ABSTRACT

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	Leslie Eugene Chipman, II Doctor of Philosophy, 2007
Directed By:	Associate Professor Allison Druin, Department of Computer Science and College of Information Studies

Children participating in classroom field trips learn first hand in an authentic context. However, activities during these trips are often limited to observation and data collection. Children synthesize their knowledge later, in classroom discussions and in the collaborative construction of a representational artifact. But the classroom is removed from the authentic context in which the knowledge was gained. My research investigated how mobile technology can bridge this gap by supporting and encouraging young children (grades K-4) to collaboratively construct knowledge artifacts, while simultaneously exploring open, educational environments. Three key elements are addressed; creating a concrete connection between digital information and the real world, supporting awareness of collaborative opportunities in an open environment, and promoting face-to-face collaboration.

This dissertation details the conception, design, implementation, and evaluation of the *Tangible Flags* technology; a tangible interface that is developmentally appropriate for children (grades K-4) to embed and access digital information through their physical environment and multi-user tools that support collaboration in open environments. Tangible Flags are simple for children to attach to the environment and promote an awareness of artifact creation and exploration activities because they are visually apparent. An interface that provides an awareness of changes to digital artifacts and enables concurrent and remote access to these artifacts further enhances collaboration.

Two studies were conducted to evaluate the concepts of Tangible Flags. A case study was conducted in an authentic outdoor learning environment, a National Park. A second study compares children's use of the Tangible Flags technology to a roughly equivalent paper system. Quantitative and qualitative analysis indicates that children using Tangible Flags participated in more asynchronous collaborative activity and were more engaged than those who did not. It also showed that awareness of peer activity combined with remote and concurrent access to digital artifacts resulted in increased face-to-face collaborative activity and examines the impact of artifact awareness and access on children's focus on the environment. These contributions will be useful to educators, designers of educational environments and researchers in the field of children's educational technology.

COLLABORATIVE TECHNOLOGY FOR YOUNG CHILDREN'S OUTDOOR EDUCATION

By

Leslie Eugene Chipman, II

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Advisory Committee:
Associate Professor Allison Druin, Chair
Associate Professor Benjamin Bederson
Professor Amitabh Varshney
Professor Emeritus Stanley Bennett
Assistant Professor Kenneth Fleischmann

Dedication

This dissertation is dedicated to my daughters, Sarah and Jocelyn, who are my primary source of inspiration.

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Motivation

Field trips give children opportunities to explore within an authentic context. There are many environments outside the classroom that can be meaningful to the context of children's learning. These include outdoors locations such as gardens, zoos, and historic sites, and natural environments such as forests, streams, and, of course, fields. These are open environments where active, mobile exploration and learning can involve significant movement by the children. A popular educational activity to enhance the learning experience of a field trip is to encourage children to observe and take notes while they explore their surrounding environment. This is followed by classroom activities where the children work together to create reports, posters or other representational artifacts using the knowledge they gained during the context of the immersive learning experience. However, this activity is limited because more detailed explorations of the physical environment cannot be replicated in the classroom. There is a disjunction in time and space, between the exploration experience and the synthesis and representation of the knowledge. As a result, opportunities are lost for direct, iterative interactions in the physical learning space that combine collaboration in an authentic context [Lave and Wenger, 1991] with construction of explicit representations [Papert, 1980], i.e. knowledge artifacts.

Mobile technology has the potential to bridge the gap between children's exploration during field trips and their collaborative creation of knowledge artifacts. Today's children are growing up in an environment where technology is becoming more pervasive everyday and a broader variety of users, including children, have access to wireless, mobile computing devices. Industry is increasingly researching [Oosterholt et al., 1996] and marketing portable devices targeted at children, such as Pixter [www.fisher-price.com], iPod [http://www.apple.com/ipod/ipod.html], Leap Pad [http://www.leapfrog.com], GameBoy [www.gameboy.com], and even cell phones [www.kajeet.com]. In research using participatory design with children to define issues of technology important to them, the key issue of the mobility of technology was identified [Inkpen, 1999].

Adults use portable computers, digital cameras, and cell phones to manage and enhance their everyday lives. Mobile technology can enable users to collaborate and to collect and create information, while retaining freedom of movement, bringing computer support to a wider range of environments [Luff and Heath, 1998; Feiner, 1999; Cole and Stanton, 2003]. But mobile technology has a far greater potential to impact how our children learn and play [Soloway et al., 2001; Roschelle and Pea, 2002]. It is therefore imperative to understand how mobile technology can be used to help children to learn and improve their lives. Computer supported collaborative learning (CSCL) is a recent research field that aims to support learners working as a group on a common task by investigating how tools can bring learners together and support learning together effectively [Marshall et al., 2003]. CSCL researchers have recognized the need for adapting mobile technology to CSCL for children [Soloway et al., 2001]. However, there is a lack of research in the CSCL community on learning environments that make use of mobile technologies to support *learning by experiencing, collaborating, and creating artifacts at the same time* [Rogers and Price, 2004]. Designing tools for children to create and share knowledge artifacts in the authentic context of an outdoor environment is an important step in using mobile technology to enhance learning.

1.2 Research Goals

The goal of my research was to investigate the role of technology in supporting and encouraging young children (grades K-4) to collaboratively construct knowledge artifacts, while simultaneously exploring open, hands-on, educational environments. A gap exists in current practice between the explorations that occur in the authentic context of these learning environments and the collaborative creation of artifacts to represent that environment. The learning theories and research discussed in Chapter 2 suggest that cognitive benefits could be gained by enabling both learning effects simultaneously. Based on this literature and my initial formative research detailed in Chapter 3, I directed my thesis research to address three key elements of my overall goal. These were places where I felt had technology had the most promise to positively influence children's cognition and learning behaviors.

1.2.1 Connecting Representational Artifacts with the Real World

One of the strongest cognitive benefits for young children may come from aiding them in relating their ideas to the real world. Researchers have noted the educational merits of using wireless devices to augment or amplify existing physical space with information exchanges [Roschelle and Pea, 2002], which suggests that children could embed knowledge artifacts in the physical environment. As will be established in Chapter 2, children in grades K-4 have the most potential to benefit from such support. Mobile technology can enable children to create digital artifacts while exploring a physical environment, for instance, by using an application on a handheld computer. Children can iteratively view and edit their artifacts while interacting with an authentic environment, enhancing the learning experience. Yet, how can children create a link between digital artifacts and the environment?

The first goal of my research was to devise an interaction paradigm that was developmentally appropriate for young children to establish a simple and concrete connection between their digital artifacts and the physical environment. This interaction needed to be usable by children for both embedding and accessing digital artifacts. Software tools based on this paradigm would enable children to easily create and link digital artifacts with the physical space.

1.2.2 Supporting Collaborative Activity in Open Environments

A young child's learning experiences need to include collaborative activity [Lave and Wenger, 1991; Slavin, 1996]. Children can benefit from collaboration during both exploration of a learning environment and creation of artifacts to represent their knowledge. Mobile technology that is to support artifact creation during exploration should also enable children to collaborate in both of these aspects. Yet, the very open, mobile, exploratory nature of a field trip will have an impact on children's collaborative activities. Children may explore independently or in small groups that do not always have visual or verbal contact with others, reducing their awareness of other children's artifact creation or exploration activities and effectively limiting opportunities for collaboration. I felt improved awareness combined with support for asynchronous or remote collaboration could increase children's collaborative activity.

The second goal of my research was to develop an appropriate set of software tools for children to asynchronously discover, access, and annotate each other's artifacts. I wanted these tools to be closely coupled with the interaction used for linking artifacts with the environments. Children should in effect use the same tools whether they were creating and linking an artifact, or accessing and annotating someone else's. Part of the research was to determine how these tools could effectively support both asynchronous and remote collaboration. A key component in the design of these tools was the need to support awareness. This included promoting an awareness of where other children have explored and embedded artifacts in the physical environment, of the changes to such artifacts, and other children's desire to initiate synchronous collaborative activity.

1.2.3 Face-to-Face Collaborative Activity in Open Environments

Research has shown the importance of face-to-face social interaction in achieving children's collaborative learning [Davidson, 1985; Johnson and Johnson, 1994; Scott et al., 2003]. The learning benefits of face-to-face collaboration on a knowledge artifact might be further enhanced when such collaboration occurs in a relevant location. Children are then situated to iteratively collaborate in both their exploration of the environment and their creation of a representation. Yet children's exploration and artifact creation activities may begin independently and their collaborative efforts may diverge into further individual explorations. There is a need integrate individual activity into joint activity.

The third goal of my research was extend tools for asynchronous and remote collaboration to promote face-to-face collaboration. A first piece of this was to explore software interfaces that could help bring children working independently into face-to-face contact, especially at the location of an embedded knowledge artifact. A second piece was to develop these interfaces such that children could seamlessly switch between individual and group efforts and integrate their work into a joint knowledge artifact. Again, supporting awareness of peer activity would be critical.

1.3 Research Contributions

This dissertation provides contributions to fields of knowledge concerned with children's education and the research and design of children's technology. It is specifically geared to children's collaboration and learning in outdoor or open environments, though some portions apply more generally to the design of children's software interfaces, especially collaborative software. It details the conception, design, implementation, and evaluation of the *Tangible Flags* technology; a tangible interface that is developmentally appropriate for children to embed and access digital information through their physical environment and the extension of multi-user tools that support collaboration in open environments where children are mobile and the learning context resides in the real world as much as it does the computer.

Figure 1. A photograph of children using the Tangible Flags technology.

The chapters of this dissertation proceed as follows:

1. Chapter 1 establishes the motivation and goals of this research.

2. Chapter 2 is a detailed discussion of relevant research literature organized into four broad topics. This provides a consolidated repository of sources that researchers interested in the field can reference.

3. Chapter 3 starts with examples of using Cooperative Inquiry [Druin, 1999], a design process for developing children's technology by working with children. The resulting design concepts and iterative developments are

discussed, followed by the technical details of a prototype, dubbed Tangible Flags. This chapter will be beneficial to anyone wishing to work with children as design partners and also provides designers with examples of the hardware and software implementation of the design concepts.

4. Chapter 4 is a description of a case study where children used Tangible Flags in the authentic environment of a national park.

5. Chapter 5 is a description of a study that compared Tangible Flags with an alternate, non-technology system. Both studies analyze children's activity patterns in open, learning environments and may interest educators and designers of children's technology. The studies also provide insight into the benefits and issues of the design concepts behind Tangible Flags.

6. Chapter 6 generalizes the results of the studies, so that researchers and designers may apply the lessons of my research to broader problems in the field.

7. Chapter 7 provides a variety of additional research ideas that occurred during the development of Tangible Flags, but were beyond the scope of my immediate thesis, which was primarily focused on establishing the basic design concepts. Future work aimed at realizing these design concepts into a robust educational tool would need to extend research and design to the areas detailed in this chapter.

Chapter 2: Related Work

This literature review covers four broad areas. The first section covers child development and learning theory, which provides the foundations for designing educational technology. The second section describes research into integrating computers with the real world directed towards adult users and the benefits of doing so. It suggests some approaches to connecting the digital domain with the physical world that may be applicable to children. The third section describes research into older children's (ages 12 and up) learning technology and the fourth section the same for younger children (under age 12). This establishes the research that has been done, how it is applicable to open learning environments, and areas that are not fully addressed.

It will be seen that previous research has demonstrated tools for young children to collaborative construct artifacts, the suitability of tangible interfaces for young children's devices, and the importance of mobility and physicality in fostering collaboration. However, no research has built onto this support of collaborative artifact creation by adding mechanisms for young children to relate their artifacts to real world environments. Learning theory shows that this is cognitively and developmentally appropriate and could enhance the hands-on learning experiences in such environments. Research into adult applications has demonstrated the benefits of embedding digital artifacts in the real world to support collaboration and suggests approaches to doing so for children. Research for older children has demonstrated the potential learning benefits of supporting collaboration in knowledge artifact creation during exploration of open environments. My research brings all of these together for young children.

2.1 Child Development and Learning Theory

This section details child development and learning theory in three general categories: representation of knowledge, the benefits of collaboration, and the importance of learning in context.

2.1.1 Concrete Representation of Knowledge

Children make rapid advances in language and sign use during preschool [Piaget, 1977a] and have begun to develop symbolic thinking by the time they enter grade school [Flavell, 1985]. Research indicates that by early grades, children are able to construct and use self-made symbolic representations of real life objects or situations [van Oers and Wardekker, 1999]. Around kindergarten or first grade, they begin to understand functional relationships, yet may have difficulty with abstract concepts because much of their cognition is tied to concrete experience. During the early grades, children tend to translate abstractions into specific examples that are related to their experience [Piaget, 1977b]. A critical factor for aiding children in construction of internal mental representations may be providing approaches that make concepts simple and concrete [Papert, 1980]. Children in grades K-4 are capable of creating knowledge artifacts and have much to gain in relating their representational artifacts to their experiences in a concrete form.

Representation is an important part of learning. Learners actively construct and reconstruct knowledge out of their experiences in the world. Constructionism suggests that learning is enhanced in a context where the learner is creating an explicit representation, or as Papert calls it, a 'public entity' [Papert, 1991]. Learners are more likely to become intellectually engaged when creating personally meaningful artifacts. The concept that artifacts can mediate human thought is central to activity theory. Activity theory attempts to describe the relationships between humans and objects in the environment and how these relationships are mediated by tools, signs and cultural means [Leontiev, 1978]. When applying activity theory to the design of educational technology, Bellamy suggests we should enable children to design new artifacts and give children experience evolving their culture by constructing artifacts and sharing them with their community [Bellamy, 1996]. Research shows that young children can engage in representational activity by making schematic representations as a part of their play activity or play objects [Venger, 1986]. Schematic representations can include drawing, telling stories, play-acting, and construction with tangible objects (blocks, art supplies, etc.). For children it is especially important to include multiple forms and extend representations beyond the verbal and visual [John-Steiner and Mahn, 1996]. This body of research indicates both the ability of young children to create artifacts that represent their understanding of the real world and the importance of supporting them in their efforts. It also indicates in importance of adding other dimensions, such as physicality, to these representations.

2.1.2 Collaboration

Collaboration is a vital part of learning [Lave and Wenger, 1991]. Vygotsky's sociocultural theory emphasizes that social interaction and cultural influence play a fundamental role in the development of cognition and cannot be separated from the process of cognition [Vygotsky, 1978]. Research provides empirical support for the cognitive perspective that interactions among children improve the cognitive process, which aids in grasping the critical concepts [Slavin, 1996]. Cognitive psychology research indicates that for information to be retained and related to other knowledge, the learner must engage in cognitive restructuring of the material. Elaborating on the material in order explain to another is an effective means to restructure knowledge [Slavin, 1996]. The collaborative construction of an explicit representation can provide a focus for this elaboration [Scaife and Rogers, 1996]. Young children also become more capable of effective collaboration around the age range of 5-7 [Wood et al., 1995]. In one field study, a majority of children ages 7-11 preferred to work in a group, and when seeking help with a problem, consulting friends was their first preference [Scott et al., 2003]. Children grades K-4 can engage in collaborative activity and collaborating on the creation of knowledge artifacts can enhance children's opportunities to learn.

Children in an open, exploratory environment may not work together collaboratively all the time, even when assigned to pairs or teams. Their collaborative groups can be a fluid and rapidly changing structure, adding and losing members as different things interest a particular child or social dynamics affect collaborative structure. Theories of collaborative learning do not exclude personal exploration and understanding [Driver et al., 1994; Salomon and Perkins, 1998; Stahl, 2000]. However, research has shown the importance of face-to-face social interaction in achieving children's collaborative learning [Davidson, 1985; Johnson and Johnson, 1994; Scott et al., 2003]. In open learning environments, children typically remain in a relatively close area that allows them the potential to participate in face-to-face collaboration. This suggests that tools for children to collaborate in such environments need to support both individual and collaborative activities, especially face-to-face collaboration. If face-to-face collaboration can be guided to occur at locations in the environment that are relevant to the collaborative learning activity, an additional learning benefit may be realized because the children would then be situated to iteratively collaborate while investigating the environment directly. Yet, children in open environments may have limited contact with their peers and reduced awareness of other's activities while engaged in exploration or artifact creation. Awareness can provide a context for their own activity and has been identified as a key element of supporting collaboration [Dourish and Bellotti, 1992], especially for mobile users [Bellotti and Bly, 1996]. Children in grades K-4 can collaborate effectively, but technology that is to support them needs to enable collaboration, especially face-to-face collaboration, and provide awareness of collaborative opportunities and peer activities. In addition, a design for collaborative support in open learning environments should accommodate both individual and collaborative activities and enable children to easily switch between the two.

2.1.3 Context

Context is an inherent part of psychological development and is closely coupled with behavior. A person's knowledge or ability is not independent of context; it is the combination of person and context that results in competence [Fischer et al., 1993]. Research has thoroughly demonstrated that children exhibit far more advanced memory skills when operating in a meaningful context [Bauer and Mandler, 1990]. Situated learning theory states that learning normally occurs as a function of the activity, context and culture in which it occurs, i.e., is situated [Lave and Wenger, 1991]. Social interaction is a critical component of situated learning as learners become involved in a "community of practice" and this learning is usually unintentional rather than deliberate. This research indicates that knowledge needs to be represented in context and learning requires social activity and collaboration.

Learning in context is often taken to mean cognitive development set within the context of cultural settings and social processes, as the child is immersed in society. Yet, spatial environment is also a vital part of context in a child's cognitive development [Downs and Liben, 1993]. Social interaction and physical space both play roles in a child's learning. Enabling children to collaborate on the construction of knowledge artifacts represented in the context of a physical learning space can bring together all the learning benefits of construction, representation, collaboration and authentic context.

2.2 Integrating Computers with the Physical World for Adults

This section describes adult user oriented research that links digital information and computation with physical space and the real world.

2.2.1 Augmenting the Real World

Research into augmented reality includes tools that enable users to access digital artifacts that are embedded in physical spaces. One way in which digital artifacts are presented to users is with a see through head mounted display [Feiner et al., 1993; Höllerer et al., 1999]. The display allows digital information to be overlaid with the user's view of the physical world, providing a very clear connection between the digital artifact and the physical world. However, this seems ill suited for younger children as the equipment necessary is currently heavy, bulky, costly, and not designed for use by children. Yet this pioneering work has indicated the benefits of embedding digital information in the context of the physical world. More portable approaches have been used to present digital artifacts in context for tour and museum guides [Abowd et al., 1997; Zimmermann and Lorenz, 2003; Hsi, 2004]. These systems provide information to the user with audio in a headset or with visual display on a portable computer. These approaches are more ergonomically suited to children. This technology is beginning to impact everyday life, such as using camera capable cell phones to provide adults with everyday access to digital artifacts embedded in the real world [The Economist, March 10, 2005]. This extensive body of research has demonstrated that embedding content in the appropriate context enhances the value of the information as well as augmenting the real environment. Yet these tools address only the presentation of digital artifacts, not their creation.

Tools for annotating the real world with digital artifacts can enable users to exchange information though the context of the physical space [Rekimoto and Nagao, 1995; Rekimoto et al., 1998; Cheverst et al., 2000; Burrell and Gay, 2002; Pinelle and Gutwin, 2003]. This demonstrates that these tools need not be limited to imparting pre-generated content or measurements of real world data to the user. The research suggests the benefits of user authoring and embedding of pertinent information in an appropriate context, which provides a medium relevant to collaborative activity. However, this research assumes an adult's cognitive ability to correlate digital information presented on a portable device with the real world context. It is not clear from this research what developmentally appropriate approach can help young children correlate digital artifacts with the real, physical environment.

2.2.2 Tangible Interfaces

Yet other research suggests an approach that may be appropriate. Adult research into tangible user interfaces [Ishii and Ullmer, 1997] has demonstrated their use for authoring web sites [Klemmer et al., 2001], video presentations [Nelson et al., 1999] and storytelling [Mazalek et al., 2002]. This suggests their suitability for the creative process of authoring. Tangible interfaces have been shown to be useful for organizing relations between artifacts for tasks related to thinking about information in order to synthesis it [Patten and Ishii, 2000]. This research has shown tangible interfaces to be more effective in supporting recall of information during such thinking processes. Research on tangible interfaces for children will be detailed in the next sections.

2.3 Technology for Older Children's Learning

There has been a fair amount of research on classroom tools that support children in construction and sharing of knowledge artifacts [Pea, 1993; Scardamalia and Bereiter, 1994; Loh et al., 1998]. This research focuses on the students' project work in the classroom, where they organize their findings and create records of their knowledge collaboratively using desktop computers and the Internet. It has demonstrated the learning benefits of supporting collaborative construction of knowledge artifacts. However, such tools are restricted to a classroom or computer lab and the research has been aimed at older students (grades 6 and up). The rest of the research described in this section focuses specifically on tools to support older children (ages 12 and up) in open learning environments.

2.3.1 Mobile Devices to Support Learning in Context

The use of mobile technology for supporting children's field trips was first investigated with the Wireless Coyote project [Grant, 1993]. A class of 6^{th} graders and their teachers on a field trip to the desert were equipped with traditional instruments for measuring scientific data, walkie-talkies and wireless computers. The teams operated in different locations and used the mobile technology to collaborate on their findings. Analyzing the data immediately, in context, gave the abstract numbers meaning and when teams shared the data gathered at their location via the wireless computers, on the spot collaboration prompted them to reflect on their analysis and investigate further. This study demonstrated that even simple technology can encourage children to reflect on their analyses and lead to more detailed investigations. Since then, mobile technology for data collection on field trips has been demonstrated to promote inquiry [Rieger and Gay, 1997; Parr et al., 2002; Slotta et al., 2002], particularly for science education. Building on these, Probeware [Soloway et al., 2001; Metcalf and Tinker, 2004] integrates the measuring and data recording processes and automatically places the data into a visualization application in real-time. These tools simplify inquiry and make more transparent the effects of dynamic phenomenon by relating abstract information to the real world during outdoor explorations. This research has shown how technology can support learning in open environments and indicates learning of abstract concepts can benefits from a more direct relation to the real world. It has been geared towards later grades (grades 5 and up) and does not address the need to more fully support collaboration while on field trips.

2.3.2 Digital Augmentation for Learning

The Ambient Wood project investigates older (ages 11 and 12) children's collaboration during exploration of outdoor learning environments [http://www.cogs.susx.ac.uk/interact]. This research demonstrated that enabling collaboration in context encouraged a more diverse set of interactions. The children were equipped with tools for investigating their environment that required overt action to use and making the actions of an individual obvious promoted awareness of activity amongst the collaborators [Price et al., 2003]. This research used digital augmentation of the physical space to promote collaboration, reflection and hypothesizing. In addition, use of a physical interface helped make the children's engagement with the digital representation more direct [Marshall et al., 2003]. Enabling children to initiate inquiry was more effective than automated presentation of information [Rogers et al., 2004]. This research showed the importance of enabling collaboration in context to promote reflection as well as the effectiveness of digitally augmenting of the physical environment. Yet it also suggests that embedding pre-generated content in the environment has limited power as a learning resource [Rogers et al., 2004]. Enabling children to create their own artifacts could be much more powerful.

2.3.3 Mobile Devices to Support Collaborative Learning

Participatory simulations have been used to relate abstract concepts to real world experience. Wearing digital devices that react to the environment, participants learn more about a phenomenon by acting out a simulation, making the learners' experience of the abstract concept more visceral and meaningful [Colella, 2000]. Participatory simulation to investigate collaborative activities for children (grades 5 to 7) encouraged increased cooperation and collaborative discussion about how best to achieve the goals of the simulation [Danesh et al., 2001]. Distributing the simulation information across multiple portable devices supported collaboration in a mobile environment and took advantage of rich face-to-face interactions [Mandryk et al., 2001]. This research demonstrated the importance of supporting both individual and face-to-face collaborative processes to help children to synthesize information and create a dynamic and engaging learning environment. While participatory simulations can support collaboration and encourage exploration, research into participatory simulation has not addressed the creation of artifacts.

The HyCon Explorer project [Bouvin et al., 2005] addresses the need for children (grades 6 and 7) to produce their own material related to the learning activity by linking child authored contextual information to the environment. Global Positioning System (GPS) is used to present this information to children on mobile devices when they move to the appropriate location in the environment, but no link outside the digital realm is used. Other such research using GPS and linkage based on location only has demonstrated the difficulty children (ages 9 to 12) may have in correlating information presented on a mobile devices with their explorations of a physical environment [Benford et al., 2005]. This illustrates the need for direct methods for connecting digital information with the real world even for older children, who are developmentally more capable of abstract concepts than younger children.

2.4 Technology for Younger Children's Learning

This section describes research into learning technology that supports younger children (under age 12), indicating the importance of collaboration, mobility and tangible interfaces.

