise or even acknowledgement of the augmentation does suggest that the technology has the potential to seamlessly enhance exhibit devices and add a kind of invisible referee to the experience—an agent that moderates the role-playing dynamic.

Devices could be enhanced to be more targeted and responsive to user input, with deliberate role-playing assignments, perhaps initially encouraging adults to act as interpreters, questioning children while they interact with the device. Then, the augmented agent might intervene and switch the roles, having children take on the role of observers and commentators while the adults assume hands-on experiential positions. This role-switching dynamic could continue throughout, liberating the parents from their presumed position of authority and giving the children space to develop their interpretive voices as scientific spokespersons. Through play, the adults strengthen their ability to comment and through commentary the children develop their confidence. The result, of course, is that the family collaboratively learns how to experience, how to interpret, and how to merge the experiential with the interpretive.

It is possible that only a few devices in an exhibit would need to be augmented with behavioral cues to support the goal of developing family learning behaviors. After a family experiences a few enhanced devices, transfer of the skills to other exhibits might follow, although this would need to be investigated. Essentially, augmented hands-on devices within an exhibit might provide the scaffolds needed to help families develop the strategies, norms, and disposition that aid in informal science learning for families who currently lack the skills. These skills could be crucial for learning not only in science but in all areas of informal learning.

This study deliberately focused on family learning during the summer out-of-school learning time. No consideration was given to the tens of thousands of children who visit the science museum during the school year—during the 21% of their waking hours that they spend with their teachers—on school field trips. The analysis, however, inevitably leads to speculation about how augmented hands-on might impact school group behavior within exhibits. The proposed augmented agents that would encourage role-play turn-taking would likewise impact behavior within school groups. A longstanding particular challenge for informal science education has been the selection, preparation, and involvement of chaperones who accompany teachers on field trips. Far too often, these volunteers are completely unprepared for their role. This study suggests the possibility that augmented hands-on devices might finally enable chaperones to know what to do with the kids in their group. Furthermore, while speculative, it does seem possible that students in small peer-groups who spend time with the augmented hands-on devices during their field trip may develop experiential and interpretive skills that they would carry back to the classroom, ultimately improving their readiness for formal science learning. Knowing how to play, what to say, and when to reflect are valuable skills in nearly any context.

Summary and Conclusion

This study was designed to respond to the compelling need for the field of informal science education to reposition itself as a vital contributor to overcoming the science crisis in America. With so much of the time spent in formal classrooms being absorbed by other subjects, the need for science learning during out-of-school time was clear. This situation suggested that the study should focus on out-of-school time at the museum—either weekends or summer vacation. During those timeframes, families represent the largest audience segment. For this reason, the decision to focus on family groups seemed appropriate.

An evaluative comparison study design was employed to determine the extent to which the application of augmented reality technology increases realization of a hands-on exhibit device's intent for learning and how augmented reality technology might influence family learning behaviors and facilitate the integration of the experiential and interpretive aspects of the informal science learning experience.

Ultimately, 20 families were invited to interact with an exhibit device called "Be the Path" that was made available in both its traditional hands-on condition and a novel augmented condition. The study was conducted at The Franklin Institute Science Museum during the summer of 2010. Ten families encountered the device in its non-augmented hands-on state. 10 other families experienced the augmented hands-on state. Each family's play and experiential outcomes were analyzed. The description of play—which included time on task, quality of play, role-playing, and discourse acts—resulted from the researcher's observation notes and video analysis. The experiential outcomes, which resulted from a qualitative analysis of interview responses, included interpretive content recall, realization of device intent, and connection to prior experience. .

The resultant qualitative analysis of the family learning behaviors suggested that the families who encountered “Be the Path” in its augmented hands-on condition played longer and at a higher level than those who encountered the hands-on device without augmentation. All of the families who experienced “Be the Path” in its augmented hands-on condition surpassed the families who experienced the non-augmented device on at least one measure, suggesting that augmented reality technology may have the potential to influence family learning behaviors around exhibit devices in ways that could create and support the development of skills needed to maximize the impact of informal learning—in science museums and elsewhere.

If augmented hands-on can positively influence family learning behaviors, then it may be a way forward for the field—a way for informal science educators to ensure that the experiential and interpretive aspects of their designed learning experiences are successfully integrated. When family learning behaviors improve, formal science education benefits too. Children who co-learn with adults how to experience and interpret scientific phenomena during a visit to a science museum carry that behavior home and back to their classrooms. When these behavioral shifts occur, outcomes improve and informal science education demonstrates the vitality of its contribution to solving the scientific and technological challenges that society faces—now and in the future.

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APPENDIX A

Observational Instrument

Observational Protocol

Cohort: 1 2

Subject Number: 1 2 3 4 5 6 7 8 9 10

Demographic Description:

Adult:	1	Gender: _____	Age:	_______ (approximated)
	2	Gender: _____	Age:	_______
	3	Gender: _____	Age:	_______
Child:	1	Gender: _____	Age:	_______ (declared)
	2	Gender: _____	Age:	_______
	3	Gender: _____	Age:	_______

Time on Task:

Start Time: ____________________

Finish Time: ____________________

Total: ____________________

Discourse Acts:

telling someone to do something, describing something, raising questions

Experimentation:

Note how the participants deviate from the prescribed play to find new configurations for completing the circuit.

APPENDIX B

Interview Instrument

1. What do you think is the intent of “Be the Path?”

2. What did the experience make you think about?

3. There was a printed graphic panel on the device. What did it say?

APPENDIX C

Data Analysis Coding Manual

Throughout this Coding Manual, columns A and B represent coders A and B, presenting a side-by-side comparison of the coders’ ratings. Coder A is the researcher. Coder B is her colleague.

Table C1

Coded Composite Family Responses to Interview Question 1 from the Non-Augmented (NA) Hands-On Device Group using a 6-Point Scale as Assigned by Both Raters

Interview Question 1: What do you think is this intent of this device?		
	A	B
It's cool! It's fun and interesting. It took a few minutes for us to figure it out.	0	0
To put hands on balls. To make the bulb light up. To complete a circuit.	2	2
To show us that you can complete a circuit. Teamwork.	1	1
To show current and how it can go through people. To activate your mind and make you think.	2	1
To show electricity going through the body. But you didn't feel it. It's only a AA battery. It felt warm. So electricity causes heat.	2	2
To show a complete circuit. To see if the body can be used to close a circuit. How electricity travels through bodies.	3	3
To teach kids about circuits. The body acts like a wire. To complete the circuit and conduct electricity. You acted like a conductor.	4	4
To show people how electricity can be conducted through their bodies. To complete the circuit. When electricity flows through the body you have to touch two to make it light. You need to complete the circuit to power an object.	6	5
How electricity goes across you. It doesn't work with three people or more. No, it only works certain ways.	1	1
The purpose is that it flows through you. Electricity goes through you to the light.	2	2

(continued)

Note. The ideal answer is: To show that the [body can act like a wire] to [conduct] [electricity] through the [circuit], supplying [power] to [light] the bulb. The coding rubric: 1 point for each [thought] to a possible total of 6 points. If the same [thought] is repeated within the excerpt, do not add additional points. The score should represent the range of [thoughts] expressed, from 0-6.

Table C2

Coded Composite Family Responses to Interview Question 1 from the Augmented (A) Hands-On Device Group using a 6-Point Scale as Assigned by Both Raters

Interview Question 1: What do you think is this intent of this device?		
	A	B
It demonstrates that electricity can flow through the human body. It demonstrates completing a circuit.	3	3
To have fun and learn. How light and electricity transmits through body. Conductivity. How electricity is going through my body. Body can act like a wire. It's like an idea! Light bulb going on!	4	4
To get the light to light. To show people how electricity works. Human bodies can conduct electricity. We're just electric!	3	2
To show how to complete a circuit. Using your body as a wire. If you're connected, it still works.	3	3
To see how electricity flows.	1	1
So you could get the bulb to light up.	1	1
To show electricity is in you and can travel through you. Teamwork. Holding hands. Get everybody to do it at the same time.	2	2
To show how electricity passes through the body. To show how to complete the circuit.	2	2
To feel electricity going through you.	1	1
To show that a current of electricity goes through the body.	2	2

Note. The ideal answer is: To show that the [body can act like a wire] to [conduct] [electricity] through the [circuit], supplying [power] to [light] the bulb. The coding rubric: 1 point for each [thought] to a possible total of 6 points. If the same [thought] is repeated within the excerpt, do not add additional points. The score should represent the range of [thoughts] expressed, from 0-6.