2.4.1 Supporting Collaboration

A couple of tools have supported young children's (age 5 to 7) concurrent and face-to-face collaborative artifact creation at a desktop computer using a single display [Fahlen et al., 1993; Druin et al., 1997; Benford et al., 2000]. But this collaborative activity is restricted to a jointly shared computer. Research into children's (age 9 to 11) collaborative interactions indicates that children participate more when they are provided with concurrent multi-user interaction [Scott et al., 2003]. But this research also suggests that a lack of physical activity may negatively impact the overall effectiveness of collaborative activity, indicating the value mobility and a physical environment has in supporting collaboration. Research has demonstrated the use of concurrent interaction with mobile computers can support young children's (grade 1) face-to-face collaboration [Zurita et al., 2003], but did not address artifact creation, only problem solving.

2.4.2 Mobility and Tangible Interfaces

Research with younger children (grades K-4) that supports artifact creation through drawing and storytelling has demonstrated the importance of mobility and tangible interfaces in fostering collaboration. In KidStory, each child used their own handheld to draw pictures, which were then uploaded to a large screen and made available to the whole group [Cole and Stanton, 2003]. As a group, the children could use all the pictures to create a story. Being able to move around while drawing their individual pictures enabled children to look at each other's pictures and discuss their efforts. This use of multi-user interaction on mobile devices allowed the children to switch smoothly between individual, small group and large group activity. Storyrooms is a physically interactive environment that provides children the ability to tell stories using objects that are computationally enhanced but physically familiar [Montemayor et al., 2004]. Storyrooms gives children the power to shape their own storytelling experience, which encourages collaboration as the children work together to create a story and to construct concrete representations by making props for their story. Storyrooms demonstrated that a tangible interface and mobility in a physical space was effective at enabling children to collaborate in the creation of an artifact

[Montemayor et al., 2002]. These technologies center on story telling and have been designed for indoor use. A later study based on the Storyrooms technology compares a computer desktop interface to a physically interactive interface for kindergarten children's learning [Fails et al., 2005]. This study and other research [Resnick et al., 1998; Stanton et al., 2001; Sluis et al., 2004] has demonstrated that the physicality of tangible interactions is especially well suited to younger children. Research has investigated tools to support young children in their collaborative efforts to construct artifacts. This research has demonstrated the suitability of tangible interfaces for children's devices and the importance of mobility and physicality in fostering collaboration. However, no research has built onto this support of collaborative artifact creation by adding mechanisms for children to relate digital knowledge artifacts to real world environments.

Chapter 3: Tangible Flags Design

The first section of this chapter describes formative research in developing a mobile technology to support children's field trips: the research process, observations of field trips, and design sessions. The second section details the design concepts that resulted from this formative research. The third section describes the hardware and software of the Tangible Flags technology, an implementation that incorporated those design concepts.

3.1 Formative Research

My formative research is based on *Cooperative Inquiry*, a research process for co-designing children's technology developed over the years by our team at the University of Maryland, led by my committee chair, Dr. Allison Druin [Druin, 1999]. This research consisted of both observations of children on field trips as well as design sessions with children.

3.1.1 Cooperative Inquiry

Cooperative Inquiry is based on the philosophy that children can and should be active design partners in developing technology for children. It is a research method that has adapted ideas from participatory design and contextual inquiry to meet the unique challenges of working with children [Druin 1999]. Child and adults partner together as members of an intergenerational design team to observe technology used by children and capture activity patterns, using sticky notes, drawing or writing in journals. Brainstorming processes start with sketching ideas to create mock-up prototypes using child friendly art supplies, and then proceed to developing and evaluating increasingly technological prototypes. The iterative process used in Cooperative Inquiry with both children and adults yields an in-depth understanding of how technology can improve the lives of children. During the course of my doctorate research, I have made several contributions to Cooperative Inquiry methods for working with younger children [Farber et al., 2002; Guha et al. 2004; Guha et al., 2005].

3.1.2 Field Trip Observations

My formative research began with observations of several classroom field trips. This includes a personal experience as a parent participating in a field trip to a woodland stream with a class of 4th grade children. It also includes several field trips with an intergenerational design team consisting of adult researchers from Dr. Allison Druin's Classroom of the Future project [http://www.cs.umd.edu/hcil/kiddesign/cof.shtml] and a class of kindergarteners at the Center for Young Children, University of Maryland's on campus research pre-school [http://www.education.umd.edu/CYC/]. The Classroom of the Future researchers accompanied the parents, teachers and children on the trips to videotape, ask questions and take notes.

3.1.2.1 Fourth Grade Field Trip

The 4th grade class went to explore a forest stream while their class was studying ecology. Children worked together groups at the assigned task of collecting and classifying the stream fauna. The groups separated up and down the stream and with seven groups participating, the class ended up spread over a distance approaching 1000 feet. In a forested area, this meant that the children could not readily see or talk to more than a handful of their classmates. On numerous occasions, a child or two from a group would go up or down the stream to visit to the site of another group's discovery. Due to the collaboration with others beyond their immediate group, children had opportunities to view discoveries made outside their group, such as the rare and exciting find of a crayfish. However, some children missed these opportunities due to a limited or complete lack of awareness of the discovery. On one occasion, after one child discovered a frog, other children started searching for frogs both individually and in small groups. These groups formed as a function of the children's social interaction and changed dynamically. The original discoverer was asked questions such as: "Where did you find it?", "Can you help me find one?", and "How did you find it?". The reply to the last question was "By looking for bubbles in the pool". The children's natural and unstructured interaction resulted in knowledge being shared and served to help refine their understanding of frogs and focus their continued investigations. However, children were not always aware of the efforts of others during this impromptu group discovery and did not always share knowledge effectively.

3.1.2.2 Kindergarten Field Trips

The first trip was to a nature center. The nature center had static displays, a few live animals, and included a tour and presentation by the staff. During this trip, each group of children was given a pen and a clipboard with a couple questions to answer. The groups stayed together during the tour and presentation. The children almost uniformly failed to complete the questionnaire at the nature center and the questions were often prompted and answers recorded by the parents and teachers. Limited reading ability may have affected the children's interest in questionnaires. The second trip was to an aviation museum. The trip involved exploration with no tour guide and many hands on activities. Each child was given a clipboard and pen and asked if they could find and draw something that they had studied in class. Each group was allowed to explore independent of the other groups for the entire hour. The children took more initiative to draw at the aviation museum than at the nature center. The third trip was to a public airport observation area that gave an overview of airport operation and included static displays related to aviation. There was no staff or official tour. The children were each given pens and small notebooks. The children explored the observation area in small groups and were asked to draw things that interested them in their notebooks. There were cases of children sitting side by side and drawing while occasionally inspecting the other child's drawing or discussing their drawings. In some cases the children were each drawing their own picture of same real world object. However, children did not work on the same artifact together, neither simultaneously working on the same page, or trading a notebook back and forth to annotate the same drawing.

3.1.2.3 Discussion of Observations

These observations prompted several basic ideas how mobile technology could support children's field trips:

- Sharing discoveries was an important part of group learning experiences. Technology could support children in sharing each other's discovery experiences by making information exchanges available through digital artifacts embedded in the environment. Children could leave behind details of discoveries for their peers to learn from at a later time. From this, other children could gain knowledge to further their own exploration or repeat a discovery by themselves.

- Dynamic social interaction is an important part of group learning experiences. Technology could provide awareness of peer activity during independent exploration. More awareness could increase communication, supporting group learning by enabling children to share ideas broadly and effectively.

- Children worked side-by-side, asking their peers questions and giving feedback, even while creating individual artifacts. Collaboration on a joint artifact could focus this interaction and enhance learning.

3.1.3 Design Sessions

To develop my basic ideas further, the Classroom of the Future research group worked with two intergenerational design teams; a group of six children, age 6-10, who joined us in our lab after school twice a week, and the kindergarten class from the Center for Young Children who had participated in the field trip observations. Design sessions included mock field trips where children worked individually or in teams to find outdoor objects, such as leaves or animal nests, and create descriptive artifacts. They then marked the environment so others could discover and annotate the corresponding artifact. The goal was to understand how children could embed artifacts into the environment and its impact on their creative processes and collaborative efforts. The children created their artifacts using various media, such as audio and video recordings, or writing notes and drawing pictures with collaborative drawing software called Kidpad [Druin et al., 1997; Benford et al., 2000]. The environment was marked with flags consisting of a pipe cleaner attached to a Popsicle stick (see Figure 2). I named these *Tangible Flags* because the children planted them like flags and they were used as a mock tangible interface for accessing artifacts. These initial flags were not computationally enhanced; so adult researchers helped the children correlate the flags with the artifacts.

Figure 2. Popsicle stick flag attached to a water bottle.

Mock field trips were followed up with brainstorming activities to develop interface ideas and additional features. These design sessions informed my research in several important ways.

- **Awareness during exploration -** Flags influenced how the children explored on numerous occasions. They made decisions on where to explore based on the existing placement of flags, both their own flags and the flags of others, e.g., exploring or not exploring an area because they could see who had already been there. This illustrated the importance of this awareness and indicated that flags should be more readily visible.

- **Unique flags -** Without actually accessing the digital artifact, children did not always accurately recall which flag they had used to embed a given piece of information. This indicated that it would be helpful to make each flags unique, such as by color or number.

- **Remote access to discovered artifacts –** Children returned to the location of flags to see if others had made changes to the digital artifact. This led to the idea of providing access to digital artifacts previously created without requiring the child to return to the location of the flag.

- **Matching artifacts to flags –** Young children sometimes drew the flag into their pictures. This led to the idea that it would be useful to have artifacts include an indication of their associated flag, especially when accessed from another location.

- **Drawing and writing in a shared space –** Access to audio and video recordings is sequential and sometimes led to children waiting on others to finish accessing the media and loss of interest in the activity. Writing and drawing was done concurrently in a shared space and resulted in more engagement and face-to-face collaboration.

- **Messaging -** Children looked for their peers and tracked them down to tell them of discoveries made or other observations, or to just socially interact. This lead to the idea of an instant message tool to communicate with peers without the necessity of physically tracking them down.

- **Aggregate information –** Children were curious to know how many flags other's had placed and also to compare the number and type of objects found with their peers' discoveries. This lead to the idea of displaying summary or aggregate information about peer activity or the status of joint artifacts.

3.2 Tangible Flags Design Concepts

The design sessions confirmed that children could use physical flags as an abstraction to embed digital information into their environment. The term *Tangible Flags* was coined to describe computationally enhanced flags used for this purpose. From my literature review, observations and design team sessions, I developed these key concepts for the Tangible Flags technology.

3.2.1 Attaching Tangible Flags to the Real World

The simple interaction of placing a Tangible Flag is an age appropriate activity for young children and the physical act may reinforce the relationship between the real world environment and more abstract digital information displayed on a computer. It is important that a child initially discovers and scans a Tangible Flag placed by another to gain access to the associated digital information. This discovery experience provides a strong mental connection because the child is situated to compare the artifact with the real world environment that it represents. Once a Tangible Flag has been scanned, access to the corresponding artifact is available through software on a mobile computer. The artifact can now be accessed from any location, but the original creation or discovery experience provides a mental association to the real world context. This can aid children in relating their current thought process to the digital information or to again locate the Tangible Flag in the physical space.

3.2.2 Increased Contextual Awareness

While both individual and collaborative learning activities are appropriate for young children, individual exploration may result in missed opportunities for collaborative learning. Children may not be aware of each other's discoveries and may not effectively share knowledge. Making the actions of an individual obvious can promote awareness of activity amongst collaborators [Price et al. 2003]. Readily apparent Tangible Flags can provide children with an awareness of other children's exploration and artifact creation activities while also focusing the child's attention on the real world. Discovery of a Tangible Flag can be directly translated into access to the embedded digital artifact, providing a mechanism to easily turn this awareness into an exchange of information. Because the child's location in the physical environment is a context relevant to the artifact, this knowledge may be more readily understood and applied to their immediate exploration efforts. The children can further enhance this knowledge by annotating the artifact with their own ideas, creating a joint knowledge artifact embedded in the physical environment.

To increase awareness, sets of Tangible Flags can have different colors to provide children with an immediate indication of the artifact's author. This may aid in promoting children to participate in face-to-face collaboration, as they know whom to seek if they wish to discuss an artifact. Numbered flags create an association to digital information and may help children to later access to digital information using the computer interface instead of the Tangible Flag.

3.2.3 Concurrent Interaction

Children in an open, exploratory environment may not work together collaboratively all the time, even when assigned to pairs or teams. As seen in both my design sessions as well as previous research [Benford et al., 2000; Scott et al., 2003], concurrent activity is very important in keeping children engaged during collaboration. Tools should provide concurrent access to a shared digital space so children can seamlessly switch between exploration and artifact creation, independent of peer activity. Such tools enable children to easily integrate their individual work into a joint artifact and provide incentive to collaborate. In conjunction with a Tangible Flag's location in the physical environment, concurrent access has the added benefit of promoting side-by-side interaction in a relevant context. This situates the children to collaborate face-to-face while exploring the real world and creating knowledge artifacts at the same time.

3.3 Tangible Flags Implementation

Development of the Tangible Flags technology was refined through several iterations using cooperative inquiry design sessions. Implementing the concepts of my formative research required these four broad components:

- **Mobile Computers –** Mobile devices with age appropriate input mechanisms, display and form factor. These needed sufficient computing power to run interface software and a wireless connection to peer computers or to a server.
- **Tangible Flag Identification -** A technology that can be integrated with the mobile computers and can uniquely identify a Tangible Flag using a tangible interaction.
- **Shared Data Structure** - Software to distribute and maintain shared data consistently on every mobile computer.
- **User Interface** - Software to provide children with an age appropriate user interface for accessing and manipulating joint artifacts.

3.3.1 Mobile Computers

I elected to use a tablet computer as it emerged as the best portable system for young children. Handheld computers have limited screen space and the stylus can be too small for a child, while a laptop is not easily used while moving and a mouse does not support freehand input as well as a stylus. I wished to use freehand input because kindergarten age children may have limited writing or typing skills. With freehand input, children can write or draw in a way that is more natural. For my research, I had available three Compaq Model TC1000 Tablet Personal Computers (PCs) donated to our group by Microsoft Corporation (see Figure 5). These provide plenty of computing power, IEEE 802.11 wireless networking, and powerful programming environments that run on the windows XP operating system. I found these tablet PCs to have a smooth pen interaction and the pen is thicker than most tablet PCs, making it easy for children to use. The size and weight of a tablet computer was a concern for small children, but I decided this was less problematic than issues with input devices and small screen size.

Wireless connectivity between computers was achieved by using IEEE 802.11g wireless local area network. Computes communicated via a wireless router that was setup prior to conducting the studies or using the University of Maryland's wireless network services when on campus [www.oit.umd.edu/nts/noc/wireless/index.html]. Using a single router provided a coverage radius of up to about 50 meters, which was sufficient for my studies. Wireless connectivity is not currently common in outdoor areas such as parks; however this may change with the increasing trends in citywide wireless network coverage using IEEE802.16e systems [www.wimaxtrends.com].

3.3.2 Tangible Flag Identification

Tangible Flags were built using Radio Frequency Identification (RFID) technology [www.rfidjournal.com]. RFID tags are nominally passive devices consisting of thin, flexible copper traces printed on paper or other substances, with a small integrated circuit chip giving each tag its own unique ID. A RFID reader, which consists of a circuit board with a microprocessor and an antenna, can detect and identify these RFID tags when placed in close proximity. For RFID tags, I used IQ-Paper (see Figure 3) from X-Ident Technology [www.iq-paper.com], which uses the International Standards Organization [www.iso.org] ISO15693 standard for RFID. For a RFID reader (see Figure 3), I used a RFID reader from SkyeTek [www.skyetek.com] consisting of a reader module, SkyeTek SkyeModule M1, and an antenna, SkyeTek SkyeRead EA1.

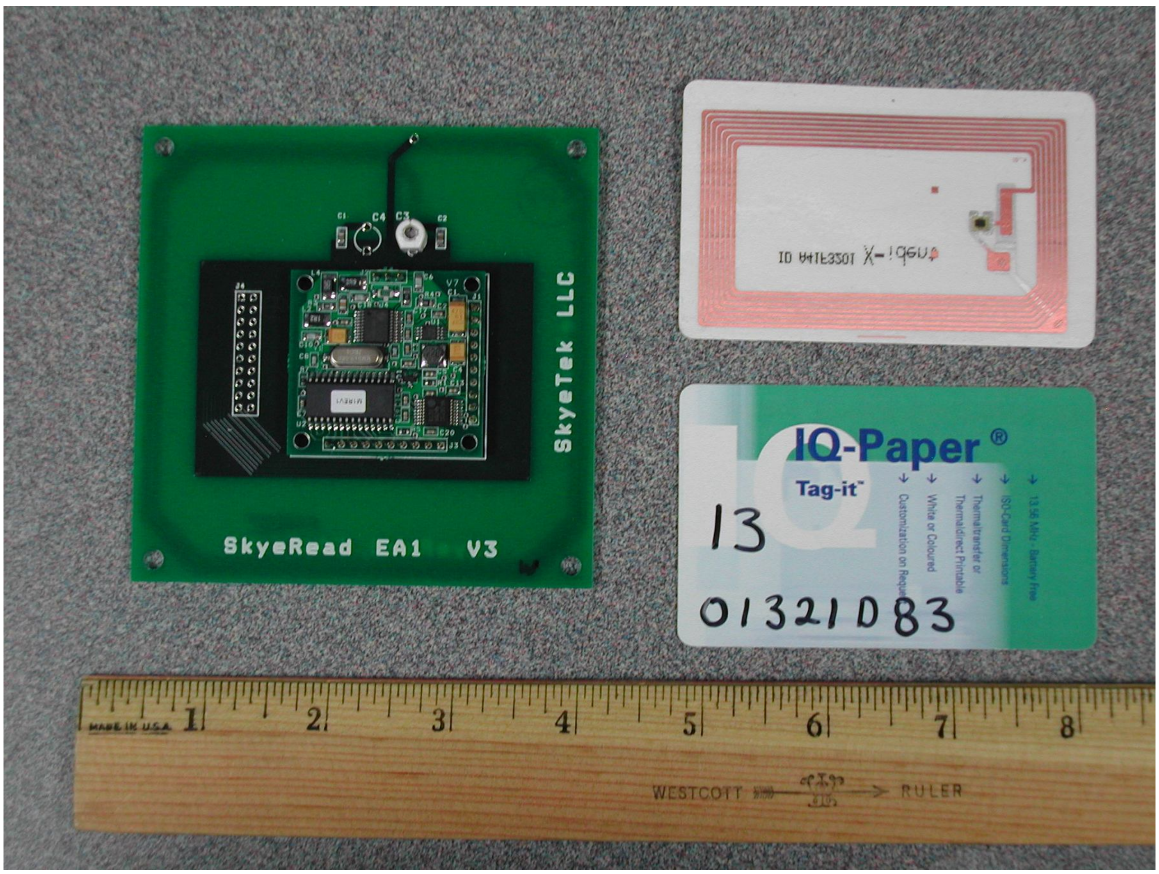

Figure 3. RFID Reader consisting of a SkyeTek M1 reader module mounted on a SkyeRead EA1 external antenna (left), and two IQ-Paper RFID tags (right), with the upper tag opened to show internal copper traces and chip.

Tangible Flags are built by embedding a RFID tag inside a flag made of art materials (see Figure 4). Tangible Flags evolved in the course of design and testing, starting with colored felt and pipe cleaners that could be attached to objects. The design sessions showed that the children wanted larger, more visible flags. The final version used in the studies has a large, yellow border for visibility and no longer included a string or pipe cleaner, which often became tangled.

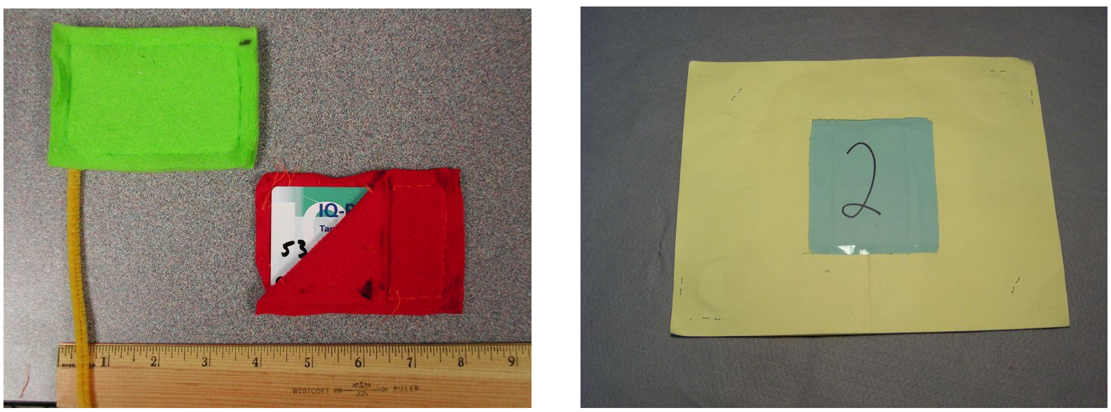

Figure 4. Two Tangible Flags of the initial design (left), with the red flag showing the embedded RFID tag, and one Tangible Flag of the final design (right) with a large, yellow border.

The SkyeTek RFID reader can detect IQ-Paper RFID tags from a range of 4 to 6 inches. Previous research has shown that young children can consistently interact with tangible interfaces built around this specific RFID system [Montemayor et al., 2004; Fails et al., 2005]. The RFID reader is attached to the computer in a prominent location so that children have a clear indication which part of their computer is used to scan Tangible Flags (see Figure 5). In the first prototype, the reader had a cover that looked like a bull's-eye. During cooperative inquiry design sessions, child design partners suggested changing the cover's color to match the color of a child's set of Tangible Flags (see Figure 5). This provides children with additional awareness by enabling them to match Tangible Flags with the computers being carried by their peers.

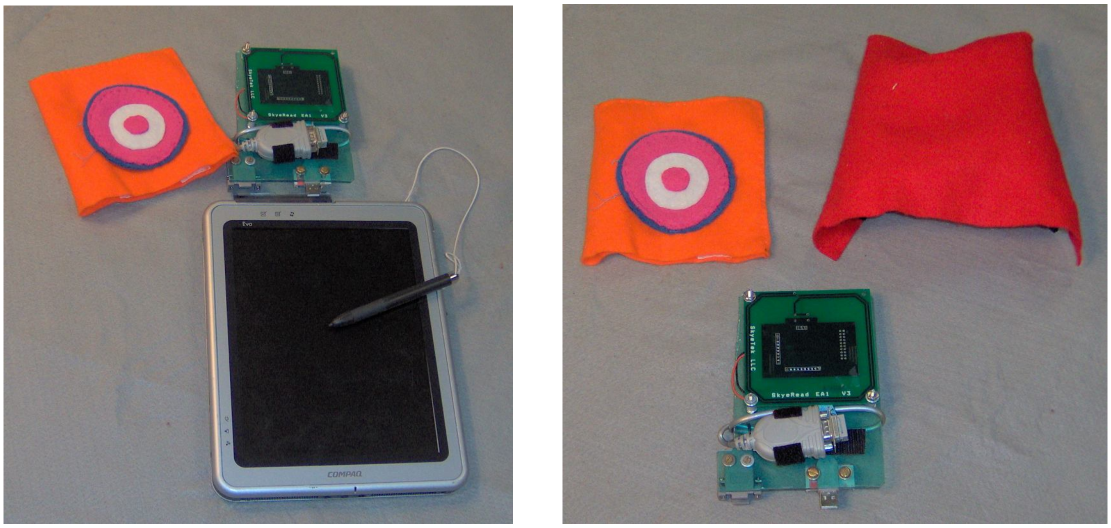

Figure 5. RFID reader attached to a Compaq Tablet PC with reader cover removed (left). A bull's eye RFID reader cover and a red RFID reader cover, and RFID reader with cables, batteries, and mount (right).

3.3.3 Shared Data Structure

I elected to use client-server architecture for maintaining joint artifact data because it provides a reliable method of logging data during studies. Only the server data needs to be logged and the server computer can have more reliable access to a power source than mobile computers, reducing the chances of data loss. I wrote a library package in C# using Microsoft's .NET [msdn.microsoft.com/net/framework] that uses remote procedure calls, called remoting in .Net, for communication between computers [msdn2.microsoft.com/en-us/library/ms973857]. I named this package TFLibrary and it consists of 20 classes and about 1,000 lines of code. Server code built on

TFLibrary is simple, consisting of one class with about 100 lines of code, including functionality for logging user changes to shared data.

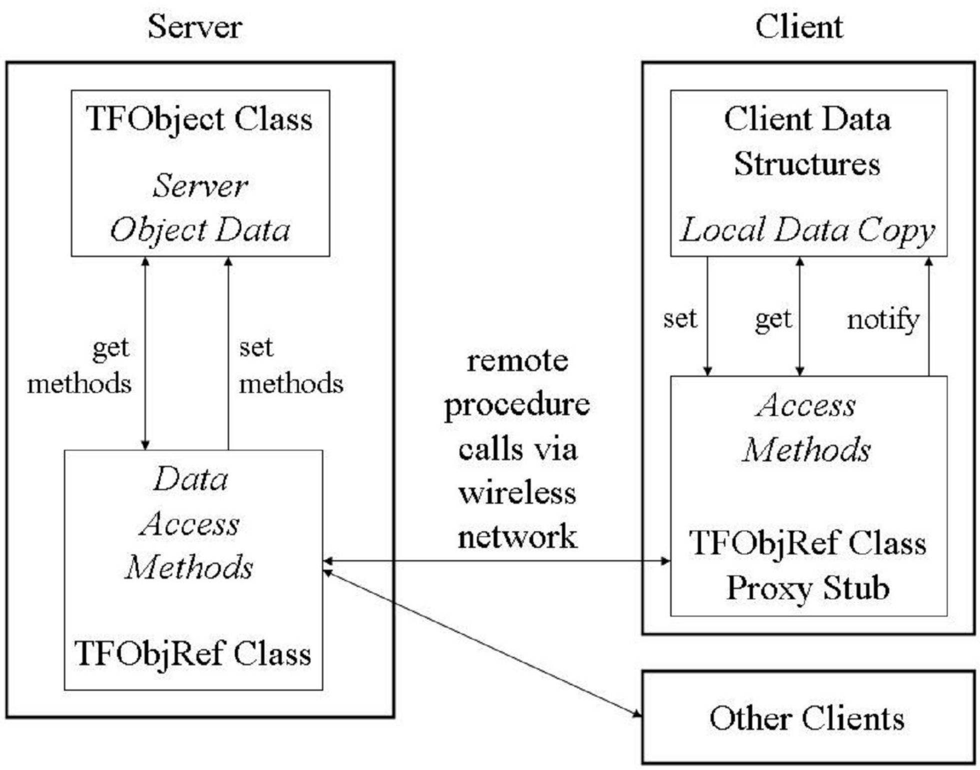

Figure 6. Diagram of TFLibrary Shared Data Architecture.

Clients use TFLibrary to access shared data objects at the server and the server uses TFLibrary to send updates to clients (see Figure 6). The two basic components of TFLibrary are the TFObject class and the TFObjRef (object reference) class. The TFObject encapsulates serializable data that can be sent via network between computers. Every TFObject includes an instance of the TFObjRef class, which is passed as a proxy to remote clients. Remote clients can then use TFObjRef class methods to read and write the server side TFObject data as well as registering for notification of changes. TFLibrary includes classes that extend the basic functionality of TFObject and TFObjRef to allow remote manipulation of common data structures such as lists and hash tables. TFLibrary also includes classes that thread remote procedures calls and handle remote procedure call exceptions when the network connection is intermittent.

TFLibrary has a decentralized structure. TFObjRef methods are generic and pass in a field name parameter to access the corresponding TFObject field via reflection [msdn2.microsoft.com/en-us/library/cxz4wk15]. Therefore, server software is very general and does not rely on prior knowledge of client software data structures. Instead, client software running on any machine can dynamically create data structures at the server, which other client machines running the same software can access. The same server application can be used for different client applications. This enabled me to make changes to client code without changing server code. Also, there is no central message pipe for network communication. Instead, each client software object registers for notification with and receives notification directly from a server side TFObjRef. This has an advantage that no high level management of client-server messages is necessary, making client software design simple and flexible. It has the disadvantage that order of client-server messages is not guaranteed. The issues of message delivery order and duplicated data were solved by using a synchronized clock combined with an at-most-once message delivery scheme [Liskov, 1991]. The client applications synchronized their clocks with the server clock. Messages were given unique identifications and were time stamped from the client's synchronized clock. Message identification was used to eliminate duplicated messages and timestamps can be used for re-ordering out of order messages. This approach is appropriate for the Tangible Flags technology because absolutely correct order of message arrival is not critical from a user standpoint. Two users operating in a shared space probably cannot distinguish between inputs that occur under one second apart.

3.3.4 User Interface

The user interface software was written in C# using Microsoft's .NET and the Piccolo 2D zooming graphics library [Bederson et al., 2004]. Piccolo does not use Microsoft's Managed INK [msdn2.microsoft.com/en-us/library/ms703388] application programming interface (API). This API provides improved display and input performance; unfortunately I was not aware of the API. I chose Piccolo because it makes animation easy to program and I was familiar with it. I wrote the majority of the code with some help from Jerry Fails. Client interface software consists of 30 classes and about 4,000 lines of code. I created several modified implementations of the user interface, including one interface for each study (see sections 4.4.4 and 5.5.4) and several interfaces used for design sessions (see section 7.3.2).

The graphical user interface (GUI) displays joint artifacts and other data for the user, accepts user inputs, and communicates data changes with the server using TFLibrary (see section 3.3.3). The interface design includes several features that previous research has shown to be important for children's collaborative software. First, the design avoids the use of a hierarchical layout, instead employing a single layer display of all interface components. This approach has been shown to improve usability for children's browsing interfaces [Hutchinson, 2006], by reducing navigation and abstraction. In addition, a flat display that places all content onscreen, without paging or scrolling, means that any content changes are immediately visible to the user. I made this a design goal because increased awareness of peer activity in a shared workspace improves collaboration [Dourish and Bellotti, 1992; Bellotti and Bly, 1996]. However, I did not address issues concerned with scaling the shared space for a larger numbers of users or greater amount of content. Finally, display changes in the interface are animated, which can help users understand interface transitions [Bederson and Boltman, 1999; Baecker and Small, 2000] and is especially important to children [Druin, 1998; Danesh and Uden, 2000].

The various different interfaces included some or all of the following components (see Figure 7).

- The working area displays the page associated with one Tangible Flag and provides an interface to modify the page. Most of the page space is a shared drawing area where users can create or delete pen strokes. More sophisticated implementations included other interactive widgets, such as the vote widgets used in the case study (see section 4.4.4). Users can concurrently interact with objects in the working area. Object locking is not necessary to maintain a consistent joint artifact (see section 3.3.3).

- Input control widgets change input modes for the working area (see Figure 7, top right corner). For instance, in the case study (see section 4.4.4) there were two buttons changing pen behavior to either draw or delete mode. Simpler implementations such as the comparative study (see section 5.5.4) may not have input control widgets. Some design implementations (see section 7.3.2) had more control widgets.

- The flag area displays a thumbnail for every Tangible Flag the user has scanned using the RFID reader. Selecting a thumbnail with the pen activates the page for that Tangible Flag. Scanning a previously discovered Tangible Flag with the RFID reader also activates the page; children can use either interaction to access different Tangible Flag pages. When selected, the thumbnail is animated to expand into the working area while the previous working area page is minimized into the flag area. Two mechanisms can provide users with awareness of changes to minimized flag pages. First, the thumbnails in the flag area are miniature replicas of the page's current working area, i.e., they immediately change when any user modifies the joint artifact. Second, the user can be provided a visual alert, such as the flashing thumbnails used in the comparative study (see section 5.5.4).

- The instant messaging area, called ScratChat, is not associated with any Tangible Flag. ScratChat provides an area for instant communication with all other clients. Writing in this area automatically disappears after a short period in order to prevent it from becoming cluttered and to emphasize its use as a message space, not a note taking space.

- The summary data area displays aggregate information about joint artifacts. Typically, this would be summary data based on interactive widgets in each page. In the case study, for instance, the summary data shows the totals of the vote widgets for all pages (see section 4.4.4). The summary data area is not interactive.

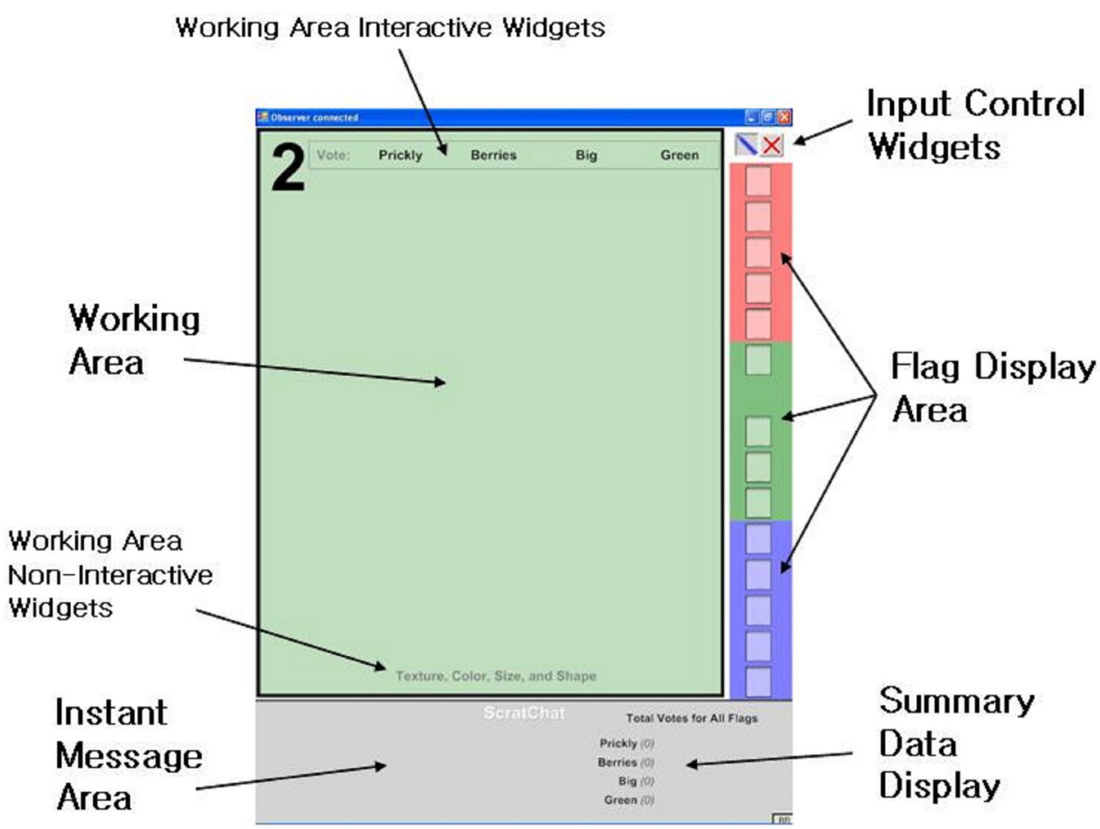

Figure 7. Example user interface showing various components. The background color of the working area and the number in the upper left corner indicate that the user is currently interacting with the Green 2 Tangible Flag.

The Tangible Flags technology enables children to collaborate easily when they are exploring independently because they have mobile access a shared digital information space. Children can review and annotate a shared page for any flagged objects they have discovered. The Tangible Flag, along with its representation on the digital page, helps children to situate this shared information. Providing context makes other children's intent more obvious and further enhances collaboration when children work on a page in a different location. The thumbnail representations of pages in the GUI provide an awareness of when others are making changes to any page the child has discovered, regardless of which page the child may be currently working on. This provides more opportunity for synchronous interaction.

For educators, the software can be run in a special 'observer' mode. In observer mode, the user does not need to discover and scan Tangible Flags placed by others. Instead, whenever a child initially scans a Tangible Flag, a thumbnail will automatically appear and can immediately be accessed by the user. Thumbnails have a flashing visual alert for a few seconds when they first appear, to alert the user to availability of the new page. Users with the observer mode software do not need an RFID reader attached to their computer in order to access artifacts.

Chapter 4: A Case Study of Tangible Flags at a National Park

In the fall of 2005, I had an opportunity to conduct a case study in conjunction with the National Park Service at Rock Creek Park [www.nps.gov/rocr/]. This provided the benefits of working with a sample of children drawn from park visitors in a very typical outdoor learning setting and with an educator; a park ranger. This was an almost ideal situation in which to apply the Tangible Flags technology. The results of this study have been peer reviewed and published in the Interaction, Design and Children 2006 conference proceedings [Chipman, 2006].

Rock Creek Park is a National Park in Washington, D.C. that has a number of cultural and natural resources, including trails through natural areas. The park has a variety of programs scheduled for visitors, one of which is a ranger-led forest walk with a scavenger hunt, a popular activity for families with children in early grade school. I worked with a park ranger familiar with the scavenger hunt program to adapt it for the Tangible Flags technology. The study was conducted on the "Edge of the Woods Trail", which is a quarter mile loop through the woods with a small pond and meadow near the center. A scavenger hunt was selected that had a focus on the variety of trees and other plants that can be seen along this trail. Some of the plants along the trail include holly trees, pawpaw trees, chestnut oak trees, raspberry bushes and devil's walking stick.

4.1 Research Goals

The goal of this case study was to investigate the use of the Tangible Flags technology in an authentic outdoor learning environment. Its objective was to assess how the use of the technology impacted children's exploration and collaboration in an outdoor environment. In addition, it examined how a learning activity would be impacted by use of the technology, both in terms of how the design of an activity could be built around the technology and also how the learning experience might differ from more typical children's experiences in outdoor learning environments.

4.2 Research Questions

During the study, children could use the Tangible Flags technology to embed digital artifacts into their environment while they explored. They could also discover Tangible Flags left by others and use these to access joint artifacts and asynchronously work together. I expected children participating in the study would find many or all of the Tangible Flags left by others, and would usually make an addition to the joint artifact when they did. I wanted to see if these additions would commonly represent some nearby real world object and how much children would build on each other's work. The technology also enabled the park ranger to engage children by asking them questions about the objects they flagged. I wanted to see if this motivated the children to further investigate the environment.

Because the area was large and the exploration activity was limited to 20 minutes, I did not expect children would return to Tangible Flags previously discovered.

However, I was curious if children might use remote access to artifacts through the mobile computers to make additional changes to artifacts, or if they would use the ScratChat messaging area to arrange face-to-face meetings.

4.3 Study Participants

The park service advertises their programs both on their website and in brochures available at the ranger station in the park. Our program was advertised for 2 p.m. on the first 3 Saturday afternoons in November of 2005 (see Appendix A, section A.1). The first of these days was intended as a pilot study and the second two as samples in the case study. In order to get more participants in the study, researchers in the HCIL lab were told about the program and invited to bring their children to participate if they wished. The children on our design team were also invited.

The park ranger and I met park visitors in the lobby of the ranger station before the program started and invited park visitors to participate. Those who did were split into three groups and assigned a color: red, green or blue. Family members were assigned to the same group. While the program was advertised for children ages 6 and up, younger siblings were allowed to participate in order to keep families together. Parents accompanied their children and were given no specific restrictions on interaction, except to limit efforts to help their children with the technology. If asked to write inputs by their children, parents were instructed to place an asterisk next to any adult input

Nine families and twelve children participated in the pilot study on the first day, November 5, 2005. There were two boys ages 6 and 8. There were ten girls, the youngest was 5, the oldest was 11 and the average age was 8. There were also several infants and toddlers, and at least one parent for each family.

Six families and ten children participated in the study on the second day, November 12, 2005. Three sisters were assigned to the red team. They were a 7th grade girl (age 12), a 5th grade girl (age 10) and a 1st grade girl (age 6). Two sisters and a brother were assigned to the green team. They were a 2nd grade girl (age 7), a kindergarten girl (age 5) and a pre-school boy (age 3). Four unrelated children were assigned to the blue team. They were a 2nd grade girl (age 7), a 4th grade boy (age 9) from our design team with extensive prior exposure to the technology, a 4th grade boy (age 9) who is the child of a HCIL researcher, and a 3rd grade girl (age 8) from our design team with extensive prior exposure to the technology. Other than the two children from the design team, none of the other children had prior exposure to the technology.

Four families and five children participated in the study on the third day, November 19, 2005. A 4th grade girl (age 9) who was a child of a HCIL researcher was assigned to the blue team. She had also participated in the pilot on the first day. A pair of siblings was assigned to the red team. They were a pre-school boy (age 4) and a 2nd grade girl (age 6). They had no prior exposure to the technology. Two unrelated children were assigned to the green team. They were a 1st grade girl (age 6) from our design team who had not been involved in the design process, but had used the technology on one previous occasion, and a 2nd grade boy (age 7) who was a child of a HCIL researcher with no prior exposure to the technology.

4.4 Materials

4.4.1 Permission Forms

The University of Maryland's Institutional Review Board approved this study, including the use of child participants. The chief park ranger at Rock Creek Park also approved this study. The parents of participating children received a short letter explaining their child's participation in our research and also signed a permission slip (see Appendix A, sections A.2 and A.3).

4.4.2 Questionnaires

Parents were asked to fill out a pre-questionnaire before the study to obtain demographic information on the participants (see Appendix B, section B.1). Parents were asked to fill out a post-questionnaire after the study to obtain their feedback on the activity and the technologies (see Appendix B, section B.2).

4.4.3 Research Team Guidelines

Conducting the study on any given day required five or more researchers. There would be one researcher to accompany each group of children to take notes and operate the video camera, one researcher to monitor the equipment, and myself to supervise. Prior to conducting the study, a guidelines were developed for the researchers to follow during the study (see Appendix C).

4.4.4 Interfaces

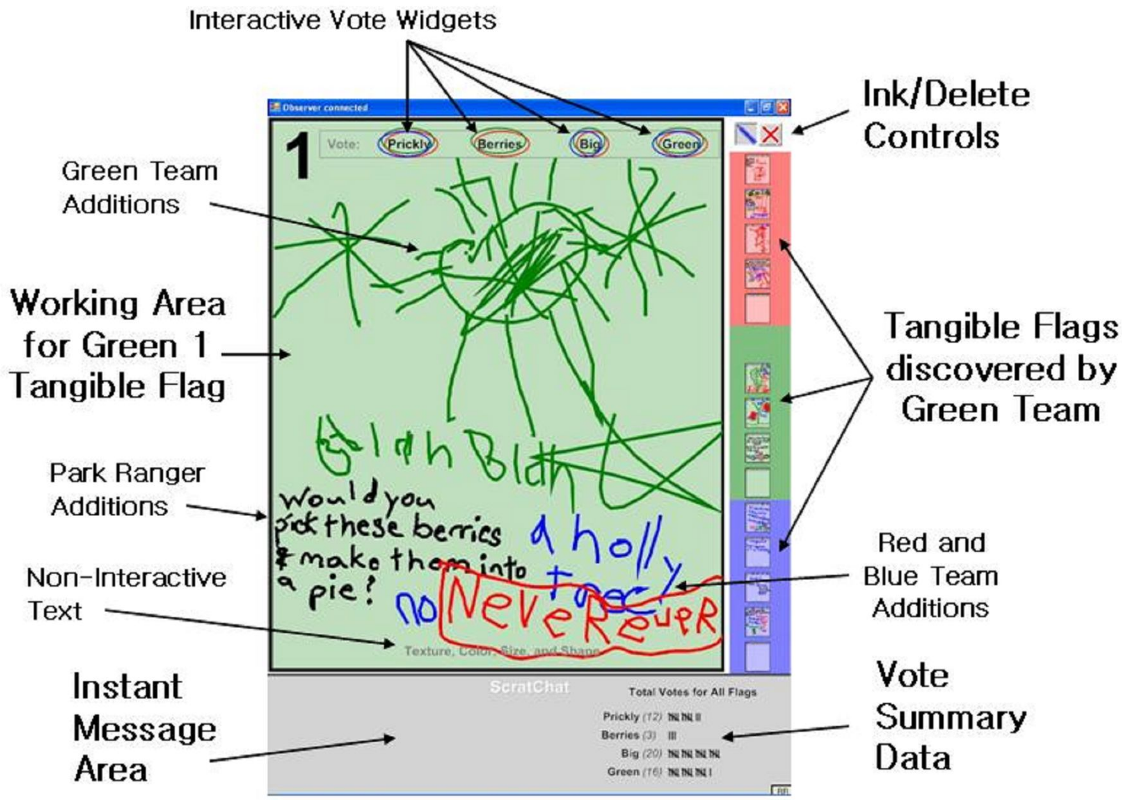

Figure 8. Example user interface for case study, showing various components. The working area for the Green 1 Tangible Flag is currently active and shows additions made by study participants.

The working area (see Figure 8) has a light background color and number that matches a Tangible Flag. At the top were four interactive vote widgets where each group could vote if an object had any of the following properties: ‘prickly’, ‘green’, ‘big’ or had ‘berries’. Clicking on the text of a widget places a circle with the group’s assigned color around the text. The circle represented a group’s vote that an object has this property. Clicking an already circled widget removes the vote for that property by removing the circle. Votes can be placed for any and all properties. The widgets also display a colored circle for the votes of other groups (see top of Figure

8). Below the vote widgets is an interactive space where users can write or draw using the tablet's pen, much as they might on a piece of paper. The pen writes in the color assigned to the group. At the bottom of the working area was a line of text, "Texture, Color, Size, and Shape", corresponding to the characteristics of objects children were asked to describe during the study activity. This text was not interactive. In addition, there are two buttons (see upper right corner of Figure 8) that select a mode for the working area. One button selects an inking mode for writing notes and the other button selects a delete mode. Users can delete their own inputs, but not those of others.

The flag area displays a thumbnail for every Tangible Flag a user has scanned (see right side of Figure 8). Selecting a thumbnail activates the working area for that Tangible Flag. Animation is used to swap pages between the flag area and the working area. Scanning a Tangible Flag with the RFID reader also selects its page; children can use either interaction to access different Tangible Flag pages. Thumbnails are simply a smaller image of the working area and are updated immediately when a change is made to the corresponding working area.

The instant messaging area, called ScratChat, provides a means for instant communication with all other clients (see bottom left of Figure 8). Writing in this area automatically disappears one minute after it is written in order to prevent it from becoming cluttered and to emphasize its use as a message space, not a note taking space.

On the left side of the ScratChat area was a vote summary area, which for each property showed the total votes across all Tangible Flags. The total was displayed as a tally count, along with a number in parenthesis (see bottom right of Figure 8). These totals were updated immediately upon a vote change on any computer. The vote summary area was not interactive.

4.4.5 Technology

The park ranger was provided with an Acer TravelMate 100 Tablet PC with a 700 MHz Intel Pentium III processor and 256 MB of ram, running Microsoft Windows XP Table PC edition 2005 version 2002 service pack 2 operating system, with a 10" diagonal display at a resolution of 768 by 1024 pixels. The keyboard was folded under the display. A standard tablet pen was available for interacting with the computer.

Each group was provided with a Compaq Model TC1000 Tablet PC with a 995 MHz Transmeta 5800 processor and 240 MB of ram, running Microsoft Windows XP Table PC edition 2005 version 2002 service pack 2 operating system, with a 10" diagonal display at a resolution of 768 by 1024 pixels (see Figure 9). The detachable keyboards were removed. Two devices were available for interaction with the software. One was a standard tablet pen attached to the computer with a piece of elastic string, which could be used to interact with the software by touching the display. The other was a RFID reader attached to the top of the tablet (see Figure 9). This input device and its use are detailed in section 3.3. Each child in a technology group was also given three Tangible Flags, numbered 1 through 3, with a color matching their RFID scanner cover of their computer (see Figure 9).

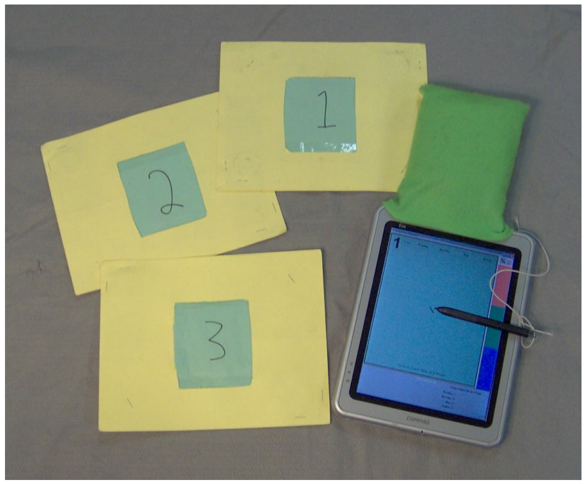

Figure 9. Equipment provided to the Green Team during the case study, showing a Tablet PC with attached RFID reader (under green cover) and three Tangible Flags.

The tablet computers used built in wireless to connect with an IEEE802.11g wireless router. The software communicated via wireless with server software running on a computer also connected to the same wireless router. The server software was run on a Dell Inspiron 600M laptop with a 1.6GHz processor and 512 MB ram, running Windows XP. The screen saver software on all tablets was disabled.

4.5 Participant Activities

The study participants were asked to take part in five activities; watching and participating in a technology demonstration for 10 minutes, listening to an introduction to the activity for 5 minutes, taking an exploratory walk for about 20 minutes, taking a guided walk for about 20 minutes, and contributing to a post-activity discussion for about 5 minutes.