Table C3

Coded Composite Family Responses to Interview Question 2 from Non-Augmented (NA) Hands-On Device Group with No Set Point Limit as Assigned by Both Raters

Interview Question 2: What did the experience make you think about?		
	A	B
Electricity. That we're all conductors. I think it's something about the positive and negative flow.	0	0
How about…electricity? And connecting things to make the electricity flow?	0	0
Looking for ways to work together to complete the circuit.	0	0
Light and electricity.	0	0
It made me think of Ben Franklin.	1	1
The potato clock experiment.	1	1
Wires. Us as a wire. It's interesting that electricity can go through the body. How electrons can go in one side of the body and flow through and out the other side.	0	1
How lights go on in your house. Experiments in my classroom.	2	2
It reminds me of the potato clock experiment. If you could get zapped when you touch something electrical, but it depends on what part of it you hold.	2	2
Mainly electricity.	0	0

Note. The ideal answer includes examples of circuits in everyday life or references to electricity in everyday situations. The coding rubric is: score 1 point for each example or reference. If an example/reference is mentioned more than once, just score it once. The score should not increase due to repetition.

Table C4

Coded Composite Family Responses to Interview Question 2 from Augmented (A) Hands-On Device Group with No Set Point Limit as Assigned by Both Raters

Interview Question 2: What did the experience make you think about?		
	A	B
It made me think about how electricity can flow through the human body. It made me think about a project in fifth grade where I had to draw a circuit.	1	1
Ding! I have an idea! How to complete a circuit. Hope the light bulb at home doesn't blow out.	1	1
Different ways to make it light. School. Ben Franklin and the kite experiment.	2	2
Think about wires. Made me feel like a wire.	0	1
Thinking about making connections. We had to use our hands, but it had to be connected.	0	1
Christmas lights! Carnival rides. We had to work together to get it to light.	2	2
Lightning. It looks like lightning. Electricity and how it travels. Electricity. Safety at home and grounding electricity.	3	3
Electricity. Circuits and the flow of electricity. Problem-solving. Ways to complete the circuit.	0	0
I didn't think about anything. I thought about the lights.	0	0
Amusement. I was thinking that he (her son) was having a good time. The times I zapped myself fixing things.	1	1

Note. The ideal answer includes examples of circuits in everyday life or references to electricity in everyday situations. The coding rubric is: score 1 point for each example or reference. If an example/reference is mentioned more than once, just score it once. The score should not increase due to repetition.

Table C5

Coded Composite Family Responses to Interview Question 3 from Non-Augmented (NA) Device Group on a 3-Point Scale as Assigned by Both Raters

Interview Question 3: There was a printed graphic panel on the device. What did it say?		
	A	B
Put your hands on each of the balls to complete the circuit and light the bulb.	1	1
No way did the boys read directions. Have you read anything all day?	0	0
Honestly, I read it but don't remember. Try to figure out how to complete a circuit?	1	1
It said to put your hands on the balls. Try to loop multiple people—it said that at the bottom.	1	2
Complete the circuit. It also said to try it with more than one person.	2	2
Place your hands on the metal balls and see if you can complete the circuit. It says to use hands, not elbows. I remember the diagram had red lines going around the body.	2	2
Put hands on both. To complete a circuit. It said to try it with more than one person.	2	2
Place both hands on two of the silver spheres. Complete the circuit.	1	1
Place hands on bulbs. Has to be more than one person. I remember the picture and the diagram with the red lines going through it.	2	2
I remember the picture of the body.	1	1

Note. The ideal answer is: Try to complete the circuit. Try it with more than one person. Describe the diagram of the person acting as a wire. The coding rubric is: Score 1 point for each concept. Repetition of a concept should not be counted. Each concept should only be counted once, resulting in a score from 0-3.

Table C6

Coded Composite Family Responses to Interview Question 3 from Augmented (A) Device Group on a 3-Point Scale as Assigned by Both Raters

Interview Question 3: There was a printed graphic panel on the device. What did it say?		
	A	B
Try to complete the circuit. Try to complete it with more than one person.	2	2
How to transmit the current. Put your hands on the bulbs to make a circuit. And try more than one person and try holding hands.	2	2
Place hands on the balls to complete the circuit. How many people can make it light? Work together.	2	2
See if you can complete the circuit. Use the balls to complete the circuit, using your body as a wire.	2	1
Try to make the circuit go through bodies.	1	1
Touch the balls to complete the circuit and make a loop so you can make electricity flow.	1	1
Complete the circuit using one person and then try with more than one person. Like in the diagram of the man/woman/person where the red lines go through the body from one sphere to the other.	3	3
Can you complete the circuit? I looked at the picture of the body.	2	2
See if you can connect the electrical current with two people.	2	2
Touch both spheres to complete the circuit.	1	1

Note. The ideal answer is: Try to complete the circuit. Try it with more than one person. Describe the diagram of the person acting as a wire. The coding rubric is: Score 1 point for each concept. Repetition of a concept should not be counted. Each concept should only be counted once, resulting in a score from 0-3.

Table C7

A Comparison of Quality of Play during Interaction with the Hands-On Device using a 3-Point Scale as Assigned by Both Raters

HANDS-ON ELECTRICITY DEVICE			AUGMENTED HANDS-ON ELECTRICITY DEVICE		
FAMILY 1	1	1	FAMILY 1	3	2
FAMILY 2	2	2	FAMILY 2	3	3
FAMILY 3	3	3	FAMILY 3	3	3
FAMILY 4	2	2	FAMILY 4	3	3
FAMILY 5	1	2	FAMILY 5	3	3
FAMILY 6	3	3	FAMILY 6	1	1
FAMILY 7	2	2	FAMILY 7	3	3
FAMILY 8	2	2	FAMILY 8	3	3
FAMILY 9	1	1	FAMILY 9	2	2
FAMILY 10	1	1	FAMILY 10	3	3

Note. Based on watching each family interact with the device, an experimentation score was assigned according to the following guidelines. Basic Play (1 Point) Each individual grasps the balls and lights the bulb. Turn-taking occurs. Conversation focuses on the task at hand, rather than on questioning. No hand-linking occurs. Advanced Play (2 Points) All of the basic play characteristics plus hand-linking and at least one person questions how the device works. At least one person proposes using other body parts, such as using elbows or fingertips. *Experimentation* (3 Points) All of the advanced play characteristics plus someone organizes sophisticated linking configurations that include more than two people around the device. Conversation focuses on the design of the circuit.

A comparison of the ratings indicated an inter-rater reliability of 88%. The reliability was calculated based upon an agreement on 70 of the 80 ratings, which represents an 88% agreement.

APPENDIX D

Ethnographies

Introduction

Informal science educators who work in science museums accept the reality that they can neither predict nor control who will be using their exhibit devices on any given day. The work of informal science education, therefore, is based upon the premise that learners vary widely and change daily. There is no ongoing relationship and the learning that takes place can be ephemeral. Within this context, all 20 of the participating families perfectly reflect the characteristics of the study's target population. The study considered each family as a distinct unit of analysis without regard for the internal composition. The following thick ethnographic descriptions portray the actual encounters in the order that they occurred, rotating between the two device conditions (non-augmented and augmented). The intent is to provide informal science educators with stories that resonate against standard daily practice in which the next family to enter an exhibit is both unpredictable and absolutely important. In total, these portrayals reflect a slice of life for informal science education during the summer of 2010.

Non-Augmented Device – Family NA1

This family included two boys, ages 11 and 12, accompanied by their mother and grandmother. The family approached the device eagerly, with the grandmother making first contact with the device. The others followed and they all began to play at once. The grandmother quickly adopted the role of group leader, as exhibited by telling the others what to do. The device interaction was almost entirely directed by her. Following the grandmother's instruction, the family tried a variety of hand placements in an attempt to experiment with the circuitry. Notably, they never tried holding hands to expand the circuit, which is indicated on the interpretive graphic panel as one thing to try. The boys were very quiet, following their grandmother's lead, but did smile and laugh, suggesting a satisfying experience. After a few unsuccessful configurations, the mother declared that there are two separate circuits, so hand placement really does matter. Until this declaration, the mother had been rather quiet, following the grandmother's lead. During the interview, the grandmother again acted as the de facto spokesperson for the family, although, when the researcher left silent pauses, the mother and boys did offer additional commentary.

Augmented Device – Family A1

This family included two boys, ages 11 and 13, and two adult women. The precise nature of the relationship within this family was not entirely clear, but the foursome definitely behaved as a single social unit as they all seemed quite familiar with one another. The older boy took the lead and jumped right in, making first contact with the device and triggering the digital augmentation. His response was, "Whoa! That's neat!" Other reactions were "Oh, wow!" and "It's electric!" He was very expressive and his actions generated discussion. He led the group in the experimentation, suggesting creative hand placements and trying various configurations. The family engaged continuously in a playful banter. When the bulb wouldn't light, he surveyed the hand placements and figured out which hands needed to move in order to be placed properly to conduct the flow of electricity and complete the circuit. He continued to be a spokesperson for the group during the interview. He connected the experience with a classroom memory from fifth grade when he had been tasked to draw circuit diagrams. He recognized and declared that this experience was very much like that one. The women expressed delight with his response through smiles and facial expressions. One said that this was as if "that project had come to life for him."