After the children were divided into groups, each group was given a set of three Tangible Flags of their team's color and one computer. From my experience with the pilot test, three Tangible Flags were chosen as a good number so that children could place all their Tangible Flags, find most of the others and yet keep the combined time for both walks at 45 minutes or less. This was a good duration for keeping the children's attention during our pilot study and when working with our child design partners. Each group was then given a 10-minute demonstration of the technology. For this demonstration, the Tangible Flag software ran with a local server that already had a Tangible Flag with some notes on it for the children to discover. This demonstration included the opportunity for the children to place a Tangible Flag, discover and scan a Tangible Flag, and use the pen to operate the software interface. During the demonstration, parents filled out the pre-study questionnaire to provide demographic data.

After the demonstration, the park ranger gave a 5 minute introduction to the area and to the kinds of plants that could be found on the trail. The children were asked to find and place a Tangible Flag near objects on the trail that had one or more of these properties: big, green, prickly or having berries. This was an intentionally broad activity in order to give the children more flexibility to explore and discuss as a group what to flag. The children were asked to write or draw some description of the object after they placed a Tangible Flag. In order to elicit input from everyone in a group and encourage sharing of the computer, children were given specific assignments on a characteristic to describe: color, shape, size or texture. Children were given a tag to wear like a nametag, which had their specific assignment on it. Children were also asked to scan any other Tangible Flags they discovered, add their descriptions, and to write or answer questions. During the introduction, researchers restarted the each group's computer and connected it to the remote server for the study activity. These were handed back to each group at the beginning of the exploratory walk.

To start the exploratory walk, each group was taken to a different part of the trail. One group started near each end of the trail and one group started near the middle. Researchers helped children use the technology as necessary and encouraged children to focus on the study activity if they became distracted. Parents also interacted with their children, asking questions concerning the activity, and helping them with drawing and writing as necessary.

During the exploratory walk, the ranger did not accompany any of the groups; instead she moved along the trail independently, to see what the different groups did. The ranger was given a tablet computer that was running in a special 'observer' mode, which has a thumbnail in the flag area for all Tangible Flags. Without scanning, the ranger could see all the notes written by each group and could write questions or responses on the Tangible Flag pages (the ranger's writing showed as black). In addition, the ranger had placed two Tangible Flags along the trail before the activity began, on which she had written some questions (see Figure 10). A third Tangible Flag was placed back at the ranger station for the post-discussion activity.

Figure 10. Picture of Tangible Flag placed prior to activity by park ranger (left), and corresponding question, along with children's answers (right).

After about 20 minutes of independent exploration, the park ranger gathered all the groups together for a guided walk of the trail. The guided walk started at one end of the trail and went around the loop, lasting another 20 minutes or so. During the guided walk, all study participants visited each Tangible Flag that had been placed. The park ranger discussed the children's joint artifacts and related their inputs to the flagged objects. Tangible Flags were recovered from the trail at this time.

At the end of the guided walk, the park ranger told the children there was one more Tangible Flag to be discovered near the ranger station. This Tangible Flag had questions for the children to answer about the activity. This was followed by a 5 minute discussion of the activity and the children each wrote down one thing they liked and one thing they disliked about the experience. At this time, parents filled out the post questionnaire.

4.6 Pilot Testing

Prior to pilot testing, the Tangible Flags technology was tested with the kids design team. This testing was done with the same interface design used for the study. It was tested both in an outdoor area on campus behind A.V. Williams building and along the trail at Rock Creek Park. During both of these tests, hardware and software failures prevented a complete test of the study activities. These technical issues were fixed prior to the park program in November, but for this reason, the first day of the park program was used as a pilot test to refine the study activity. There were a large number of participants for this pilot, which helped illustrate the need for a shorter overall activity and a smoother procedure.

As a result of the pilot testing, a number of changes to the study procedure were made. The number of Tangible Flags per team was reduced from four to three. This helped reduce the time of the exploratory activity. The demonstration was changed to include preset data using a demo server instead of the server used for the study. This saved time transitioning the technology from the demo to the study. Tags for the children to wear showing their specific assignments were also introduced. The pilot test confirmed that children could find enough objects along the trail that fit the scavenger hunt to keep them engaged in the activity. Finally, the pilot study gave the researchers who aided me in conducting the study an opportunity to practice the procedure based on the guidelines provided.

4.7 Analysis Methodology

Children were videotaped during the study to capture their activity patterns, though one family participating in the study opted out of signing the video tape permission. Therefore, no video taping was done for the red team on the second day of the study (November 12, 2005). The Tangible Flags technology server logged the children artifacts, which includes timestamps for every change to the artifact. Review software can provide a view of the artifact at any moment in time. However, a server failure occurred on the second day of the study (November 12, 2005) due to a change in procedure caused by the loss of electrical power combined with a software error. This resulted in a loss of server data. For these reasons, the analysis in this study focuses on the results of the third day of the study (November 19, 2005). Still, results of the children's responses to the discussion session for both days of the study are provided.

Analysis of this study is done using qualitative analysis methods [Stake, 1995; Creswell, 1998]. The video was reviewed to examine children's exploration and artifact creation activities. Frequency counts were generated for the Tangible Flags discovered and inputs to artifacts. Artifact creation activities were also confirmed in a review of the children's artifacts. Illustrative examples were selected to provide further insight into these activity patterns and other general observations. Children's contributions during the post-activity sessions were grouped based on similarity of response and the groups labeled by their common element.

4.8 Results

4.8.1 Placement and discovery of Tangible Flags

Each group had the potential to discover 8 Tangible Flags, besides their own, during the exploratory walk; three for each of the other groups and two the ranger had placed. During the exploratory walk, all group added inputs to every Tangible Flag they discovered. By the end of the guided walk, every group had scanned every Tangible Flag, but only red and blue groups added inputs during the guided walk. In addition to the two ranger Tangible Flags, the ranger asked a question on two of each groups' Tangible Flags as they were placed during independent exploration, so 6 out of the 8 Tangible Flags discovered by any group had questions from the ranger.

Group	Exploratory Walk	Guided Walk
Red	4	7
Blue	5	7
Green	4	4

Table 1. Number of Tangible Flags (out of 8) with inputs from each group at the end of each walk, during the case study.

4.8.2 Examples

Four examples are given here to illustrate how the Tangible Flags technology supported the children's creation of joint artifacts while independently exploring.

These examples show children choosing their own points of inquiry, discovering Tangible Flags left by others (including those left by the park ranger), elaborating on the inputs of others, accessing artifacts concurrently, and adding relevant inputs without returning to the location of a previously visited Tangible Flag.

4.8.2.1 Example 1 (Figure 11)

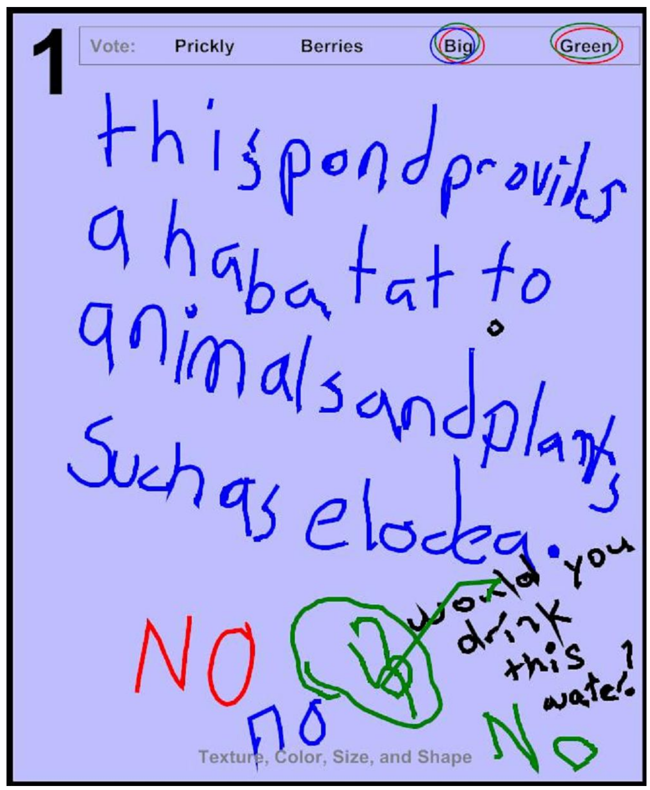

Figure 11. Case study, Example 1, placed next to the pond.

The blue group girl chose to place a Tangible Flag next to the pond and wrote “this pond provides a habatat *(sic)* to animals and plants such as elodea.” After she had moved on, the red and green groups arrived at the pond simultaneously and both groups discovered the Tangible Flag. The green group boy elaborated on the writing by drawing a picture of the pond. At this time the ranger also started writing a question, “would you drink this water?” The red and green groups concurrently answered the question, each using their own computer. Near the end of the exploratory walk, the blue group girl examined the blue Tangible Flags using the flag area and added her response (bottom center of Figure 11) without returning to the pond.

4.8.2.2 Example 2 (Figure 12)

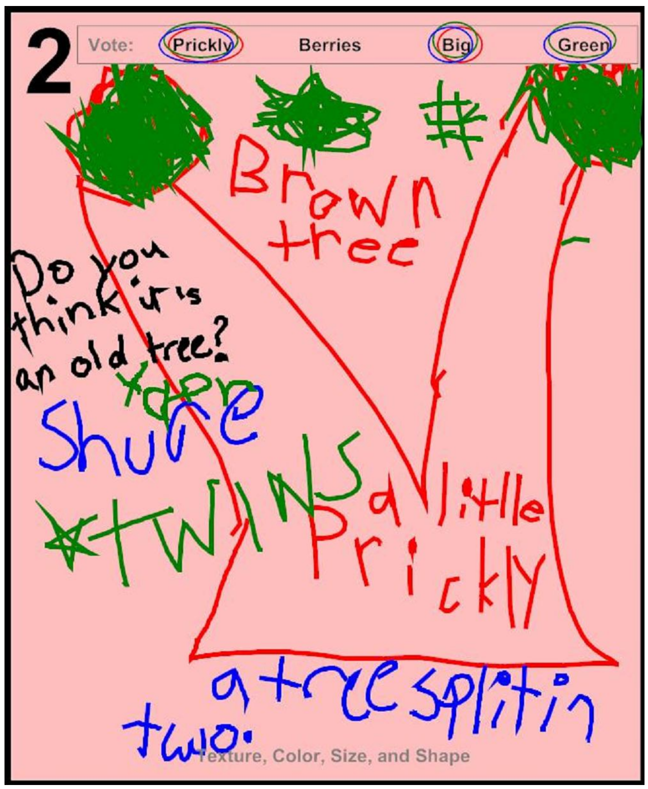

Figure 12. Case study, Example 2, placed under a chestnut oak tree.

The red group chose a large oak tree with split trunks as being of interest. The red group girl drew a picture of the tree and wrote ‘brown tree’ and ‘a little prickly’. After the red group had moved on, the ranger added a question “do you think it is an old tree?” The blue group girl discovered the Tangible Flag and answered the ranger question “shure *(sic)*”. She elaborated on the drawing by writing “a tree split in two.” Some time later the green group discovered the Tangible Flag. Based on a comment from the green group boy, a parent added “twins” for the green group (note asterisk in Figure 12). During the guided walk, the green group boy answered the ranger question with “yaeh *(sic)*” and elaborated on the drawing by coloring leaves on the tree.

4.8.2.3 Example 3 (Figure 13)

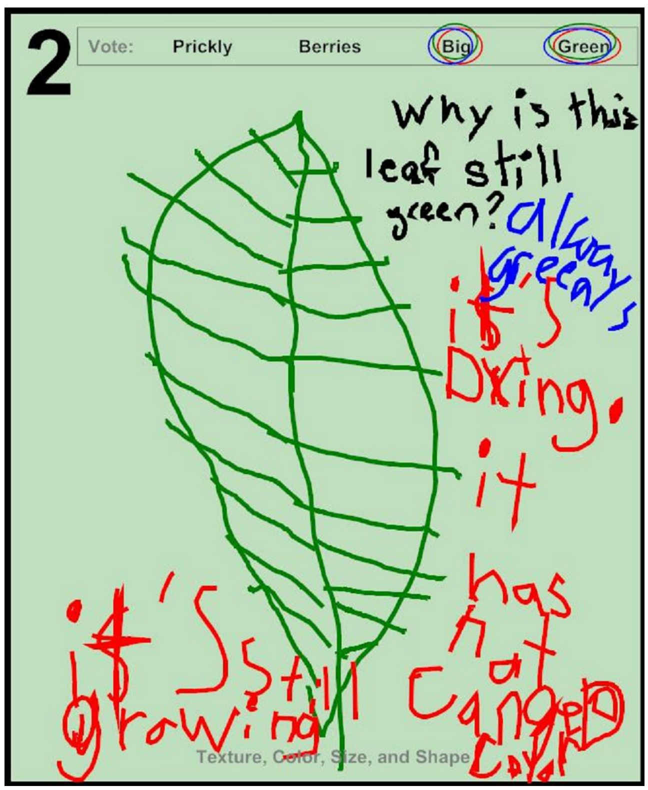

Figure 13. Case study, Example 3, placed under a pawpaw tree.

The green group liked the pawpaw tree, which has very large leaves. The green group boy started the drawing of a leaf and added all the veins seen on the left side. The green group girl then finished the drawing, adding all the veins on the right side.

After the green group had moved on, the ranger added a question “Why is this leaf still green?” The red group discovered the Tangible Flag and the girl answered the ranger question with “it's dying”. The red group boy said aloud “it has not changed color” and the girl added his comment (bottom right of Figure 13). After the red group had left, the blue group girl discovered the Tangible Flag and answered the ranger question with “always green”. During the guided walk, the green group girl responded aloud “it’s still growing” when the ranger read the question aloud. The red group girl wrote the green group girl’s response on the page (bottom left of Figure 13).

4.8.2.4 Example 4 (Figure 14)

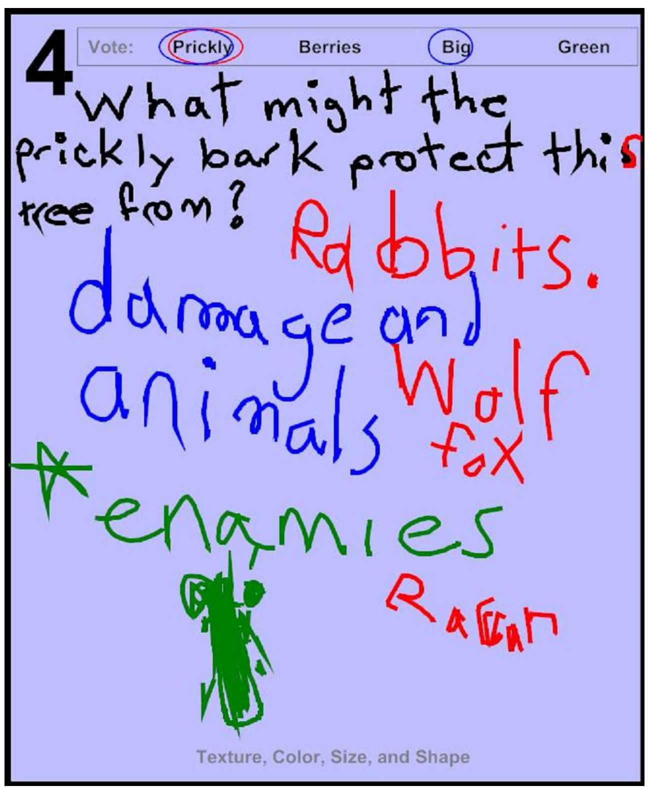

Figure 14. Case study, Example 4, placed under a devil’s walking stick tree.

Prior to the activity, the ranger placed a Tangible Flag near a devil's walking stick tree and asked, "What might the prickly bark protect this tree from?" The blue group girl discovered the Tangible Flag first and answered the question with "damage and animals". After the blue group had left, the green group discovered the Tangible Flag and the green group girl elaborated by drawing a picture of the prickly bark of the tree (bottom left of Figure 14). The green group boy responded aloud with "enemies" when the question was read aloud by a parent. The parent wrote this comment (note asterisk in Figure 14). After the green group had left, the red group discovered the Tangible Flag. The red group girl elaborated on the blue girl's answer with "rabbits". When the red group boy said aloud "wolf", "fox", "deer" and "worm", the red group girl added "wolf" and "fox", and then she added "raccan *(sic)*". During the guided walk, the red group girl corrected the ranger's writing (notice 's' on upper right of Figure 14) and her spelling of raccoon.

4.8.3 Children's likes and dislikes

During the post activity contribution session, children were asked to give at least one answer each to two questions; "Write down something you liked" and "Write down something you disliked". Out of 15 children responding, 5 were either children of HCIL researchers, design team partners, or both. The set of answers from both sessions are presented below. These answers fell into the following general categories.

Things children liked	Count
Liked Tangible Flags, finding Tangible Flags or seeing contents of Tangible Flag	7
Liked writing or drawing	4
Liked learning or learning about nature	4
Liked using the computer	2
Liked aspects of the environment	2
‘Cool’	1

Table 2. Children’s positive responses to case study activity.

Things children disliked	Count
Disliked walking around or too hot	5
‘Nothing’	3
Computer was hard to use	2
Disliked aspects of the environment	2
Disliked a conflict over shared space	1
‘Boring’	1

Table 3. Children’s negative responses to case study activity.

4.8.4 Other observations

During the guided walk, there was a conflict over one of the artifact pages. The children scribbled over each other’s writing and wrote argumentative comments to each other. This occurred about 40 minutes into the activity, near the end of the guided walk.

During the guided walk, one child consistently viewed the Tangible Flag being discussed by the park ranger by accessing them with the GUI. All other children scanned the Tangible Flags using the RFID reader, even though the Tangible Flags had been previously discovered.

At the start of the exploratory walk, children did not know that the ranger had left flags for them or would write questions on the pages. Some children figured out that black represented the ranger's writing (see Appendix D). In addition to using color to recognize author, in one instance (see section 4.8.2.2), color formed the basis for collaboration.

4.9 Discussion of results

Children used the Tangible Flags technology to independently explore in a mobile environment, while jointly authoring digital information, which was directly connected to the real, physical world. The technology also enabled the park ranger to participate fluidly and guide the educational activity.

4.9.1 Impact of a concrete connection between real and digital

All groups discovered at least half of the Tangible Flags left by others (see Table 1). Tangible Flags provided children with awareness of where other groups had explored. This helped focus the children's attention on the relevant places in the environment. Children almost always viewed the digital information for all Tangible Flags they discovered, which provided them with awareness of other group's artifact creation activities. This indicates how Tangible Flags can promote awareness in open, exploratory environments.

Children gave input on every Tangible Flag they discovered while exploring, usually answering ranger questions and sometimes elaborating on each other's work by adding drawings (see section 4.8.2.1) or comments (see section 4.8.2.2). In all four examples, children answered questions or elaborated on content created by others. This shows how access to a joint artifact in context can promote asynchronous collaboration. Children were able to understand what object a drawing represented and make appropriate comments (see section 4.8.2.2). Children also gave multiple opinions in response to ranger questions (see section 4.8.2.3 and 4.8.2.4). This shows how children's shared understanding of a joint artifact is enhanced with a concrete connection to the real world.

Using Tangible Flags, each group was able to explore independently and find things that interested them. In Examples 1, 2 and 3, the children chose objects in the environment they felt matched the activity. In Example 4, the pre-placed Tangible Flag enabled the ranger to draw the children's attention to an important part of the environment she wished to highlight. This gave a good balance of directed input from the ranger combined with open exploration by the children. The children had more ownership of the guided walk than they would have without the technology, since they played a part in determining the highlights of the walk.

4.9.2 Impact of mobile access

The Tangible Flags software provides users immediate awareness of changes to joint artifacts as well as mobile access to the shared space for collaboration. This further enables collaboration while children independently explore.

During the exploratory walk, the ranger was able to engage the children by writing questions based on the children's choices, even as the children continued their investigation of the environment. She did this even as she walked around between the groups. Based on the children's artifacts and her knowledge of the park, she was sometimes able to ask the children relevant questions without ever seeing the placement of the corresponding Tangible Flag. Children almost always answered the park ranger questions, either when they discovered a Tangible Flag during the exploratory walk, or later when reading the question during the guided walk. Use of the Tangible Flags technology enabled a novel learning experience where children could explore independently yet still collaborate with an educator.

In Example 1, the blue group girl accessed a Tangible Flag she had originally placed, but while at a different location (see section 4.8.2.1). She then answered the park ranger's question. Mobile access enabled this additional collaboration without restricting her freedom to explore independently. Because she had originally placed the Tangible Flag when she created the artifact, she could answer the question based on her knowledge from a first hand visit to the pond. The context of the original discovery helped inform her response.

4.9.3 Impact of concurrent access

Children concurrently accessed the joint digital artifacts by answering questions at the same time (see section 4.8.2.1) and by writing down verbal comments while other children viewed the same artifact on a different computer (see section 4.8.2.3).

Concurrent interaction enabled children to freely explore and access artifacts without taking turns, which may have helped keep their attention.

The scribbling episode suggests that children may need additional support to moderate and negotiate the creation of joint artifacts, especially with concurrent interaction. However, this only occurred once during the entire activity and that it occurred near the end of the activity when the children may have been tired and losing interest. In addition, it occurred during the guided walk, when the activity was less interactive for the children and consisted more of listening to the park ranger. Design of the learning activity may be as important as the design of the collaborative interface in preventing conflict and keeping children working together.

4.9.4 Usability of Tangible Flags

During the exploratory walk, children usually scanned the Tangible Flags they discovered without adult help. During the guided walk, all but one child also used the tangible interactions instead of the GUI to access artifacts when following along with the park ranger. This indicates that using tangible interaction may be more natural for children than using a GUI, at least when the digital information is coupled to a real world context.

Children's positive responses indicated that discovering Tangible Flags, viewing their contents, and writing and drawing in the shared space was a very enjoyable element of the activity. There were fewer negative responses and most of these centered on aspects of an outdoor environment, such as being too hot or too much walking. Two responses indicate that the computer was hard to use. This is likely a combination of sometimes marginal performance by the interface (see section 3.3.4) combined with a mobile device (see section 3.3.1) that is not ergonomically designed for children. One response indicates shared space conflicts could be an issue. In addition, children used most of the space on many of the pages, indicating a need to scale for larger groups of children and provide tools for resolving conflicts in the shared space.

4.10 Limitations

4.10.1 Participant population

The participants in this study were a convenience sample drawn from two distinct populations; visitors to Rock Creek Park and children of HCIL researchers. Park visitors may not represent a broad demographic; however they do represent a target audience for at least one major application of the Tangible Flags technology. Children of scientific researchers likely represent the higher end of the socio-economic spectrum. As such, they do not represent children from a broad cross-section of families. Yet all of the researchers' families involved in the study have on other occasions visited National Parks of their own volition. So while they may not be representative of random park visitors, they are certainly representative of a portion of that population.

The children who are members of the design team who participated in the study had some previous exposure to the technology. There were also children that participated in the study more than once. This probably affected their use of the technology. However, these children were teamed together when they participated. On both days of the study, there were teams participating where no child had any prior exposure to either the technology or the activity.

4.10.2 Interface design

This study was limited by the use of a single interface design for the technology. Thumbnails for Tangible Flags were presented across the right side of the interface. This was chosen in order to maximize the use of space on the computer screen for a right-handed user. During the design of Tangible Flags, a number of other placements for the thumbnails have been used and this study does not examine the effects various layouts may have on collaboration or for left-handed users. Also, vote widgets were placed at the top of the working area in order to make them more apparent and encourage children to place votes. Several placement options were considered during the design of the technology and this study does not examine other possible designs.

The Tangible Flags technology runs on a tablet PC and this platform was chosen because it was an available resource for this research. This many not present the ideal size and weight for a child's mobile device, a function which is also probably highly dependent on a child's age. Children participating in this study ranged for ages 3 to 12 and often took turns carrying the computer and the Tangible Flags. Therefore, this study does not give much insight into how size, weight and form factor may affect the use of the technology.

4.10.3 Study activity and environment

This study was limited in that it only examined children's activity patterns for a single, activity and for a single learning environment. However, this activity and environment are a typical case. Yet the study may provide limited applicability to other activities and environments. In addition, the activity in this study was tailored for the use of the Tangible Flags technology at this particular park. Therefore, this study may provide limited insight into how other programs might be enhanced by using the Tangible Flags technology.

4.10.4 Data collection

This data collection of this study was limited because multiple researchers were involved in interaction with the participants and collecting data. This probably led to increased variability in children's activity and use of the technology during the study. It also resulted in slightly differing patterns of using the video camera. Both could have resulted in more variance in the resulting data. It was not possible to conduct this study using a single researcher. Therefore, detailed guidelines for interacting with the participants were developed to promote a consistent process regardless of researcher. A pilot study was conducted to practice the guidelines before the actual study.