Non-Augmented Device – Family NA2

The family included two boys, ages seven and eight, and their parents. The family worked deliberately as a group, interacting collaboratively around the device. Each boy moved immediately to opposite sides of the device, initiating contact. The mother positioned herself with the younger boy and the father joined the older boy so that each duo was opposite one another. The parents behaved as if they were focused on providing an interactive learning experience for their children, facilitating their interaction with the device. The mother spoke most often, encouraging creative hand placements and even, eventually, elbow, nose, and forehead placement. Their facilitative posture continued during the interview. The parents waited for the boys to respond first and encouraged them to try to answer all of the questions. When the father responded to the questions, he altered his tone and spoke carefully so that the boys might take his answer as a model for their own. When asked about the interpretive content on the graphic panel, the boys declared that they did not read the panel. Their mother asked them if they had read anything all day, and they confidently declared that they had not. The family's successful interaction with the device seemed likely to have been a result of the parents' leadership. The father's ability to recall the interpretive content suggests that the content may have been useful for his facilitation.

Augmented Device – Family A2

This family included two boys, ages 10 and 12, and their sister, age eight, along with their parents. The boys were the first to initiate contact with the device, triggering the digital augmentation. The mother did not react to the projection but, instead, suggested that the boys should "read the directions first." The family worked together as a group, with no one person acting as the obvious leader. Everyone contributed ideas and comments, although the little girl at first was very reluctant to join the group, asking questions from the side, such as "They use a battery to make this work?" It was later revealed that she had been shocked at another device (the Van de Graaff generator) in the Museum that day and did not like it. So, until her brothers assured her it wasn't shocking them, she did not touch the device. Eventually, though, she joined in and the family tried creative hand placements. The father suggested that they all link hands, forming a five-person chain circuit with arms wrapped around shoulders and they were delighted to see that the device worked, as evidenced by their happy facial expressions and laughter. They completed the circuit, the bulb lit, and the projected flow of electricity expanded accordingly to represent their unusual solution to the challenge. Throughout the interaction, nobody commented about the projected animation as it appeared and disappeared, suggesting that it was seamlessly integrated into their experience.

Non-Augmented Device – Family NA3

This family included three boys—ages 7, 13, and 14—and their parents. The parents approached the device first, each taking a position on opposite sides. The mother clearly paused to read the directions before doing anything. (Interestingly, while it appeared that the mother was paying very close attention to the interpretive panel, she could not recall the content during the interview. She said, “Honestly, I read it but I don’t remember [what it said].”) The father also appeared to read the graphic panel. The 13 and 14 year-olds waited for their parents, looking at the directions from the sides of the device. The mother and the oldest boy made first contact, holding hands and succeeding in completing the circuit. The youngest boy stood off to the side a bit, furthest away from the device. The parents then invited the kids to try it together, and the mother announced that “We got this.” The mother smiled and nodded in a way that suggested that she was satisfied and pleased. All family members were smiling and laughing throughout the experience. The father and the 13-year-old worked on the opposite side, completing that circuit. The father began to direct the hand placements, so that the whole family was working together. The mother said, “We got this as a family.” The father said, “We can try other ways,” and had them try some twister-like configurations. During the interview, the father expressed the opinion that the intent of the device was to use teamwork and it made him think about family fun, suggesting that, for him, the focus for the visit to the Museum was a family-bonding experience.

Augmented Device – Family A3

This family included a 16-year-old boy and his parents. All three approached the device together, but stood back and appeared to read the interpretive panel. The father went first, making first contact, but he used just his fingertips and his light touch was not enough to complete the circuit. The mother reacted to his failure by suggesting that they should “look at the directions.” After doing so, they linked hands and all three of them completed one circuit, making it work right away and triggering the animation, which generated no comments. The boy then tried by himself and it worked. The father began to suggest creative configurations. The boy also suggested hand placements while the mother was asking questions. The three of them worked together, with all of them suggesting configurations, describing what was happening, raising questions, and taking turns directing the action.

Non-Augmented Device – Family NA4

This family included a 9-year-old girl, her 7-year-old brother, her mother, and her grandfather. The family approached the device with the girl and boy taking positions on opposite sides. The girl led the way, making first contact and showing her brother what to do. The mother watched from the side, correcting the girl even though the mother had not tried it yet. The grandfather suddenly took control of the situation, as if he had processed what was happening and decided what needed to be done. He announced that, “It’s a current thing,” and began telling everyone what to do. He told the boy that it has to use your body. The boy interpreted this as using more than his hands, so he put his chin on the ball and all smiled and laughed when it worked. The grandfather said, “See!”

He continued to direct their configurations. The girl quietly commented on the direction of the flow of current around the circuit that they made, but nobody acknowledged her. The young girl's learning experience seemed to be overshadowed by her grandfather's forceful personality and personal satisfaction. She appeared to be very interested in the phenomena but lacked a receptive audience for her discovery. During the interview, she proudly declared that she "didn't read anything!" Her enthusiasm may have meant that she was pleased that she figured out the device for herself and made it work without resorting to the printed information.

Augmented Device – Family A4

This family included an 8-year-old girl, her 11-year-old brother, and their mother. The boy initiated contact with the device, completed the circuit, and triggered the augmentation. The girl also jumped in and succeeded. Nobody commented on the appearance of the projected animation. The girl called her mother's attention to what she was doing and the mother watched and listened while the girl described what was happening. The girl tried various configurations and began directing play. The boy was participating and cooperating with his sister, but quiet. After a bit, the mother took the lead and began to direct the play and it became more animated as they all smiled and laughed. They were very playful. The girl noticed that one finger was not enough contact to succeed in completing the circuit. The mother suggested that they use their forearms, which brought more laughter as they tried doing so. The mother and boy linked hands and then broke the circuit by releasing the hold. They playfully continued "opening" and "closing" the circuit by "high-fiving" each other. This very creative activity produced lots of laughter and smiling. The digital augmentation adapted perfectly, starting and stopping in time with their hand-clapping. From a technical perspective, this was a triumph for the exhibit designers, yet the family never acknowledged the projection at all. For them, the experience was seamless and the device behaved as they expected it to in concert with their creative play.

Non-Augmented Device – Family NA5

This family included two boys, ages seven and eight, and their grandparents. The family approached the device together, with the grandmother and grandfather each taking a boy to opposite sides of the device. The grandfather began to read the interpretive panel aloud, but after a few words, the grandmother interrupted him and finished reading them aloud for the group. Between the two of them, they read all of the interpretive panel copy aloud. Meanwhile, the boys had jumped right in, making first contact, and completing the circuit, smiling as the bulb lit. The grandmother told the boys what to do, showing them how to place their hands. The grandfather made a playful buzzing noise when the boys completed the circuit. Both grandparents described what they saw happening, offering their own interpretive commentary for the boys. The grandmother tried to explain how it works. The grandfather asked questions. Both the grandfather and grandmother were interpreting, following along, describing, and noticing. The boys were playful, trying various configurations, but quiet. The grandmother was focused on the boys, rather than on doing it herself. When one boy commented that the sphere felt warm she probed by asking, “So, electricity causes heat?” The boy’s face lit up with his discovery and said, “Yeah! Electricity causes heat!” In this family, the adults seemed to play an important interpretive role, facilitating the experience in ways that went beyond the graphic panel content.

Augmented Device – Family A5

This family included a 7-year-old girl, her 9-year-old brother, and their parents. The mother began by reading the interpretive panel aloud. Everyone waited for her to finish reading. The girl then made first contact with the device, completing the circuit and triggering the augmentation, which met with no comments from anyone in the family. Now that they had seen what would happen, the mother began to direct their interaction, while the boy joined his sister on her side of the device. The mother described what was happening and attempted to explain it for them. The father stood aside, watching and then announcing what he had figured out about the two circuits. He explained what he saw happening. The mother continued directing hand placements. The girl and boy succeeded, but said very little. The father and the boy linked hands and the mother and the girl then followed suit, mimicking them. The boy suggested that all four try to link hands but wasn't quite sure how to arrange everyone. The father stepped in and figured out how to make it work, directing them to make an unusual and successful configuration.

Non-Augmented Device – Family NA6

This family included two boys, ages eight and nine, and their parents. The family approached the device together, dividing into pairs and taking positions on opposite sides. The boys jumped right in, initiating contact with the device, and completed the circuit while their mother was reading the interpretive content aloud. (It never appeared obvious that the boys paid attention to the graphic panel, but, they must have been listening to their mother because they recalled it well during the interview.) There was a lot of smiling as the family was working together. The mother asked questions and challenged the boys to try new configurations. The mother linked hands with a boy and it worked right away, to everyone's obvious delight. They tried to link hands across the device, but the father noticed and announced that "It's two separate circuits." The father suggested that they try connecting their feet instead of hands. It did not work at first because, as the father pointed out, his shoes were insulated. The mother and boy were wearing sandals, though, so they were able to touch their feet skin-to-skin and make it work. They all linked hands and formed one big circuit, which brought smiles and laughter. The boys continued to try new hand placements and configurations, including seeing if just the lightest touch of fingertips would work.