The data collection was also limited due to the impact of the environment on video capture. Glare from sunlight and noise from wind sometimes interfered with video capture. In addition, multiple conversations sometimes overlap on the audio. There was not sufficient equipment and expertise to improve on the video capture in these conditions. However, the use of multiple cameras helped offset the impact in some cases, capturing several takes that could be compared.

Finally, this study was limited because data was incomplete on the second day of the study. This prevented a thorough analysis for that day and a comparison between two different groups of participants. However, the bulk of the data for the final day of the study was intact, allowing video to be compared with digital artifacts. The study was schedule on three different days for the purpose of dealing with such contingencies as weather, lack of participants or equipment failure. A compete set of data for a single day was sufficient for analysis.

4.10.5 Qualitative analysis

The qualitative analysis is limited because it relies on peer review of interpretations and conclusions. A single researcher analyzed the raw data and interpreted the results. It was not possible to interview participants after a session due to time constraints. Therefore the analysis relied on review and interpretation of the video, the children’s digital artifacts, and responses to questionnaires. However, images of the artifacts are provided to support the conclusions.

Chapter 5: A Comparative Study of Tangible Flags with a Kindergarten Class

For a second, in depth, study, I had the opportunity to work with a classroom of kindergarteners. One option was to compare the Tangible Flags concept with a system similar to the research for older children discussed in Chapter 2, i.e., a system that used an intangible connection, such as location awareness, to provide information in context. But the results of that research, as well as learning theory, suggest that such a system would be problematic for kindergarten age children, and a comparison study would likely be very one sided. Instead, I decided a more useful study would be to control for the effect of information in context in an effort to understand the impact of mobile awareness and access.

Building on the results of the case study detailed in chapter 4, I designed the more comprehensive study detailed in this chapter. This study provides a comparison between the Tangible Flags technology and a paper system, using both quantitative and qualitative analysis. In the course of this study, children participated over multiple sessions in activities based on finding real world objects, drawing objects on a page, and finding and adding to each other's pages. For the entire duration of the study, one half of the population used the Tangible Flags technology and the other half used a paper system. With the paper system, the page that the child drew on was left to mark the real world object, providing a shared space for collaborative activity as well as giving a contextual connection, in the same manner as a Tangible Flag.

However, in contrast to the Tangible Flags technology, children using the paper system could only access a page by returning to its physical location and did not have a mobile computer to support their awareness of peer activity. The quantitative analysis of the study is based largely on a direct comparison between the paper system and the Tangible Flags technology.

5.1 Research Goals

The effect on children's learning and collaborative activity by providing digital information in context has been well established by the research detailed in Chapter 2. The case study detailed in Chapter 4 examined how Tangible Flags can provide children with a highly visual awareness of such information and a tangible means of embedding and accessing it in the real world. This study specifically assesses the children's awareness of peer activity and the extent and manner of the children's collaborative activity. Studying multiple examples of use in conditions that were tightly controlled in terms of the activities and ages of the participants provides a clearer picture of why such collaborative behaviors occur and how they are influenced by the technology and other factors, such as environment.

Another goal of this study was to further support the conclusions of the case study detailed in Chapter 4. I was specifically interested in further understanding the effects of these elements:

1. The concrete and tangible connection between the real world and information. This was provided by both the paper system and the technology.

2. The flexibility to explore independently, combined with immediate awareness of peer activity and access to the shared workspace. This was provided only by the technology.

3. Concurrent interaction in shared workspace. The paper system provided the opportunity for children to work together only in the same physical space. The technology provided children the opportunity to work together in separate physical spaces on each tablet computer but in a shared workspace.

4. General usability. This includes observations on differences in use between the paper system and the technology as well as any difficulties associated with marking the real world with either a Tangible Flag or a paper page.

5.2 Hypotheses

I had the following hypotheses about the results of this study:

H1. *Using the technology, children would demonstrate more awareness of each other's drawing activities.*

With the paper system, children must return to the physical location of a page in order to see any additions made by other children. With Tangible Flags, children have the flexibility to review pages without returning to the physical location. The thumbnails in the software interface give an indication whenever changes have been made to a drawing and children can immediately access the page to view the changes. The color and number of the pages in the interface matches that of the physical flags marking the environment, providing continual and immediate feedback of which pages have been discovered.

For these reasons, I expected children to demonstrate an increased overall awareness of other's activities when using the Tangible Flags technology. Specifically, I expected an increase in the number of times children interacted with pages; either by discovering other children's pages or by reviewing previously discovered or created pages. I expected this increase to come primarily from an increase in the number of reviews of previously discovered pages. However, I also expected that children would still return to the physical location of the page as often as those using the paper system did. I also expected that while children would interact with more pages, they would not require more prompts when locating pages. Finally, I expected that the children would have a better recall of the color and number of Tangible Flags they interacted with when answering a questionnaire immediately after the activity.

H2. *Using the technology, children would participate in more collaborative activity.*

In addition to providing children immediate awareness of other's drawing activities, the Tangible Flags technology enables children to make additions to pages without physically returning to the location of the Tangible Flag. Because every child has their own tablet, there may also be implicit permission to modify drawings. This contrasts with a paper page that may carry a sense of possession and ownership. In addition, children can simultaneously access and concurrently draw on the same page using their own tablet computers without the limitation of sharing the physical space inherent to a paper page

For these reasons, I expected children to participate in more collaborative activity when using the Tangible Flags technology. Specifically, I expected children to make additions to pages more often. I also expected that while children would make more additions, they would not require more prompts to do so. I expected more instances of children drawing on top of or inside an existing drawing on the page, as opposed to making their additions to a page in an empty space on the page. I expected more instances of children working on the same page simultaneously and in some cases from different physical locations. I expected more instances of children discussing their drawing activity with each other and watching each other work on a page.

H3. *When using the technology, children would participate in the activity longer.*

During the design process and the case study of Chapter 4, children were often very engaged when using the Tangible Flags technology. Children are also very social by nature. Increased collaborative activity should result in children having more desire to continue the activity even after drawing on every page. For these reasons, I expected the children to spend more overall time participating in the activity when using the technology.

H4. *The technology would not distract the children from the drawing activities and from their inspection of the physical environment while participating in the drawing activities.*

Both paper pages and Tangible Flags provide a similar visual and tangible connection between the drawings and the real world. There was expected to be no difference between paper and technology in how often the children inspected the environment during their drawing activity. It was also expected that there would be no difference in how often the children's drawings would represent real world objects.

5.3 Study Design

Eighteen children participated in this study (see section 5.4). The children were assigned to six groups with three children per group and group assignments did not change during the course of the study. Two groups were all boys, two groups were all girls, and two groups were mixed gender. One group of each type was assigned to use the Tangible Flags technology and one group of each type was assigned to use a paper system with a look similar to the technology (see sections 5.5.4 and 5.5.5). This assignment did not change during the course of the study. Every group participated in three distinct activities, with each activity occurring in a study session conducted for that group alone, for a total of 18 sessions during the course of the study (6 groups and 3 activities). These three activities all had a similar structure but each had a different goal (see section 5.6). The activities were conducted in the same order for every group.

Verbal communication, coordination, and activity awareness are some common heuristics that have been suggested for evaluating collaborative systems [Pinelle et al., 2003; Convertino et al., 2004]. Metrics of these heuristics can be obtained from directly measurable observations of system, user and group activity or performance [Drury et al., 1999]. Some suggested metrics for collaborative systems include: countable events, recorded times or durations, responses to questions, observed methods of tool usage, expert judgments, and conversational constructs. To capture metrics for quantitative analysis, as well as children's activity patterns for qualitative analysis, all study participants were videotaped during the sessions and artifacts created were kept for analysis. Researchers followed a set of written guidelines (see Appendix G) for helping children and giving appropriate prompts (see section 5.6.4), which provided a structured means of eliciting responses from the children as well as metrics of their activity. Finally, the study participants answered a short questionnaire after the study (see Appendix F). See section 5.8.1 for details of the data collection and coding process.

The analysis of the study data used mixed methods. The data was collected using methods familiar in ethnography; the researchers participated in the study with the children while observing their responses and activities. Both qualitative and quantitative analysis was performed on the data collected. The qualitative analysis methods are described in section 5.8.3. Quantitative analysis was conducted using general estimating equations (GEE), a repeated measures statistical regression model, using five binary explanatory variables. Three of these were obtained from the distribution of participants in the study: gender of the participant, whether the participant's group was of same or mixed gender, and whether the participant used the Tangible Flags technology or the paper system. Two dummy variables were created as binary explanatory variables in order to analyze the effect of the different activities. Section 5.8.2 provides a detailed description of the metrics and regression models used.

5.4 Participants

Eighteen children from a kindergarten class participated in this study. The children were all classmates at the Center for Young Children, the University of Maryland's on campus preschool. None of these children had any previous exposure to the Tangible Flags technology and had not participated in any design sessions related to it. There were 9 boys and 9 girls, all around late 5 to early 6 years in age. There was another girl with parental permission to participate in the study that was available as an alternate. Children had the option to decline participation in the study at any time. One girl did so and was replaced by the alternate. Detailed demographics were not collected, but the preschool primarily serves the University of Maryland, which is an ethnically diverse population. All of the children had used computers before in their classroom. The participants had no vision related conditions. Since reading was not integral to the study activities, data on the children's reading ability was not collected.

Prior to conducting the study, children were assigned to 6 groups of three children. Three of the groups were assigned to use the Tangible Flags technology (see sections

5.5.4 and 5.5.5) and three groups were assigned to use a paper system with a look similar to the technology (see section 5.5.4). For each system, one group consisted of three boys, one group consisted of three girls and one group was mixed gender. The mixed gender group for the technology condition consisted of two girls and one boy while the mixed gender group for the paper system consisted of two boys and one girl. Children of different ethnic backgrounds were evenly distributed among the six groups. The classroom teachers also gave several constraints on which children had difficulties when working together. Children were assigned to groups alphabetically by last name within these constraints.

The study took place over the course of five weeks. Each group of children participated in three sessions, each session for a group occurring on a different day, typically a week apart. Sessions were usually conducted twice per week, with one or two sessions for different groups being conducted any given day. The study was conducted at school during the classroom's 'Center' time, when children are free to participate in various classroom activities such as painting, dress-up, blocks, etc. A few sessions that were started during 'Center' time did not end until during the children's playground time. This was only an issue for a child on one occasion and the child was allowed to end the study activity early and join his classmates on the playground.

5.5 Materials

5.5.1 Permission Forms

The University of Maryland's Institutional Review Board approved this study, including the use of child participants. The assistant director of the Center for Young Children also approved this study. The parents of participating children received a short letter explaining their child's participation in our research and also signed a permission slip (see Appendix E).

5.5.2 Questionnaires

Researchers asked children questions from a post questionnaire. These questions were read aloud to the children and the answers recorded on a questionnaire form (see Appendix F).

5.5.3 Research Team Guidelines

Conducting each session of the study required three researchers, one to accompany each child with a video camera. I was one of the three for every session, with two others chosen from a group of four. Prior to conducting the study, a guideline form was developed for researchers to follow during the study (see Appendix G).

5.5.4 Interfaces

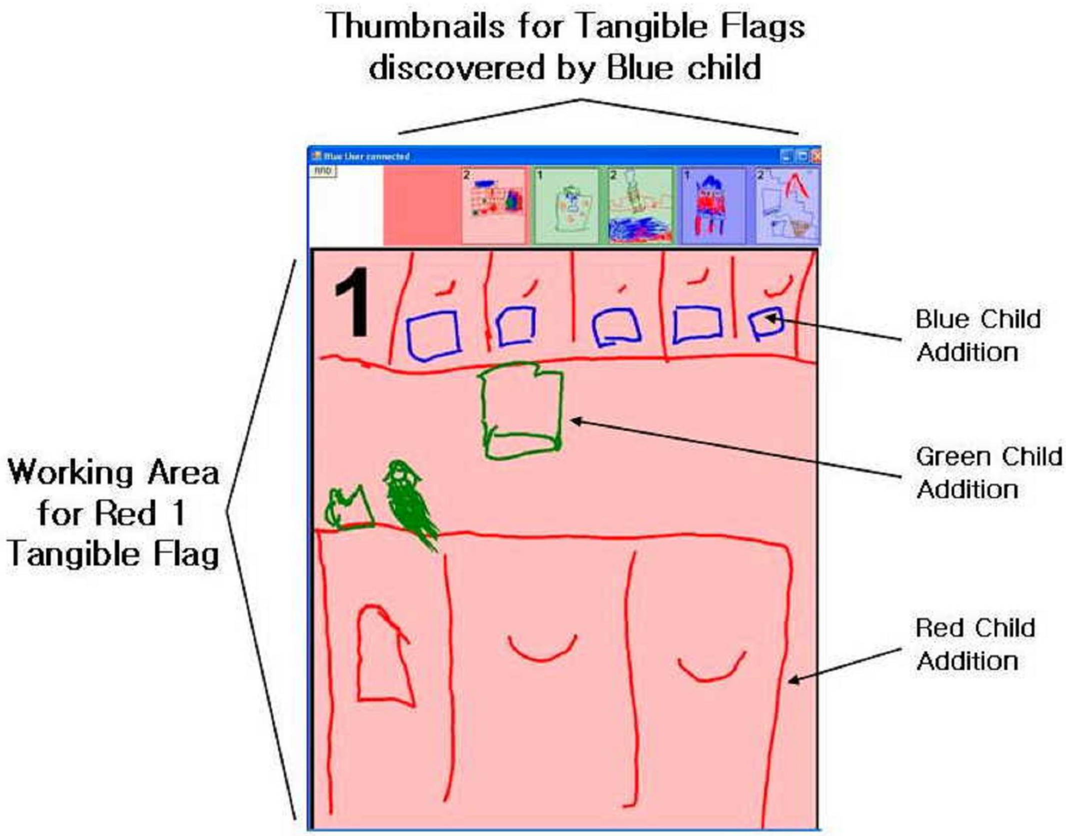

Figure 15. Example user interface for comparative study, showing various components. The working area for the Red 1 Tangible Flag is currently active and shows additions made by study participants.

The software interface was a simplified version of the interface developed and used in the case study detailed in Chapter 4. The inking and delete tool buttons were removed from the interface. The ScratChat area was removed from the interface. The flag thumbnail area (see Figure 15) was positioned across the top of the screen and had space for 6 thumbnails, two of each color, and the working area for Tangible Flags below (see Figure 15). The main working area was void of any markings except the Tangible Flag number in the upper left corner. There were no vote widgets and no vote summary area.

This simplified interface had one new feature. A visual alert occurred on a flag thumbnail whenever another user made an addition to the working area of that Tangible Flag. This alert was a flashing effect accomplished by alternating the flag thumbnail brightness between one half second at normal brightness and one half second at 50% brighter. The alert only occurred for the thumbnails of minimized pages, since the page currently displayed in the working area does not display a corresponding thumbnail. An alert would continue to flash until a user selected that thumbnail to be displayed in the working area. If minimized again, the alert would only occur again after a new change.

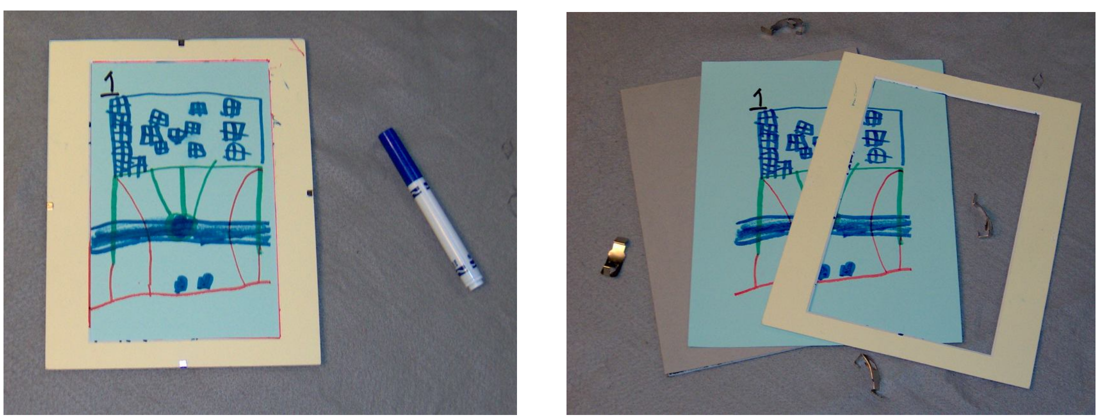

Figure 16. Paper system with blue marker showing children's drawings for Blue 1 (left), and paper system disassembled, showing hard writing surface, colored page for drawing, yellow matte border, and clips that hold it together (right).

Each child in a paper group was given a child safe marker of a specific color (red, green or blue) and two pages. A page consisted of an 8” x 11” hard writing surface covered with a lightly colored sheet of paper, which was covered by a yellow matte border about 1” thick (see Figure 16). The paper’s color matched the marker color and the pages were numbered 1 and 2 with black ink in the upper left corner.

5.5.5 Technology

Each child in a Tangible Flag group was provided with a Compaq Model TC1000 Tablet PC with a 995 MHz Transmeta 5800 processor and 240 MB of ram, running Microsoft Windows XP Table PC edition 2005 version 2002 service pack 2 operating system, with a 10” diagonal display at a resolution of 768 by 1024 pixels (see Figure 17). The detachable keyboards were removed.

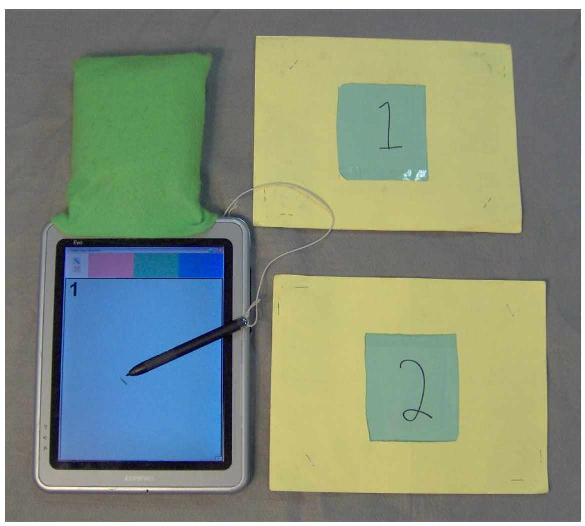

Figure 17. Equipment provided to a ‘Green’ child in a Tangible Flag group during the comparative study, showing Tablet PC with attached RFID reader (under green cover) and two Tangible Flags.

Two devices were available for interaction with the software interface. One was a standard tablet pen attached to the computer with a piece of elastic string. The other was a RFID reader attached to the top of the tablet (see Figure 17). The use of this input device is detailed in Chapter 3, Section 3. Each child in a technology group was also given two Tangible Flags, numbered 1 and 2, with a color matching the RFID scanner cover of their computer (see Figure 17). The tablet computers used built in wireless to connect with an IEEE802.11g wireless router. The Tangible Flags client software communicated via wireless with server software running on a Dell Inspiron 600M laptop with a 1.6GHz processor, 512 MB ram, and Windows XP.

5.6 Procedure

Each session began with asking a group of three children if they would like to help us with the study. The children joined the researchers in the hallway outside their classroom for a few minutes discussion about the upcoming activity. I explained that we would go to the activity area and then each of them was to find objects of a certain type and draw pictures of them. Depending on the activity, this object was: a piece of furniture, a pattern, or a structure. I would then ask them to explain what furniture/patterns/structures were and asked the children find a few examples of this type object in the hallway. I then explained that after creating their first drawing, they would leave behind the Tangible Flag, or the actual page in the case of the paper system. They could then look for each other's pages and draw on them when they found one. They could also create a second page at any time they wanted. They could only create two original pages, but could revisit pages and make additions as often as they liked. Children were told that they could quit the activity at any time.

Each child was assigned to a researcher for the duration of the activity. Researchers followed a set of written guidelines (see Appendix G) for helping children and giving appropriate prompts (see section 5.6.4). These procedures were practiced during the pilot study and carried out consistently. Researcher also operated a video camera to capture the child's activity and asked questions about the child's activities in order elicit detailed explanations. After the child finished with the activity, the researcher would ask them the questions from the questionnaire (see Appendix F). After finishing this, the child would be escorted back to join their class. After 20 minutes any children that were still participating in the activity were asked to finish their current drawing and answer the questionnaire.

Each group participated in three different activities, with each activity on a different day and each activity in order. After the brief group discussion before each activity, children and researchers went to the activity area. Children looked independently for their first object with the researchers reminding children to split up when necessary. After creating their first drawing, the children were free to interact.

5.6.1 Activity 1

The first activity was the training activity. It was conducted in an empty classroom. The children were asked to find and draw pictures of furniture in the room. Various furniture found by the children included tables, chairs, desks, bookcases and other classroom items. During this activity, researchers were free to help children with any questions without strictly following the guidelines for prompting (see section 5.6.4). Researchers encouraged children to interact, including prompting them to find and add to each other's drawings, showing them how to use the technology, and make suggestions that helped children to discover pages and keep them engaged and participating in the activity.

5.6.2 Activity 2

The second activity also occurred in the same empty classroom as the first activity. During this activity, children were asked to find and draw pictures of patterns. Patterns found by the children included floor tiles and carpet, pillows and cushions, tablecloths, cabinets and cubicles, and various other classroom objects. During this activity, researcher followed specific guidelines on when and how to prompt children to find pages and make additions to drawings (see section 5.6.4).

5.6.3 Activity 3

The third activity occurred on the fenced playground outside the school. The children were allowed to explore anywhere inside the fence. They were asked to find and draw pictures of structures. Many structures found by the children included the numerous playground structures, the school, the maintenance shed, nearby buildings outside the fence and even the fence itself. We sometimes had to share the playground with children from other classes. During these times, the non-participating children were asked not to move pages or Tangible Flags and were also discouraged from interacting with the children in the study. The activity was timed to never occur while the children's classmates were on the playground. During this activity, researcher followed specific guidelines on when and how to prompt children to find pages and make additions to drawings (see section 5.6.4).

5.6.4 Prompts and Questions

During the activities, researchers followed specific guidelines on when and how to prompt children to find pages and make additions to drawings. Prompts were provided to help reduce frustration children might have when trying to find others' drawing. Prompts also provided as a means to help children stay on track with the activity. This was important because the activities were broad enough that the children might have uncertainty about what to do next. They could also become involved in doing things not central to the study as a result of being in a fun environment, especially on the playground. Finally, and most importantly, prompts were a structured means of eliciting responses from the children while still providing a metric of their activity.

Prompts were primarily phrased as questions. Prompts provided by the researchers consisted of two types. The researchers asked basic prompts when children were deciding what object to draw, deciding where to place a page or Tangible Flag, or deciding whether to create a new page or look for an existing one. A basic prompt consists of a single question that could be repeated or slightly varied to match circumstances as necessary. The researchers gave leveled prompts a child was looking for others' pages or Tangible Flags, and when a child discovered a page and was making decisions on what to add. Leveled prompts consisted of a series of related questions or statements that were to be asked in order or at a certain point during an interaction with a page. Leveled prompts were used when a more detailed metric of the children's behavior was desired and counting of a basic prompt might not provide data as useful for analysis. See Appendix G for details.

In addition to prompts, the researchers asked the children questions intended to elicit a descriptive response. These questions were focused on asking the children what their drawings were, either in part or in whole. Additional questions might be asked based on a child's response. Questions were also asked about the children's use of the technology. All descriptive questions were neutral in nature and did not suggest a specific course of action to the child, instead, questions attempted to elicit a response that indicated the child's intent. See Appendix G for details.

5.7 Pilot Testing

Participants for a pilot test in the age range of the study participants, late 5 to early 6 years old, were not available. As an alternative, I conducted pilot tests with children a year older or a year younger. Before conducting the study, I pilot tested portions of the technology, material and procedure with two younger members of the children's design team, who were between six and seven years old, about a year older than the study participants. I further tested the materials and procedure over several sessions with four children from the Center for Young Children who were a grade younger than the study participants. This pilot testing helped set the number of pages for each child at two and helped decide the activity duration that was reasonable to keep the children's attention. The pilot testing confirmed that furniture, patterns and structures were reasonable choices of objects for the children to draw. Pilot testing helped refined the wording and timing of the prompts given, as well as the number of prompt levels. Most importantly, the pilot study gave an opportunity for all the researchers involved to practice. Conducting the pilot study proved to be immensely valuable in achieving consistent prompting and interaction between researchers and study participants and consistent video taping of children's activity.

5.8 Analysis Methodology

Videotaping of every participant combined with the researcher guidelines (see Appendix G) was designed to capture the children's activity patterns. In addition, the artifacts created by the children were available for analysis. For the paper system, their drawings were kept. For the Tangible Flags technology, the server logged the children artifacts, which includes timestamps for every addition to the artifact. Review software can provide a view of the artifact at any moment in time. Finally, the children answered a short questionnaire after the study (see Appendix F).

5.8.1 Data summarization and coding

To review and encode the raw data, a coding sheet was created (see section 5.8.1.1). During review of the raw data, a coding sheet was filled out each time a child interacted with a page. A coding sheet summarizes all data beginning with the child's search for a page and ending after the child's discovery, inspection and possible addition to a newly found page. Subsequent visits to previously discovered pages were detailed on a new coding sheet, but only if they involved an addition to the page, prompting by the researcher, or interactions with other children. At the end of reviewing the tape of a child's session, there was one sheet for every time the child interacted with a page by: creating a new page, discovering page created by another child, or returning to previously discovered page. These page interactions form the basis for both quantitative and qualitative analysis.

The coding sheet has fields to organize notes around various components of interaction, such as the search for a page, additions to a page, interactions with other children and researchers, and notes concerning environment or technology. Some fields are specifically for recording time or prompt counts, while others are more generic, allowing for recording of pertinent details. These were usually recorded in a field provided for observation about specific components of the page interaction, but were also sometimes recorded as footnotes to an event count field, or as notes in the margin of the summary coding sheet.

5.8.1.1 Validity

An initial coding sheet (see Appendix H, section H.1) was created. After some initial efforts at coding video, a small adjustment was made to the coding sheet (see Appendix H, section H.2) to improve organization and provide a few additional fields. After conducting inter-reliability on the coding of 25% of the video (see Appendix H, section H.4), coding guidelines were developed (see Appendix H, section H.5). Also, some additional codes were developed at this time and incorporated into the final coding sheet (see Appendix H, section H.3). The guidelines and final coding sheet were used to summarize the remaining 75% of the video. Afterwards, a review of the coding sheets was conducted and activity patterns emerged in the general notes. These were developed into additional codes for qualitative analysis. Event counts, times, codes and other summary data were entered into an excel spreadsheet. This spreadsheet was used to calculate totals across groups and sessions.

Coded fields that did not attain better than 80% rates of inter-reliability are not used for analysis (see Appendix H, section H.4). During video coding, unknown or difficult to determine events were verified by looking at the children's artifacts, if possible.

5.8.2 Quantitative Analysis

Quantitative analysis is used to evaluate whether the hypotheses of this study are supported. This section details the metrics and statistical models used for the quantitative analysis.

5.8.2.1 Metrics

The metrics used for statistical analysis are event counts or times recorded on the summary coding sheets (see section 5.8.1). Time and event count totals per session were calculated for each child. The metrics include the following:

- **Page Interaction Count** - The number of page interactions beyond the initial creation of two pages. This metric relates to the first hypothesis.

- **Review Count –** The number of page interactions in which the child reviewed a previously viewed page, either using the technology or by returning to the physical location. This metric relates to the first hypothesis.

- **Physical Return Count –** The number of page interactions in which the child returned to the physical location of a previously visited page. This metric relates to the first hypothesis.

- **Find Recall Count –** The number of correct answers to the "How many (*Red, Green, or Blue)* flags/papers did you find?" questions on the questionnaire. This metric relates to the first hypothesis.

- **Add Recall Count –** The number of correct answers to the "How many (*Red, Green, or Blue)* flags/papers did you add something to?" questions on the questionnaire. This metric relates to the first hypothesis.

- **Location Prompt Count –** The sum over all page interactions of the number of location prompts given. For each page interaction, up to four prompts could be given (see Appendix G). In cases where the same level prompts were repeated or given out of order, the count value for that page interaction was taken as the maximum of either the highest level prompt given or the total number of prompts given. This metric relates to the first hypothesis.

- **Addition Count –** The number of page interactions in which the child made an addition to the drawing on the page. This metric relates to the second hypothesis.

- **Overlay Count –** The number of page interactions in which the child's addition to a page was done on top of or inside the drawing that was already on the page. This metric relates to the second hypothesis.

- **Addition Prompt Count –** The sum over all page interactions of the number of level one and level two interaction prompts (see Appendix G) given. Level three interaction prompts were not used in the analysis because it became clear during the coding process that there was some ambiguity between this prompt and the basic intent prompt. This metric relates to the second hypothesis.

- **Inspect Count –** The number of page interactions in which the child inspected the environment while drawing on a page. This metric relates to the fourth hypothesis.

- **Exist Count –** The number of page interactions in which the child's drawing represented a real element of the environment. Ambiguous cases were treated as not existing. This metric relates to the fourth hypothesis.

- **Total Time –** The total time the child participated in the session. This metric relates to the third hypothesis.

- **Average Time per Page –** The average time the child spent per page interaction, both locating a page and drawing on it. This was calculated from the total time divided by the number of page interactions for the session. This metric relates to the third hypothesis.

5.8.2.2 Models

For each activity session, observations for different children are treated as independent samples (see section 5.11.6 for limitations of this approach). Observations for the same child in different activities cannot be considered independent. Therefore, any statistical analysis must be performed separately for each activity, or performed on a summary measure for all three activities, or conducted using methods for correlated data, also known as repeated measures or panel data [Everitt, 1995]. Dr. Harring of the University of Maryland's Dept. of Measurement, Statistics and Evaluation confirmed that regression analysis using generalized estimating equations (GEE) would be a good approach and gave invaluable advice on how to apply it to this study. GEE is an extension of the general linear model of statistical regression for modeling correlated data [Hardin and Hilbe, 2003]. GEE is a population-averaged model; also know as a marginal distribution model. Such models can be used for examining effects of a treatment on an entire population, but is limited in that it cannot be used to predict the effects for specific subjects. This was appropriate for this study since I wish to establish the overall effects, not specifically predict a child's future response.

GEE regression analysis provides a model for response variables, i.e., measured values of the metrics, based on a set of explanatory variables, i.e., predictors. Values of the model's coefficients predict each explanatory variable's contribution to a response. Post-hoc calculation of a p-value for each predictor is based on an estimation of the Wald-z statistic [Hardin and Hilbe, 2003]. A value of 0.05 or less rejects the null hypothesis that a regression coefficient for a predictor is zero; hence the predictor's contribution is statistically significant. A p-value for the entire model is calculated from a Wald statistic based on the Chi squared value of the model. A value of 0.05 or less rejects the null hypothesis that every regression coefficients is zero [Rabe-Hesketh and Everitt, 2003]; hence the model as a whole is significant. Identifying significant explanatory variables are my primary interest for this study. Both the model and the predictor should be significant before making claims of significance for a given explanatory variable. For count metrics, the regression coefficients predict the incidence rate ratio (IRR) of counts, i.e., the number of expected counts when the explanatory variable equals 1 divided by the number of expected counts when the explanatory variable equals 0, across all values of the other explanatory variables. For time metrics, the regression coefficients predict the explanatory variable's direct effect on the measured response. Regression coefficients are of secondary interest, mostly in that they indicate a direction of an explanatory variable's effect.

All statistical calculations were performed using Intercooled Stata 9 [www.stata.com]. The measurements for each child are treated as independent panels, while the measurements for the same child in each of the three different activities are treated as correlated data, i.e., the repeated measure. GEE calculates a matrix that is used for correlating the repeated measures during regression analysis. This matrix can have different structures depending on the nature of the repeated measure. The data for this study consists of a small number of panels and the repeated measure has no direct time dependency other than the order of the activity. For these reasons, the only two choices for the GEE correlation matrix structure are the independent matrix and the unstructured matrix [Hardin and Hilbe, 2003]. The independent matrix is the most basic; however the unstructured matrix can give additional insight into correlation between activities. Therefore, both were used in this analysis. The choice of correlation matrix structure for each measurement was based on which gave the best model fit. The criteria for determining model fit are dependent on the type of statistical distribution used. This process is detailed below, in the sections specific to the different metrics.

Stata implements GEE using generalized least squares (GLS) for estimating the covariance matrix. For all regression calculations, the Stata option was used that calculates the GLS covariance matrix using the N-P divisor, where N = number of samples and P = number of parameters, instead of the standard N only divisor. This modified divisor is suggested for use with small sample sizes [Hardin and Hilbe, 2003]. GEE requires that missing data be missing completely at random (MCAR), i.e., that the chance of a missing observation is independent of any observed or unobserved measure [Hardin and Hilbe, 2003]. Two sets of observations are missing from this study's data; both for the same child, a girl in an all girl group using the Tangible Flags technology. One set of data is missing for the first activity, due to a malfunction with the video camera used during the session. The other set of data is for the last activity, due to a failure of the tablet used in the study. Both causes are independent of the observations made and so meet the requirements of GEE.

Three binary explanatory variables were obtained from the distribution of participants in the study. Two dummy variables were created as binary explanatory variables in order to analyze the effect of the different activities. So these five explanatory variables were used in the regression analysis:

- **Group** - indicates whether the participant's group was mixed gender.
- **Gender** - indicates the participant's gender.
- **Tech** - indicates whether the participant used the Tangible Flags technology.
- **Training** - dummy variable for the training activity (first activity).
- **Outdoors** - dummy variable for the outdoor activity (third activity).

For every metric, I investigated three different models. The basic model used only these five explanatory variables, the two-way interaction model used the five variables plus three double interaction terms (group X gender, group X tech, gender X tech), and the full model used the five variables plus the three double interaction terms and one triple interaction term (group X gender X tech). However, models using interaction terms were very limited because a small number of independent samples combined with an increased number of regression parameters likely results in over-fitting [Zucchini, 2000]. In a number of cases, the GEE analysis would not converge for two-way interaction and full models, very likely due to the small sample size. The basic model always converged.

Depending on the type of statistical distribution used, two different model evaluation criteria are appropriate for comparing models. These are the Pearson dispersion and the quasilikelihood under the independence model information criteria (QIC). Pearson dispersion nearer to one indicates a good model fit, as does a lower QIC value. The QIC provides two values, the basic QIC, which is appropriate for comparing the correlation matrix structures, and the QICu, which is appropriate for comparing models with different predictors [Hardin and Hilbe, 2003]. Stata evaluates all these criteria for GEE. Only the basic model was used for comparing the independent correlation matrix structure with the unstructured correlation matrix structure. See sections 5.8.2.3, 5.8.2.4, and 5.8.2.5 for details on the statistical distributions and model evaluation criteria used in each case.

Significant results are reported from the correlation matrix that provided a better model fit. Correlation matrix results are reported for models when an unstructured correlation matrix is used. Significant interactions indicated by the two-way and full models are reported only if the overall model is significant and the model criterion was at least as good as the basic model. Histograms provide further insight into interactions.

5.8.2.3 Analysis for Page Interaction, Review, Physical Return, Addition, and Prompt Counts

These event counts have no exact upper limit on the number of times they could occur during a session. Two discrete probability distributions that are appropriate for modeling this type of count data are the Poisson distribution and the negative binomial distribution. In a Poisson distribution, the mean and variance are equal, so a single parameter, the mean, describes the distribution. This has a limitation that it cannot account for over-dispersed data, where the variance is larger than the mean. The negative binomial distribution gives a second parameter that expresses the variance as a function of the mean. The negative binomial distribution is commonly used in statistical modeling when data is over-dispersed [Simonoff, 2003].

All of these measurements were tested for over-dispersion. This was accomplished in three ways. First, examination of the data gave an indication of whether over-dispersion was to be expected. Data with either few zeros or no outliers was less likely to be over-dispersed and tended to match a Poisson distribution well. Second, the mean and variance of each measurement was examined for each activity separately, since responses across activity cannot be considered independent. The variance divided by the mean is a rough gauge of how over-dispersed the data is. Third, regression analysis provides a deviance-based dispersion statistic, which, if greater than 1.5, is generally considered to be an indication of over-dispersion [Hardin and Hilbe, 2003]. However, this interpretation is dependent on the sample size and number of predictors, amongst other factors. For consistency, I based choice of distribution on the dispersion statistic for a GEE regression analysis on the basic model with an independent correlation matrix. Based on the above three criteria, a Poisson distribution was chosen for modeling page counts, addition counts and addition prompt counts. A negative binomial distribution was chosen for modeling review counts, physical return counts and location prompt counts.

The GEE analysis for these models was run using a log link function, standard for Poisson and negative binomial regression. In addition, the standard errors were divided by the Pearson dispersion value, a common post-hoc correction for over-dispersed count data [Hardin and Hilbe, 2003]. Since this has a minimal effect when the dispersion value is near one, this was used for all models regardless of dispersion and distribution, for the purpose of consistency. Both the Pearson dispersion and the QIC are appropriate model evaluation criteria for Poisson and negative binomial regression in GEE.

5.8.2.4 Analysis for Inspect, Exist, Overlay, Find Recall, and Add Recall Counts

These event counts fit a multiple trial binomial distribution because they represent the number of times that a child responded in a certain way, out of a fixed number of opportunities. For recall counts, this is the number of correct responses out of 2 questions. For the overlay counts, this is the number of times an overlay event occurred, where every addition represents an opportunity for the event to occur. For inspects and exists counts, every time a child either created a page or made an addition represented an opportunity for the event to occur. In other words, each time a child made an addition to a page, there was an opportunity to inspect the environment, to draw something that existed, and to make the addition as an overlay.

These metrics were modeled in the GEE analysis using a logit link function, which is standard for binomial trial regression. Using an observation variable for the number of binomial trials violates the MCAR requirement of GEE whenever that variable has a value of zero. This occurred a single time, for the addition count, out of 52 total observations across 18 panels. Since this has minimal impact on the results, it was ignored. The standard errors were corrected by dividing by the Pearson dispersion value. Only the Pearson dispersion was used for an evaluation criterion since the QIC is unavailable for multiple trial binomial distributions.

5.8.2.5 Analysis for Total Time and Average Time per Page

It was expected that these measurements would follow a normal distribution. Two normality tests were conducted on the data for each measurement, a skewness/kurtosis test and the Shapiro-Wilk W test. Both tests indicated that total time was normally distributed. The Shapiro-Wilk W test indicated that average time per page was not normally distributed, at a significance level of 0.047. Therefore, regression analysis for average time per page was conducted on a logarithmic transformation of the raw data [Jaccard, 1983]. GEE analysis was run with Gaussian distribution using an identity link function, which is standard for normally distributed data. Only the QIC was used for an evaluation criterion since the dispersion is mostly relevant for count data.

5.8.3 Qualitative Analysis

Qualitative analysis was also used in this study [Stake, 1995; Creswell, 1998]. It use frequency counts of metrics coded from the data to make a qualitative assessment for cases where the counts were of insufficient importance or simply not amenable to a detailed statistical analysis. The codes were developed during summary and review of the raw data (see section 5.8.1) and illustrative examples are selected to validate the results and provide further insight into children's activity patterns. These examples include transcriptions from the video of children's conversations with each other and with researchers, and images of the children's artifacts. See appendix I for complete details for all examples.

5.9 Results

5.9.1 Quantitative Results

5.9.1.1 Page Interaction Count

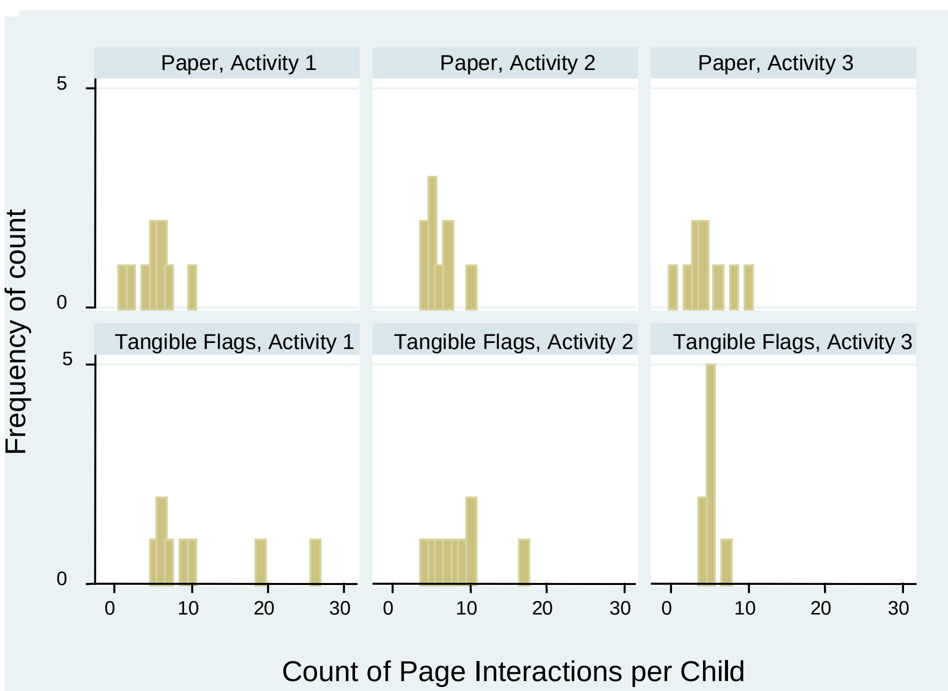

Figure 18. Histograms of Page Interaction Count per Child by Technology and Activity

Summary statistics for page counts for the second and third activity indicated a Poisson distribution. For the first activity, the data was over-dispersed. The dispersion value was 1.85 for a Poisson model and 0.27 for a negative binomial model. Therefore, a Poisson model was chosen. Both the Pearson dispersion and the QIC marginally favored the independent correlation matrix. The basic model was significant at p = 0.005. The tech variable was significant at p = 0.004, with an IRR = 1.562 and a standard error = 0.244. The outdoors variable was significant at p = 0.046, with an IRR = 0.669 and a standard error = 0.135.

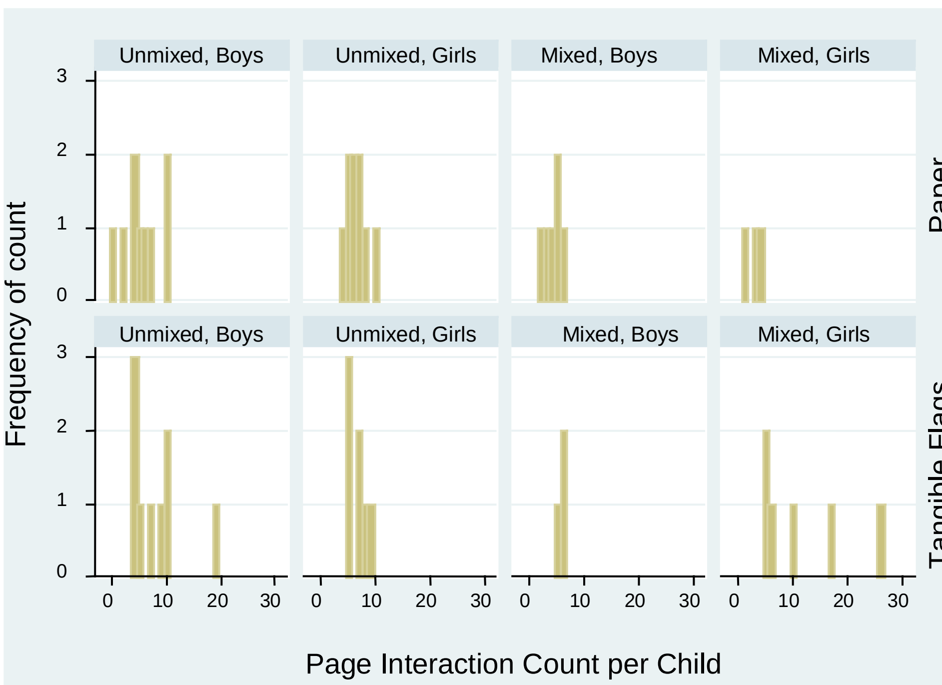

Figure 19. Histograms of Page Interaction Count per Child by Technology, Group Mix, and Gender

The full model had a better QIC than the basic model and indicated a significant interaction between group, gender and tech. Because of small sample size and over-fitting, this is unlikely to be an indication of an actual interaction effect. A look at a histogram (Figure 19) shows that girls in mixed groups using Tangible Flags had two of the three largest counts. Both of these counts occurred for the same participant (Girl, Group 6, and Green). This graph also indicates that these three largest counts (17, 19 and 26) were much larger than all the other counts, which were 10 or less. Conducting regression analysis with data from this participant (Girl, Group 6, and Green) removed still shows technology to be a significant effect.

5.9.1.2 Review Count

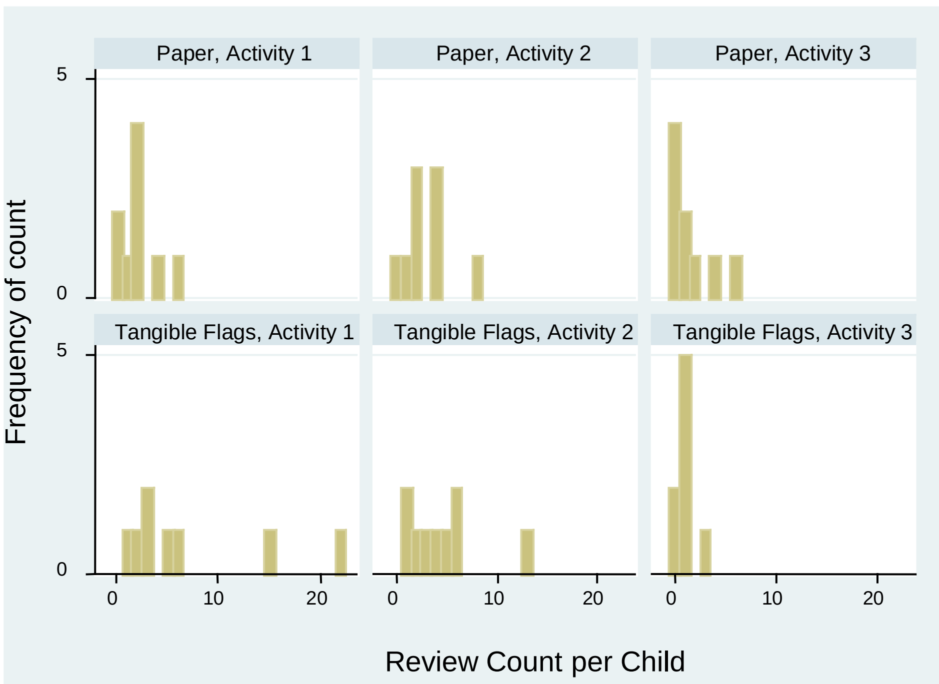

Figure 20. Histograms of Review Count per Child by Technology and Activity

Summary statistics for review counts for all three activities indicated over-dispersion. The dispersion value was 3.03 for a Poisson model and 0.83 for a negative binomial model. Therefore, a negative binomial model was chosen. The QIC marginally favored the unstructured correlation matrix, with Pearson dispersion being roughly equivalent for both. The basic model was significant at p = 0.024. The outdoors variable was significant at p = 0.007, with an IRR = 0.347 and a standard error = 0.135. The correlation matrix indicates a moderate correlation (r = 0.574) between the first and second activity, a weak negative correlation (r = -0.014) between the first and third activity and a weak correlation (r = 0.006) between the second and third activity. The basic model had better QIC than the two-way interaction model. The full model did not converge.

5.9.1.3 Physical Return Count

Summary statistics for physical return counts for all three activities indicated over-dispersion. The dispersion value was 2.92 for a Poisson model and 1.11 for a negative binomial model. Therefore, a negative binomial model was chosen. The QIC marginally favored the unstructured correlation matrix, with Pearson dispersion being roughly equivalent for both. The basic model was not significant at p = 0.246. The basic model had better QIC than the two-way interaction model. The full model did not converge.

5.9.1.4 Find Recall Count

The independent correlation matrix was used for the model, with a Pearson dispersion of 1.185. This was marginally better than the Pearson dispersion of 1.251 for the unstructured correlation matrix. The basic model was significant at p = 0.012. The tech variable was significant at p = 0.001, with an IRR = 13.384 and a standard error = 9.991. Neither the two-way interaction model nor the full model converged.