Augmented Device – Family A6

This family included two girls, ages seven and nine, and their mother. The girls approached the device and looked at it, but waited. The mother asked if they were reading "what is says." The mother then read the interpretive panel aloud in its entirety. The girls proceeded to make contact with the device, completing the circuit, and triggering the augmentation. No comments about the projection were made. The mother asked what else they "have to do." The girls were very quiet, not responding to their mother's questions. The mother asked if they could think of other ways to make it work. She encouraged them to continue playing, but did not suggest any specific hand placements or ask probing questions. Their unhappy facial expressions seemed to suggest that they were treating the device as a chore or task that had to be accomplished, rather than an opportunity for playful learning. The girls tried crossing their arms, but were not successful. The younger girl tried using her forearms. The mother stood back, observed, commented, and questioned but never actually stepped in to help facilitate the learning experience.

Non-Augmented Device – Family NA7

This family included a 4-year-old girl, her 7-year-old brother, their mother and grandmother. The family approached the device together and the mother began by reading the graphic panel aloud. The boy jumped in before she had finished and completed the circuit. He got it right away and was delighted as evidenced by his big smile. He boisterously described what he saw happening. The girl was on the other side with the grandmother. She was participating but was silent and stoic. The mother took control and began directing play. The grandmother was playful but compliant, just following her daughter's lead. The mother figured out how all four could link hands to complete the circuit. She continued to suggest creative hand placements. The mother was clearly the leader and, as a result, the family was organized and achieved a lot of success with the device. After a while, the boy began to propose configurations and the family followed his lead. The mother seemed willing and happy to let her son take over as the leader. After her son succeeded in designing a complex configuration, the mother noted that they probably had both series and parallel circuits working there; this level of interpretation did not appear on the graphic panel, indicating that the mother had engaged her own prior knowledge about the topic. She provided an uncommon level of facilitation for her family that exceeded the capacity of the device and its interpretive content.

Augmented Device – Family A7

This family included two adult females, an 11-year-old girl, an 11-year-old boy, and an 8-year-old boy. One mother read the entire interpretive panel aloud before they began to do anything. The girl jumped in first, making contact, completing the circuit, and triggering the augmentation. The first mother seemed to be taking control, directing the hand placements, and explaining what was happening. The kids were all taking turns and succeeding individually. The second adult female suggested that they try to link three people together. The younger boy began to direct the action to accomplish that goal. The first mother continued to play the role of the leader or director, while the second mother was more involved hands-on, figuring out how they could all link themselves together to create one complete circuit successfully. They smiled and laughed when they succeeded. The digital projection adapted perfectly to their complex arrangement, yet the family never acknowledged it. As a final thought while walking away from the device, the second mother suggested that the Museum should add information to the interpretive panel to explain that it's actually two circuits. Interestingly, her own playful discovery had allowed her to deduce the circuitry yet she wanted to preempt that discovery by revealing the information on the panel for others.

Non-Augmented Device – Family NA8

This family included a 7-year-old girl, her 10-year-old brother, and their grandparents. After the family approached the device, the grandmother appeared to be reading the text to herself, but not aloud. The boy jumped right in, initiating contact, but the grandmother stopped to ask him if he had read “the directions.” The girl was on the opposite side and both children had success right away, expressing delight through big smiles. The grandfather commented that they were acting like wires and described what was happening, despite not yet having tried it for himself. The grandfather figured out that they should try holding hands and then the grandparents took over, directing various configurations. The boy also suggested configurations, and the family followed his lead. The grandmother pointed out the picture on the interpretive panel to call their attention to what was happening. She asked the girl if she could feel the electricity flowing through her. The girl was very quiet, but her eyes and facial expression seemed to suggest keen interest and delight. She became more vocal during the interview, happily reporting that the experience reminded her of devices she had seen “downstairs” in the Museum’s Electricity exhibit.

Augmented Device – Family A8

This family included an 11-year-old girl and her parents. Before he even touched the device, the father announced that “It’s going to show you how electricity passes through your body.” The mother initiated first contact, completed the circuit, triggered the augmentation, and announced that she “got flashing lights.” The girl succeeded and the mother reminded her that she already knows “how that works.” The father continued explaining what he saw happening, acting as a commentator, although only standing off to the side and not actually interacting with the device himself. The girl invited her mother to link hands with her and figured out how to complete the circuit. The father watched them work together and pointed out the pathways. The girl was very playful while the mother continued to direct play. At one point, the mother mentioned the sweat on her hands, reminding the girl that "we know about water and electricity." The father explained that electricity has to pass through the body and it "needs an in and an out." In the interview, he was able to recall the contents of the interpretive panel, although he actually went far beyond it in his sideline commentary, clearly referencing his own prior knowledge of electricity, conductivity, and circuitry. When asked what was on the interpretive panel, he was able to describe the diagram in detail. His description of the interpretive diagram prompted his wife to ask, "There was a picture?" She then explained that, "Once I get to the doing, I forget what I read anyway."