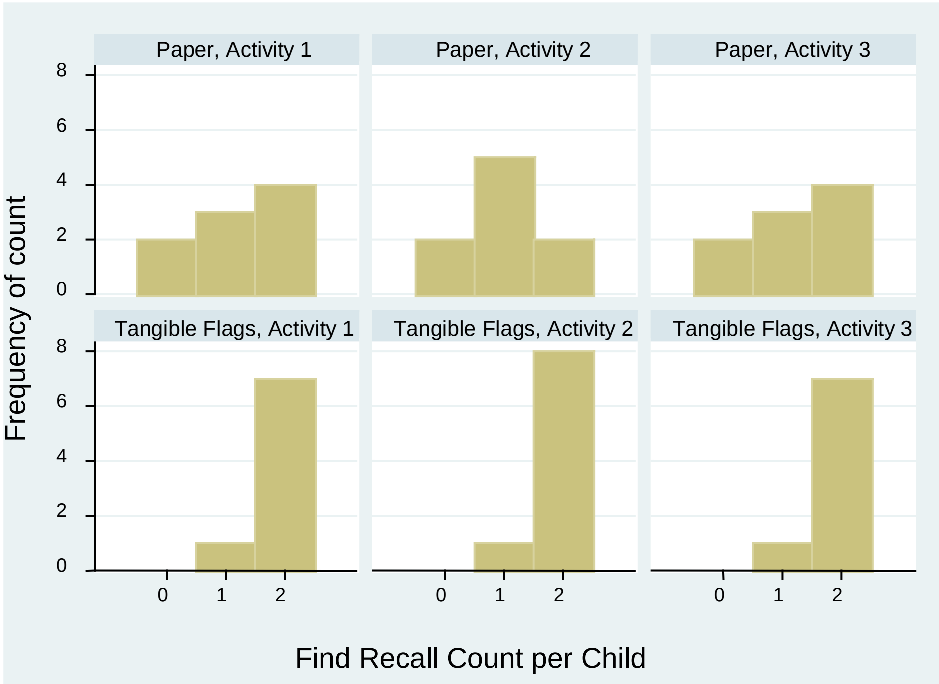

Figure 21. Histograms of Find Recall Count per Child by Technology and Activity

5.9.1.5 Add Recall Count

The independent correlation matrix was used for the model, with a Pearson dispersion of 1.994. This was better than the Pearson dispersion of 2.434 for the unstructured correlation matrix. The basic model was significant at $p = 0.046$. The tech variable was significant at $p = 0.002$, with an IRR = 15.922 and a standard error = 13.935. Neither the two-way interaction model nor the full model converged.

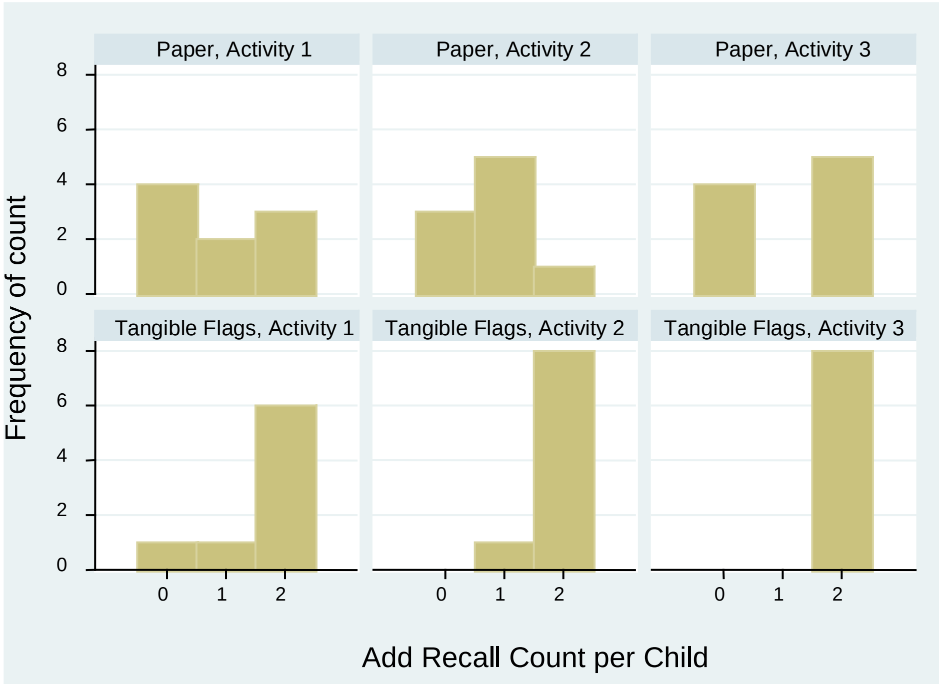

Figure 22. Histograms of Add Recall Count per Child by Technology and Activity

5.9.1.6 Location Prompt Count

Summary statistics for location prompts counts for all three activities indicated over-dispersion. The dispersion value was 5.66 for a Poisson model and 1.52 for a negative binomial model. Therefore, a negative binomial model was chosen. The QIC marginally favored the independent correlation matrix, with Pearson dispersion being roughly equivalent for both. The basic model was not significant at $p = 0.124$. The basic model had better QIC than both the two-way interaction model and the full model.

5.9.1.7 Addition Count

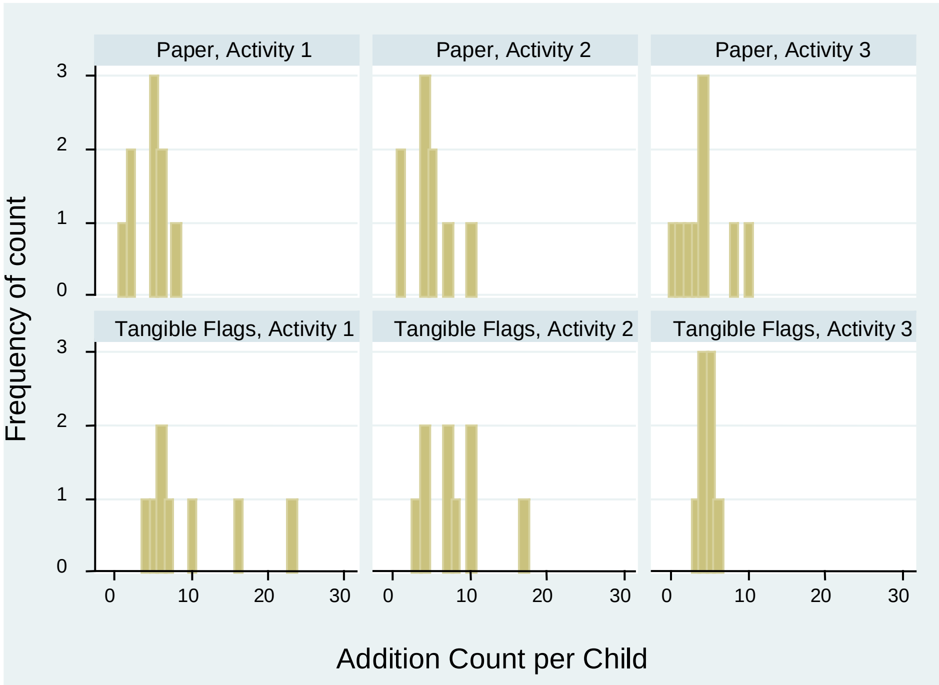

Figure 23. Histograms of Addition Count per Child by Technology and Activity

Summary statistics for addition counts for the third activity indicated a Poisson distribution. For the first and second activity, the data was over-dispersed. The dispersion value was 2.03 for a Poisson model and 0.34 for a negative binomial model. Therefore, a Poisson model was chosen. The QIC marginally favored the unstructured correlation matrix, with Pearson dispersion being roughly equivalent for both. The basic model was significant at $p = 0.017$. The tech variable was significant at $p = 0.030$, with an IRR = 1.581 and a standard error = 0.344. The correlation matrix indicates a moderate correlation ($r = 0.657$) between the first and second activity, a weak correlation ($r = 0.080$) between the first and third activity and a weak correlation ($r = 0.014$) between the second and third activity.

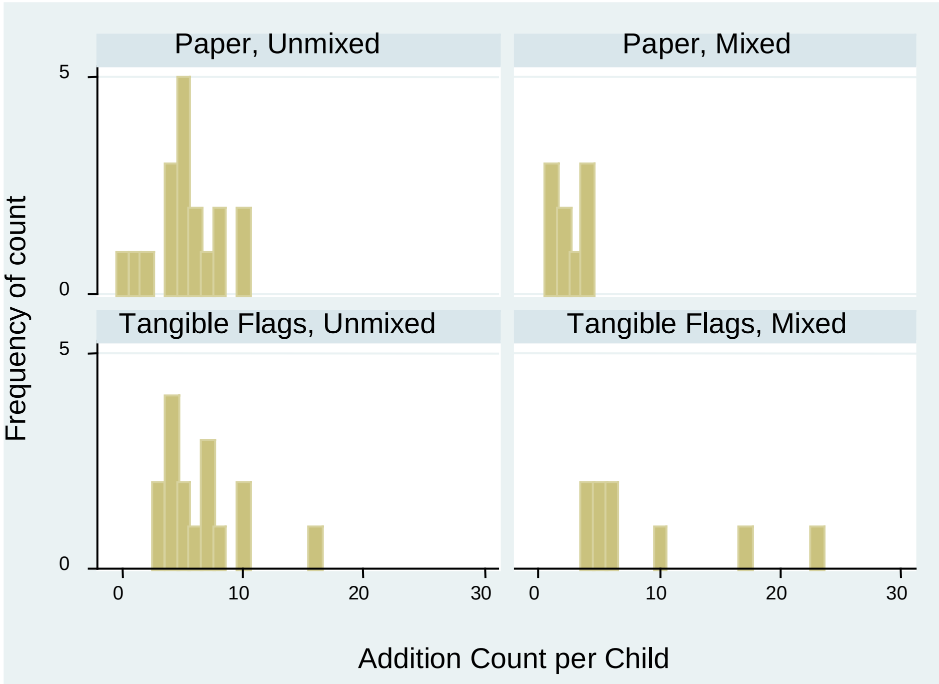

Figure 24. Histograms of Addition Count per Child by Technology and Group

The two-way interaction model had a better QIC than the basic model and indicated a significant interaction between group and technology. Because of small sample size and over-fitting, this is unlikely to be an indication of an actual interaction effect. A look at a histogram (Figure 23) shows that mixed groups using Tangible Flags had two of the three largest counts. Both of these counts occurred for the same participant (Girl, Group 6, and Green), just as with the page interactions. This graph also indicates that these three largest counts (16, 17 and 23) were much larger than all the other counts, which were 10 or less. Conducting regression analysis with data from this participant (Girl, Group 6, and Green) removed still shows technology to be a significant effect.

5.9.1.8 Overlay Count

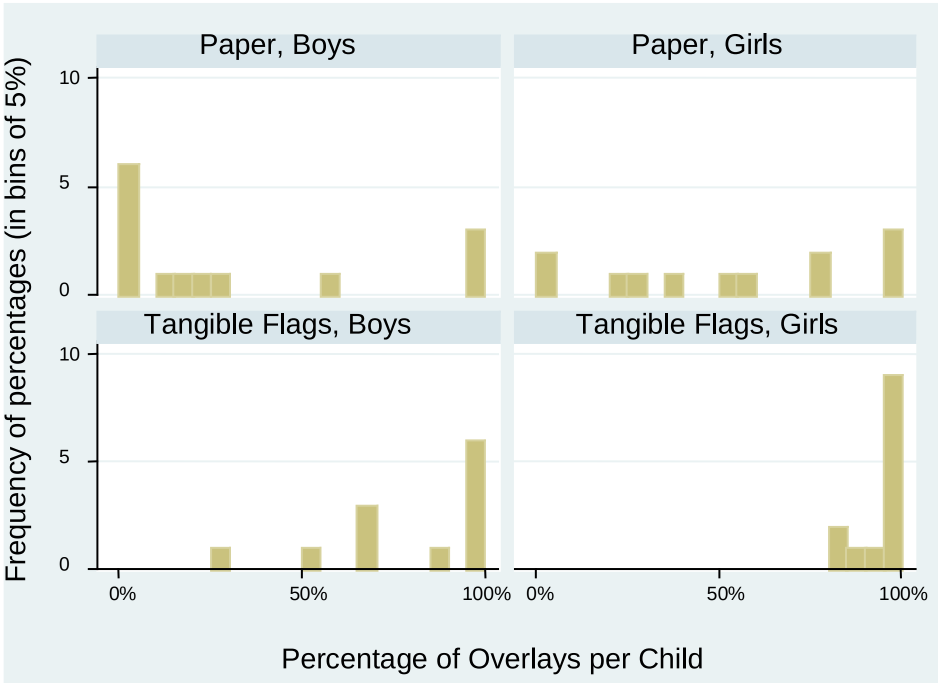

Figure 25. Histograms of Percentage of Additions that were Overlays per Child by Technology and Gender. Histogram frequency is for data sorted into bins with a range of 5%.

The unstructured correlation matrix was used for the model, with a Pearson dispersion of 1.752. This was marginally better than the Pearson dispersion of 1.779 for the independent correlation matrix. The basic model was significant at p = 0.000. The gender variable was significant at p = 0.014, with an IRR = 3.668 and a standard error = 1.941. The tech variable was significant at p = 0.000, with an IRR = 16.190 and a standard error = 8.689. The correlation matrix indicates a mild correlation (r = 0.288) between the first and second activity, a weak correlation (r = 0.070) between the first and third activity and a mild correlation (r = 0.376) between the second and third activity. The basic model had lower Pearson dispersion than both the two-way interaction model and the full model and neither model indicated any significant interactions.

5.9.1.9 Addition Prompt Count

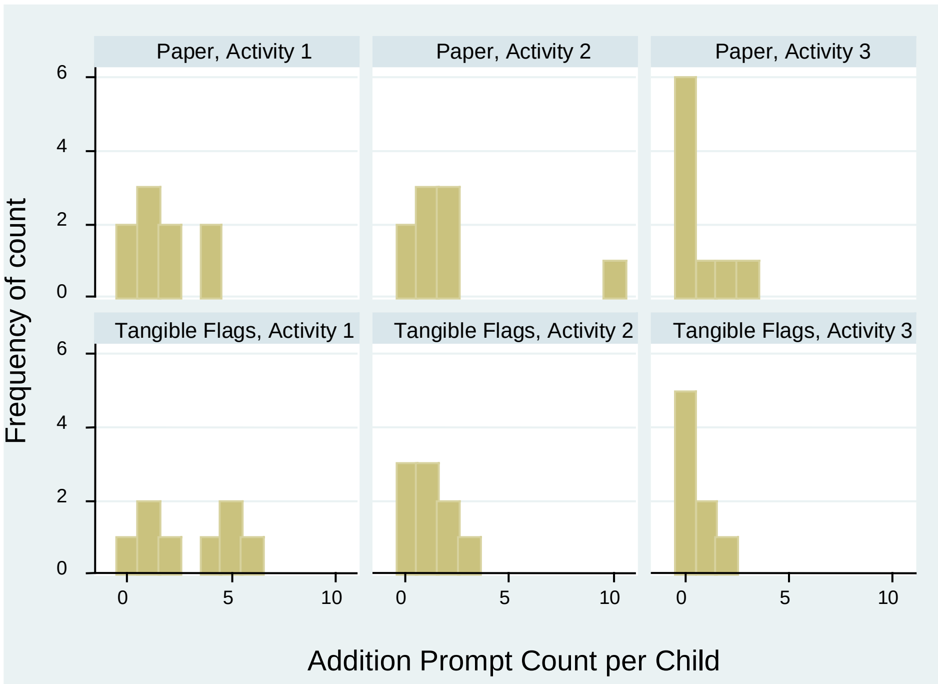

Figure 26. Histograms of Addition Prompt Count per Child by Technology and Activity

Summary statistics for page counts for the first and third activity indicated a Poisson distribution. For the second activity, the data was over-dispersed. The dispersion value was 1.79 for a Poisson model and 0.85 for a negative binomial model. Therefore, a Poisson model was chosen. Both the Pearson dispersion and the QIC favored the independent correlation matrix. The basic model was significant at p = 0.024. The outdoors variable was significant at p = 0.046, with an IRR = 0.366 and a standard error = 0.185. Both the two-way interaction model and the full model had a better QIC than the basic model and indicated significant two and three way interactions between group, gender and technology. Because of small sample size and over-fitting, this is unlikely to be an indication of an actual interaction effect.

5.9.1.10 Inspect Count

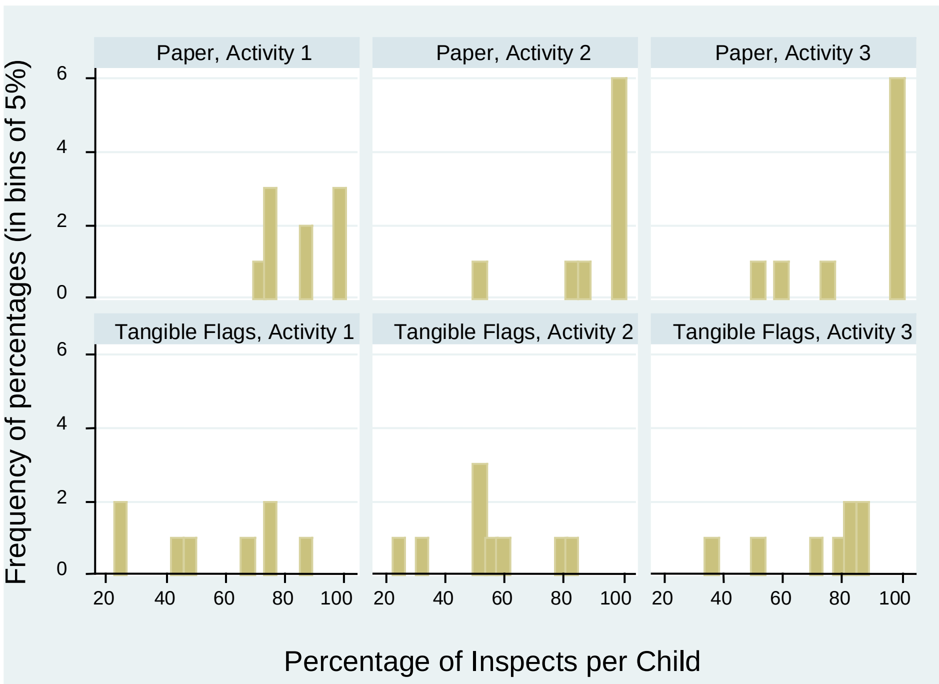

Figure 27. Histograms of Percentage of Page Interactions with an Inspect by Technology and Activity. Histogram frequency is for data sorted into bins with a range of 5%.

The independent correlation matrix was used for the model, with a Pearson dispersion of 1.897. This was marginally better than the Pearson dispersion of 1.922 for the unstructured correlation matrix. The basic model was significant at $p = 0.000$. The tech variable was significant at $p = 0.000$, with an IRR = 0.207 and a standard error = 0.074. The basic model had higher Pearson dispersion than both the two-way interaction model and the full model and both models indicated a significant interaction between gender and technology. Because of small sample size and over-fitting, this is unlikely to be an indication of an actual interaction effect.

5.9.1.11 Exist Count

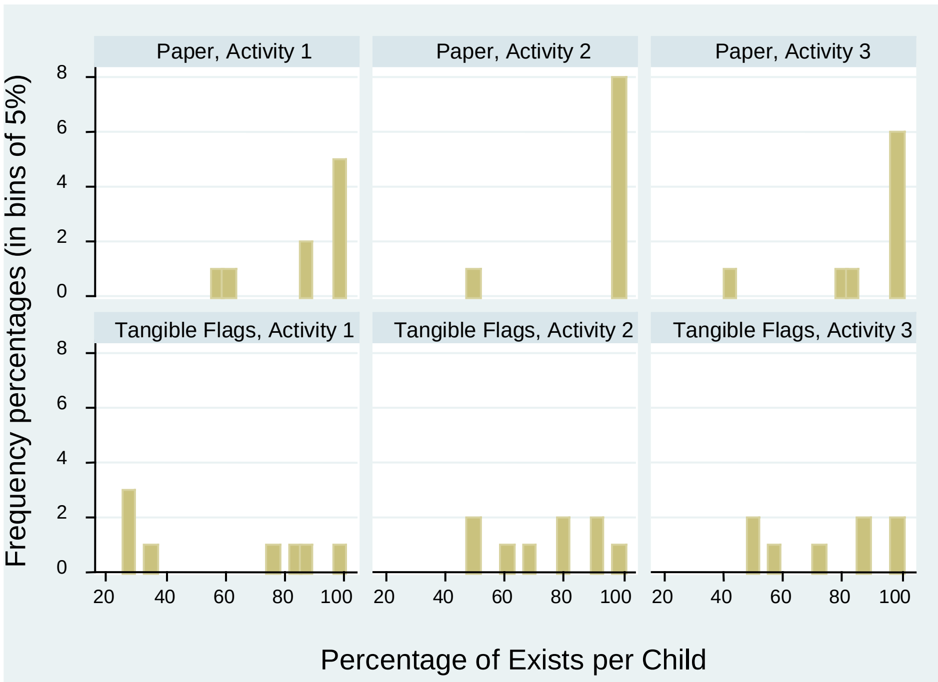

Figure 28. Histograms of Percentage of Page Interactions with an Exist per Child by Technology and Activity. Histogram frequency is for data sorted into bins with a range of 5%.

The unstructured correlation matrix was used for the model, with a Pearson dispersion of 2.106. This was marginally better than the Pearson dispersion of 2.145 for the independent correlation matrix. The basic model was significant at p = 0.021. The tech variable was significant at p = 0.010, with an IRR = 0.282 and a standard error = 0.138. The training variable was significant at p = 0.015, with an IRR = 0.425 and a standard error = 0.150. The correlation matrix indicates a mild correlation (r = 0.284) between the first and second activity, a weak correlation (r = 0.139) between the first and third activity and a moderate correlation (r = 0.607) between the second and third activity. The basic model had higher Pearson dispersion than the two-way interaction model, which indicated a significant interaction between gender and technology. Because of small sample size and over-fitting, this is unlikely to be an indication of an actual interaction effect. The full model did not converge.

5.9.1.12 Total Time

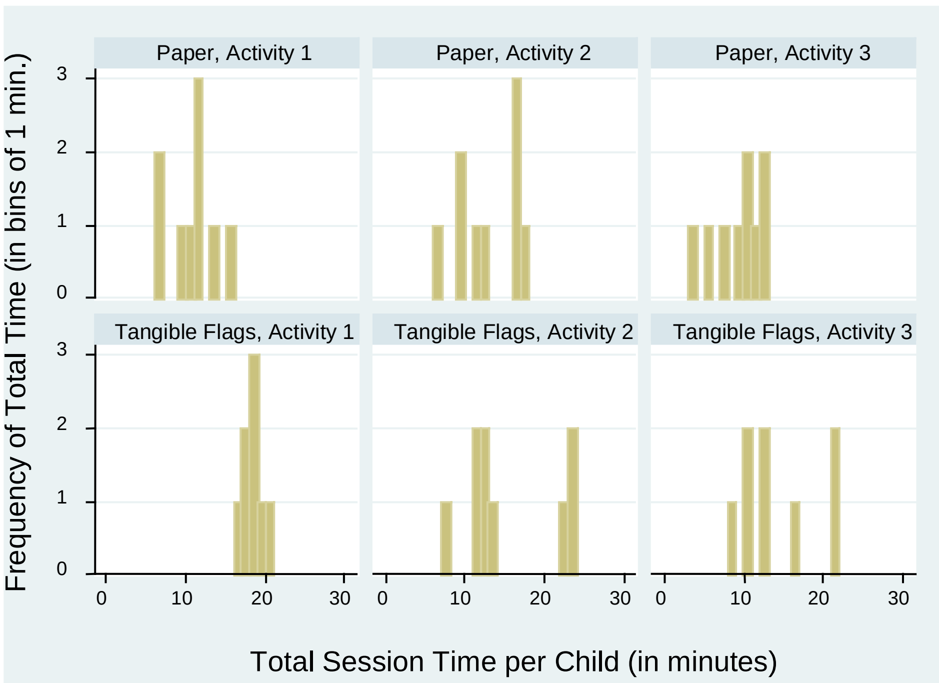

Figure 29. Histograms of Total Time per Session per Child by Technology and Activity. Histogram frequency is for data sorted into bins of one minute.

The QIC favored the unstructured correlation matrix. The basic model was significant at p = 0.000. The gender variable was significant at p = 0.003, with a regression coefficient = 3.067 minutes and a standard error = 0.1041. The tech variable was significant at p = 0.000, with a regression coefficient = 5.069 minutes and a standard error = 0.1041. The outdoor variable was significant at p = 0.045, with a regression coefficient = -2.261 minutes and a standard error = 0.1126. The correlation matrix indicates a negative correlation (r = -0.125) between the first and second activity, a negative correlation (r = -0.130) between the first and third activity and a mild correlation (r = 0.239) between the second and third activity. The basic model had better QIC than both the two-way interaction model and the full model.