Non-Augmented Device – Family NA9

This family included a 10-year-old girl, her 20-year-old sister, and their mother. All three approached the device together, but stood back while the mother read the graphic panel aloud before anyone touched the device. The older girl went first, placing her hands on the balls and completing the circuit. The younger girl was very hesitant. The mother and the older girl started working together, trying configurations. The mother was explaining and leading, suggesting placements and noticing what was happening, calling attention to the circuits. The younger girl still had not engaged, but finally tried it after her sister invited her to join in. She barely touched it and then stepped back again. The older girl noticed patterns and wondered about how the device was working. She noted that the electricity was going through their bodies. They never figured out how to link hands to extend the circuit. They acted primarily as three individuals, taking turns at the device.

Augmented Device – Family A9

This family included a 7-year-old boy, his 9-year-old sister, and their mother. The girl jumped right in, completed the circuit, and triggered the augmentation. She did not appear to read the interpretive content, but actually remembered a lot of what it said when interviewed. The mother appeared to read the graphic panel, but not aloud. The girl took the lead and organized the interaction. She directed the boy to join her configuration. The mother asked the kids if they could feel the electricity flowing through them. The kids did not respond and seemed slightly perplexed. The mother pressed, asking again if they could “feel the tickling.” The girl agreed that, yes, she could feel it. Later, in the interview, though, the girl disagreed with her mother that there was anything coming from the device that they could feel. The boy linked hands with his mother while the girl tried to have all three of them work together. The girl described what she saw happening. The boy participated fully, but was very quiet and stoic. The mother’s insistence that she could feel electrical impulses seemed to short-circuit the family’s interaction with the device. The children seemed unwilling to argue with her, but they knew that they were not feeling anything. Interestingly, they could have been discussing that they *saw* when the augmentation was triggered, but they never did. Instead, they wasted their time seeking a rationale for the mother’s phantom tingling sensation.

Non-Augmented Device – Family NA10

This family included two 8-year-old boys and their mother. One boy jumped right in and initiated contact with the device, while the other boy was a bit more tentative. The mother suggested that they read the panel and see what it said to do. She asked the first boy to read it aloud, which he did entirely. Meanwhile, the second boy was silently playing on the other side. The mother began asking questions and calling attention to the positive and negative poles on the battery. The first boy described what he was doing and explained how he thought the circuit worked. He and his mother interacted playfully while his brother was more quiet, working independently. The mother began to engage him, though, mentioning that she couldn't quite recall if the electricity flows out of the negative or positive pole. He volunteered that he thought it should be the positive pole. The mother was designing and suggesting creative hand placements, organizing the group. They tried many interesting configurations but never actually tried linking hands. The first boy noted the interpretive content and suggested that maybe the battery had weakened as an explanation for why they hadn't succeeded. (While this was a creative suggestion, it was not the cause. The device is not actually powered by the battery that is on display.) The mother commented that she thought that they were not accomplishing the two-person goal. She was correct; they never correctly figured out how to link hands to complete one circuit, although they certainly tried.

Augmented Device – Family A10

This family included an 11-year-old boy and his parents. The boy read the label aloud in its entirety before any of them touched anything. The boy took control, announcing that he had an idea. He linked hands with his mother and succeeded, completing the circuit and triggering the augmentation. The mother looked up for the source of the projection. The boy was directing the interaction, and instructing his parents what to do next. The father explained that the device is actually two circuits. The mother followed the boy's lead. He explained that the electricity was flowing through their bodies. He acted as facilitator and commentator for the group, responsible for nearly all of the discourse. He called his father over to join them and the three of them formed a complete circuit to which the projected animation smoothly adapted. The boy happily exclaimed, "Yay! Family glow!" The boy continued to act as the leader during the interview. When his mother mistakenly said that the intent was to complete the circle, he promptly corrected her, saying "complete the circuit, not circle."

Summary

The families who encountered "Be the Path" in The Testing Zone were enthusiastic and eager. Without exception, they wanted to "do the right thing," both to please the researcher and to derive the best possible experience from the device. In some cases, however, knowing the "right thing to do" was not easy. These ethnographic descriptions, when taken as a whole, offer a challenging portrait of the need for improved informal science learning experiences. Serving the needs of an unpredictable population on a day-to-day basis has never been easy, but the current crisis demands that informal educators find solutions that maximize the potential for all experiences to contribute to overcoming the science learning deficit. The findings presented in Chapter 4 showed that augmented reality technology did facilitate slightly improved informal science experiences for the participating families, suggesting that the technology may be a strategic response.