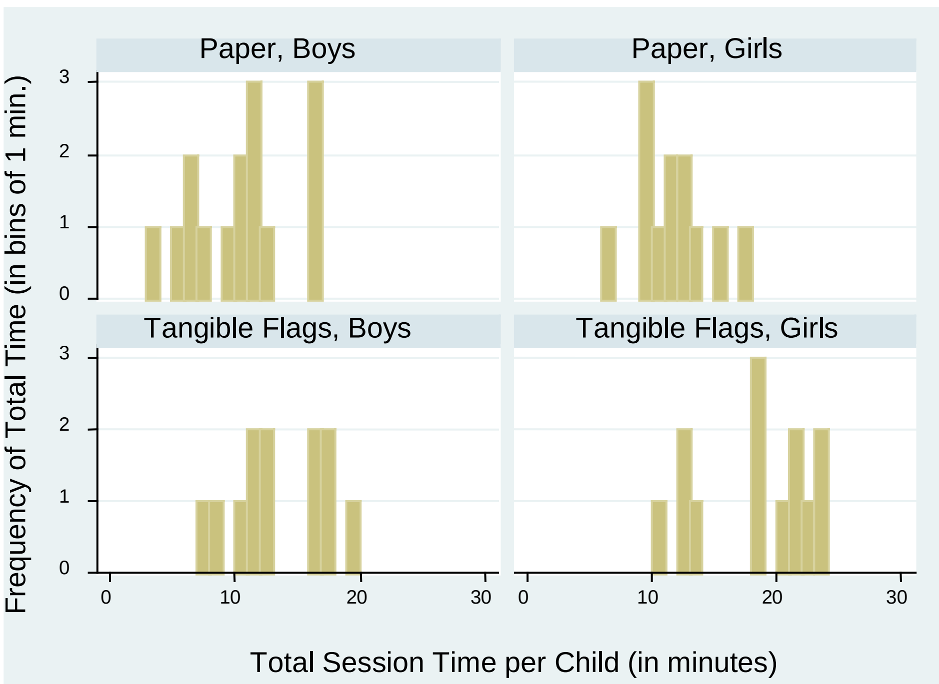

Figure 30. Histograms of Total Time per Session per Child by Technology and Gender. Histogram frequency is for data sorted into bins of one minute.

5.9.1.13 Average Time per Page

The QIC favored the unstructured correlation matrix. The basic model was not significant at p = 0.686. The basic model had better QIC than both the two-way interaction model and the full model.

5.9.2 Qualitative Results

5.9.2.1 Frequency Counts

Total counts for the paper system are out of 27 data points (9 children across 3 activities), and for Tangible Flags, total counts are out of 25 data points (2 missing). For the following tables, table cells show the sum of events of all three children in a single group while participating in a single activity. Two of the cells in tables for Tangible Flags are summed only over two children in the group, due to loss of data on the third child. These cells are marked with an asterisk (*).

5.9.2.1.1 Co-located Drawing

Activity	All Boy Group	All Girl Group	Mixed Group
1	0	0	0
2	0	0	0
3	0	6	0

Table 4. Count of co-located drawing cases while using the paper system, by activity and group.

Activity	All Boy Group	All Girl Group	Mixed Group
1	10	7*	0
2	0	8	2
3	0	4*	0

Table 5. Count of co-located drawing cases while using Tangible Flags, by activity and group.

The co-located drawing count is the number of page interactions in which, during the observed child's interaction with the page, another child at the same physical location drew on the same page (any overlap in drawing times between the two children). There were a total of 6 cases of co-located drawing while using the paper system and a total of 31 cases while using Tangible Flags. With the paper system, only two children participated in co-located drawing, two girls in the all girl group during the third activity. With Tangible Flags, co-located drawing occurred for all groups, though it occurred most consistently for the all girl group.

5.9.2.1.2 Distributed Drawing

Activity	All Boy Group	All Girl Group	Mixed Group
1	4	0*	0
2	2	5	0
3	0	0*	0

Table 6. Count of distributed drawing cases while using Tangible Flags, by activity and group.

The distributed drawing count is the number of page interactions in which, during the observed child's interaction with the page, another child drew on the same page while not at the same physical location, i.e., any overlap in drawing times between the two children. This could only occur for children using the Tangible Flag technology and there were a total of 11 cases. No cases occurred for the mixed group.

5.9.2.1.3 Conversations

Activity	All Boy Group	All Girl Group	Mixed Group
1	11	1	4
2	11	1	0
3	0	4	0

Table 7. Count of conversation cases while using the paper system, by activity and group.

The conversations count is the number of page interactions in which, during the observed child's interaction with the page, the child had a conversation with another child. At a minimum, the child either spoke to another child or was spoken to. A total of 32 conversations occurred while using the paper system and a total of 54 while using Tangible Flags. Fewer conversations occurred for mixed groups and during the third activity, for both the paper system and Tangible Flags. The all girl group using Tangible Flags had many more conversations than the all girl group using the paper system.

Activity	All Boy Group	All Girl Group	Mixed Group
1	12	7*	1
2	7	15	0
3	6	6*	0

Table 8. Count of conversation cases while using Tangible Flags, by activity and group.

5.9.2.1.4 Co-located Watching

Activity	All Boy Group	All Girl Group	Mixed Group
1	9	1	2
2	5	7	0
3	0	6	0

Table 9. Count of co-located watching cases while using the paper system, by activity and group.

Activity	All Boy Group	All Girl Group	Mixed Group
1	10	5*	2
2	3	10	1
3	2	3*	1

Table 10. Count of co-located watching cases while using Tangible Flags, by activity and group.

The co-located watching count is the number of page interactions in which, during the observed child's interaction with the page, another child at the same physical location watched. A total of 30 instances of co-located watching occurred while using the paper system and a total of 37 while using Tangible Flags. Fewer instances of co-located watching occurred for mixed groups and during the third activity, for both the paper system and Tangible Flags.

5.9.2.1.5 No Additions

The no additions count is the number of page interactions in which the child does not make an addition to a page. The cases are relatively evenly distributed over all groups, regardless of technology use. There were a total 22 cases for the paper system and a total of 22 for Tangible Flags.

Activity	All Boy Group	All Girl Group	Mixed Group
1	2	2	2
2	3	4	5
3	0	0	4

Table 11. Count of no addition cases while using the paper system, by activity and group.

Activity	All Boy Group	All Girl Group	Mixed Group
1	5	3*	3
2	4	1	2
3	1	2*	1

Table 12. Count of no addition cases while using Tangible Flags, by activity and group.

5.9.2.1.6 Placement Prompts

The placement prompts count is the sum over all page interactions of the number placement prompts given when a child placed or moved a page or Tangible Flag (see section 5.6.4). A total of 39 placement prompts were given while using the paper system and a total of 49 while using Tangible Flags. Placement prompts were generally higher during the first activity, the training activity, for both the paper system and Tangible Flags. Placement prompts was also higher for the mixed group using Tangible Flags.

Activity	All Boy Group	All Girl Group	Mixed Group
1	3	10	8
2	3	3	3
3	4	3	2

Table 13. Count of placement prompts while using the paper system, by activity and group.

Activity	All Boy Group	All Girl Group	Mixed Group
1	10	2*	13
2	3	2	8
3	3	2*	6

Table 14. Count of placement prompts while using Tangible Flags, by activity and group.

5.9.2.1.7 GUI Access

The GUI access count is the number of page interactions in which the child accessed the page using the software interface (i.e., GUI), not by scanning the Tangible Flag with the RFID reader. The GUI was used to access previously discovered pages a total of 70 times. The software interface was used much less during the third activity, the outdoor activity.

Activity	All Boy Group	All Girl Group	Mixed Group
1	19	1*	17
2	5	11	14
3	1	0*	2

Table 15. Count of GUI access cases while using Tangible Flags, by activity and group.

5.9.2.1.8 Walking to a Tangible Flag after GUI access.

On nine different page interactions, a child walked to physical location of a Tangible Flag after accessing the page for that Tangible Flag with the GUI from a different location. Four children did this, three only once and one child did this six times across two different activities.

5.9.2.1.9 Scanning a previously discovered Tangible Flag.

On 36 different page interactions, a child scanned a Tangible Flag that had been previously discovered. These are cases when child could have accessed the Tangible Flag either by scanning or via the GUI.

Activity	All Boy Group	All Girl Group	Mixed Group
1	7	3*	10
2	3	1	7
3	2	2*	1

Table 16. Count of cases where children scanned previously discovered Tangible Flags, by activity and group.

5.9.2.1.10 GUI access while looking at Tangible Flag.

On four different page interactions, a child walked up to a Tangible Flag and looked at it, then accessed the page for that Tangible Flag using the GUI. Two children did this once and one child did it twice during the same activity.

5.9.2.1.11 Scanning a Tangible Flag then inspecting another page with the GUI.

On five different page interactions, a child scanned a Tangible Flag, but before making an addition, used the GUI to switch to a different page and inspect it. They then used the GUI to return to the just scanned page and make an addition. One child did this once and two children did this twice, though they were not in the same sessions together. Both children did the action twice during the same activity.

5.9.2.2 Technology Issues

Four distinct types of issues occurred for the Tangible Flag system during the study.

5.9.2.2.1 RFID Reader Failures

RFID reader failures occurred nine times. Failures most likely occurred due to batteries that were not fully charged. When a failure occurred, it was necessary for a researcher to take the tablet from the child briefly (10-15 seconds) to use a software interface partially hidden from the child to activate the appropriate page. These 9 reader failures were out of 184 times the RFID reader was used. Seven of these failures occurred for the reader on the green tablet, two for reader on the red table, and the reader on the blue tablet did not fail. During one session, a reader failure occurred twice for the same child. During another session, a reader failure occurred twice for one child and five times for another child.

5.9.2.2.2 Tablet restart

When the tablets were dropped a short distance or roughly bumped, they occasionally restarted. Restarting the computer and loading the Tangible Flags software took 4 to 5 minutes. After a restart, the software automatically reloaded all joint artifacts previously discovered. Restarts occurred twice during the study. In one session, a restart occurred 7 minutes into the session. The child quit the activity immediately after the restart. In another session, a restart occurred 15 minutes into the activity.

The child continued to work for several minutes after the restart, until the activity was terminated at the maximum session time of 20 minutes.

5.9.2.2.3 Server delay

On one occasion, the laptop functioning as the Tangible Flags server went into hibernation and ceased to deliver page changes from the tablets. This occurred 12 minutes into the session and lasted for a little over 1 minute before it was noticed. A researcher woke the laptop from hibernation and all page updates were immediately delivered. All three children noticed the change, as they were working together at the time. All three children continued to participate in the activity afterwards.

5.9.2.2.4 Dropped tablet

On one occasion, one of the tablets was dropped and ceased to function. This occurred approximately 4 minutes into the session. The child was allowed to continue participation in the activity using Tangible Flags software run on a laptop. However, the laptop was not equipped with a RFID reader. The collected for that child during that session was not included for analysis in this study.

5.9.2.3 General observations and examples

5.9.2.3.1 Making additions while moving around

Children using the Tangible Flag system usually put the computer down before drawing on a page. On occasion children used the software interface while walking to a different location, by making an addition to a drawing or using the GUI to inspect a page. An interesting counterpoint to this behavior occurred for one boy while using the paper system. He ended up carrying a paper page around in order to create drawings of many different objects, instead of leaving the page next to the object he drew. Initially, he placed the page next to an object he drew, as prompted by the researcher. However, after having placed both of his pages, he discovered a third object that matched the activity, which was drawing patterns. He moved one of his pages to the new object and added to it. Later, after discovering and adding to some of the other children's pages, he discovered a fourth pattern he wished to draw and again moved the page and added to it. After this, he began to carry the page with him instead of placing it and made six more additions to it. See Appendix I, section I.1 for details.

5.9.2.3.2 Examples of Context, Collaboration and Concurrent Interaction

Numerous examples illustrate the following (see Appendix I):

- Setting the context of a drawing with the paper system (sections I.2, I.3, and I.11) and with Tangible Flags (sections I.6 and I.7)
- Asynchronous collaboration with the paper system (section I.3) and with Tangible Flags (sections I.7 and I.8)
- Synchronous collaboration with the paper system (sections I.4 and I.5) and with Tangible Flags (sections I.9 and I.10)
- Concurrent interaction with the paper system (section I.5) and with Tangible Flags (sections I.9 and I.10)

5.9.2.3.3 Using color for identification

There were several examples (see section I.8, Example 15, and section I.11, Examples 21 and 24) where children identified the author of a drawing by recognizing the color of the ink. The color of the ink was also an element of collaborative efforts (see section I.9, Example 18). However, there was a single case when the color of the ink restricted a child's creative efforts. This occurred during the second activity, which was finding patterns, for a boy using the paper system. He wished to match his drawing to a real object's color and had difficulty choosing what to draw. During this session he had a total of three page interactions total, his two starting pages and one other child's page that he added to. However, he spent nine and a half minutes on these three page interactions, an average of 3:10 minutes per page. This is well above the average time per page of 1:36 minutes per page for paper users and 1:47 minutes per page for Tangible Flag users. Most of his time was spent searching for patterns with a color to match his pen's ink.

5.9.2.3.4 Personalization

Some children added a personal touch to their drawings, a way of 'autographing' their drawings. One girl put her name next to many of the pictures she drew, regardless if it was her original page or not. She did this in all three activities. One boy placed a star next to many his drawings, again on all three activities and regardless of whose page it was originally. Another boy drew a box around the frame of pages he worked on, but only during one activity. Interestingly enough, personalized additions primarily occurred for children working on the paper system. This only occurred in one case for children using Tangible Flags, when a child wrote his name, one time, on a single page, during a single activity.

5.10 Discussion of results

5.10.1 Effect of Tangible Flags on Awareness

Children using the Tangible Flags technology interacted with significantly more pages than children using the paper system. This supports the first hypothesis. The statistical model predicts a greater than 50% increase in page interactions for children using Tangible Flags. Data totals show 61 more page interactions for children using Tangible Flags over those using the paper system. Compare this with a total of 70 GUI accesses by children using Tangible Flags, of which 66 occurred at a remote location. This close correspondence indicates that increased page interactions were a direct result of GUI access from remote locations.

There was no significant difference in the number of times children using Tangible Flags returned to the physical location of a page versus children using the paper system. This provides additional support for the first hypothesis. The actual event counts show that children physically returned to the location of a Tangible Flag 50 times, compared with 60 returns for the paper system, all physical, of course. The significant gain of 61 page interactions when using Tangible Flags came with an insignificant decrease of 10 returns to the physical location of the page. Instead, the gain occurred primarily from additional reviews at other locations besides that of the Tangible Flag.

There was not a significant increase in the number of times children using Tangible Flags reviewed previously discovered pages. While this does not support the first hypothesis as expected, it is interesting to note that there were 46 more page reviews for children using Tangible Flags, a 77% increase over the reviews occurring with the paper system.

Children using Tangible Flags had both significantly better recall of the number of pages they found and significantly better recall of how many they added to. This supports the first hypothesis. Children using Tangible Flags made extremely few errors in recall, fewer than 10% error in recall for both questions. This is a strong contrast to children using the paper system, who had over 40% error in recall of pages found and over 50% error in recall of pages added to. This is a clear indicator that children using Tangible Flags had a better grasp of their recent actions immediately after an activity, most likely as a result of displaying thumbnails for discovered Tangible Flags.

There was not a significant difference in the number of location prompts given for children using Tangible Flags versus the paper system. This supports the first hypothesis. The actual event counts show that children were given 151 location prompts when using the paper system and 104 location prompts when using Tangible

Flags. The fewer number of location prompts for children using Tangible Flags could be related to the fewer number of physical returns to a page.

Many examples indicate how flagging the environment can provide a context for another child's drawing. This can be seen in examples with both the paper system (see sections I.2 and I.3) and Tangible Flags (see sections I.6 and I.7). Using the context of the activity and the placement of a page or Tangible Flag, children could tell what object another child's drawing represented. While there were occasional misinterpretations, the children correctly guessed the original author's intent quite often, sometimes from a drawing as simple as a square.

5.10.2 Effect of Tangible Flags on Collaboration

Children using the Tangible Flags technology made additions to significantly more pages than children using the paper system. This supports the second hypothesis. The statistical model predicts a greater than 50% increase in the number of additions for children using Tangible Flags. Data totals show 66 more page additions for children using Tangible Flags over those using the paper system, very close to the increased number of page interactions. Yet, the number of page interactions in which children did not make an addition was the same for both systems, 22 for each. This would indicate that most of the increased page interactions that occurred with Tangible Flags resulted in additions.

There was not a significant difference in the number of addition prompts given for children using Tangible Flags versus the paper system. This supports the second hypothesis. The actual event counts show that children were given a total of 40 interaction prompts when making additions using the paper system and a total of 38 interaction prompts when making additions using Tangible Flags. This indicates that while children made more additions when using Tangible Flags, it was of their own initiative and not as a result of researcher prompts.

There are more cases of children conversing and drawing simultaneously on the same page when using Tangible Flags. The event counts show 6 cases for the paper system and 42 cases for Tangible Flags, both co-located and distributed combined. Only two children drew on a page at the same time with the paper system. With Tangible Flags, all but two children participated in simultaneously drawing activity at least once and most did so multiple times. Conversations were more common when using Tangible Flags, occurring 1.69 times more often than with the paper system. This increase corresponds closely with the increased number of page interactions, indicating that there may not be an increased rate of conversation per page interaction, but more opportunities due to more page interactions. The number of cases when children watched others work on a page was roughly equal for the two systems. This indicates that using Tangible Flags resulted in children participating in more collaborative efforts, either through conversations or joint drawing activity.

Children using the Tangible Flags technology overlaid their additions to existing work on the page significantly more often than children using the paper system. This supports the second hypothesis. The statistical model predicts that children using Tangible Flags are 16 times more likely to overlay their additions on previous work. The actual event count totals show that children using Tangible Flags overlaid their additions on previous work 90% of the time compared to 37% of the time for children using the paper system. It might be expected that an increase in overlays would be a direct result of the increase in additions, as the available blank space on a page would decrease as a result of increased additions. However, the data cannot be explained by this reason alone. The number of cases in which children did not overlay their addition illustrates this clearly. For children using the paper system, 72 out of 117 additions were not overlaid, compared with only 16 out of 182 for children using Tangible Flags. If limited space were the primary cause of overlaid work, the number of additions that are not overlaid should be similar, as it would take about the same number of additions to fill the available space. The increased number of overlays can instead be attributed to two factors. First, children sometimes promptly switched to a page in the GUI after noticing another child had made an addition (see section 5.9.2.1.11). The prompt cycle of feedback on what changes were made combined with immediate access to the page likely influenced additions. Children may be able to quickly recognize what portion of a drawing changed and focus their further additions in the same part. Second, the increase in joint drawing activity likely resulted in a natural tendency for children mark on each other’s work. This effect would be amplified because children could concurrently interact in the shared digital space without the necessity of interaction in the shared physical space required by the paper system.

Examples show how children used context to asynchronously make appropriate additions to a joint artifact. This can be seen in examples (see sections I.3 and I.7) where children made additions to a page that complemented or enhanced the existing work. This was likely result of their understanding what object a drawing was intended to represent. This effect was further enhanced by the use of Tangible Flags. This can be seen in examples (see section I.9) where children often went beyond adding another nearby object to a drawing, but instead added features to an object already represented on the page.

Examples show that children using Tangible Flags collaborated on a joint artifact over an extended period, building on each other's additions. Examples of this occurred for all three groups using Tangible Flags (see sections I.8 and I.9). This collaboration often started as asynchronous additions to a page, which was seen with both systems. However, when children using Tangible Flags noticed a change to a page in the software, they often reviewed the page using the GUI and possibly made another addition. Other participants noticing the new addition would then do the same, reinforcing the interaction cycle. This led to extended asynchronous collaboration and in some cases to synchronous collaboration, either co-located or remotely (see sections I.9 and I.10).

5.10.3 Effect of Tangible Flags on Focus and Engagement

Children using the Tangible Flags technology inspected the environment significantly less often than children using the paper system. This refutes the fourth hypothesis. The statistical model predicts that children using the paper system will be 5 times more likely to inspect the environment on a page interaction. The actual event count totals show that children using Tangible Flags inspected the environment 54% of the time while children using the paper system did so 85% of the time.

Children using the Tangible Flags technology made additions representative of an object existing in the environment significantly less often than children using the paper system. This refutes the fourth hypothesis. The statistical model predicts that children using the paper system will be 4 times more likely to make a drawing that represents an object that exists in the environment. The actual event count totals show that children using Tangible Flags made 157 drawings of real objects, which was 67% of the time, while children using the paper system made 152 drawings of real objects, which was 89% of the time. One example of extended collaboration (see section I.9, Example 17) shows how Tangible Flags can make it easy for children to initially participate in the collaborative construction of a joint artifact, but after repeated interactions they can lose sight of the original activity.

Children using the Tangible Flags technology participated in the activities for a significantly longer time than children using the paper system. There was no significant difference between the average times per page interaction for children using either system. This supports the third hypothesis. The statistical model predicts that children using Tangible Flags would spend 5 more minutes participating in the activity than children using the paper system. The data shows that children using the paper system spent an average of 11 minutes participating in an activity while children using Tangible Flags spent an average of 16 minutes participating in an activity. This 45% increase in time spent on the activity corresponds closely with the increased number of page interactions. The data also shows that children using the paper system spent an average of 96 seconds per page interaction and children using Tangible Flags spent an average of 107 seconds per page interaction. This indicates that the increased number of page interactions when using Tangible Flags did not come at the expense of less time spent per page interaction.

5.10.4 Usability of Tangible Flags

Children could scan Tangible Flags to access pages without difficulty. After the first activity for training, children scanned Tangible Flags without assistance the bulk of the time. Several times a researcher had to move a Tangible Flag away from a metal surface in order for the RFID reader to function; though after watching researchers, children also moved the Tangible Flags for themselves when the reader did not scan a Tangible Flag initially. Reader failures requiring researcher assistance were fairly rare. It is clear that children can quickly learn how to scan Tangible Flags to access pages and consistently use them without assistance.

Children required fewer placement prompts after the first activity. For children using the paper system, a total of 21 placement prompts were given in the first activity, compared with 18 for the second and third activity combined. For children using the Tangible Flags technology, there were a total of 25 during the first activity, compared with 24 during the second and third activity combined. During the first activity, children had a tendency to carrying the paper pages with them, but quickly understood the process and did not do so during the second and third activities. Those using Tangible Flags were usually given assistance in scanning a Tangible Flag during the first activity, as part of training. Since the researcher would have either placed the Tangible Flag, or would still be holding it, it was often necessary to prompt the children to place the Tangible Flag. During the second and third activities, children carried their own Tangible Flags for the most part and usually placed them without prompting.

Children using Tangible Flags regularly accessed pages using the GUI after training; however they typically scanned a nearby Tangible Flag rather than using the GUI. During the first activity, children with Tangible Flags used the GUI to access pages 37 times. They were normally given prompting to do so several times as part of the training. During the second activity, children used the GUI 30 times, but only 3 times during the third activity. No prompting was given during the second and third activity and every child used the GUI to access a page at least once. Use of the GUI in the second activity indicates that children understood the interface and would use it to access pages without help. In the third activity, the reduce use of the GUI could be attributed to the reduced number of additions and time spent on the activity. It is interesting to note children almost always scanned a Tangible Flag instead of using the GUI when they were near it, 36 cases of scanning compared to 4 cases of GUI use. Scanning a Tangible Flag may be a more natural method for children this age to access pages.

Children used the mobility provided by the Tangible Flags technology to look at pages and sometimes draw while moving around. Children naturally took advantage of the added mobility when using Tangible Flags. It is interesting to note that one child using the paper system created his own mobility by carrying a paper page around (see sections 5.9.2.3.1 and I.1). This illustrates that mobility is an important concern for children in exploration activities.

The form factor of the tablet computers created some usability issues. One broken computer and two computer restarts can be directly attributed to computers being dropped during the activity. The tablets were not ergonomically suited for the children and not designed for rugged use.

5.10.5 Effects of Gender

Gender effects how children collaborate in shared environments [Inkpen et al., 1997]. This was the likely cause of the following effects on this study.

Girls overlaid their additions to existing work on the page significantly more often than boys. The statistical model predicts that girls are more than 3 times more likely to overlay their additions on previous work. The actual event count totals show that girls overlaid their additions on previous work 79% of the time compared to 57% of the time for boys.

Girls participated in the activities for a significantly longer time than boys. There was no significant difference between the average times per page interaction by gender. The statistical model predicts that girls would spend 3 more minutes participating in the activity than boys. The data shows that boys spent an average of 11.7 minutes participating in an activity while girls spent an average of 15.1 minutes participating in an activity.

Girls simultaneously drew together on the same page more often than boys. Girls drew together 31 times, while boys did so 17 times. With the paper system, there was no case of boys working together.

5.10.6 Effects of Environment

The third activity had a significant effect on the number of page interactions, the number of reviews of previously discovered pages, and the time spent on the activity. The statistical model predicts the third activity to have about a one-third reduction in page interactions, a two-thirds reduction in page reviews, and a greater than two minute decrease in the time spent. The correlation matrix for reviews, physical returns and additions provides further evidence of the impact of the third activity, in every case it showing the strongest correlation in the measurements occurs between the first and second activity. The third activity was conducted outdoors in a larger space, while the first and second activities occurred indoors in a more confined space. However, there is not a significant difference in the average time spent on a page interaction for the third activity versus the first and second activities. This discounts the possibility that more time was spent locating pages. Instead, this general decrease may be the result of cold weather during several days when the outdoor activity was conducted, in late February and early March.

During the first activity, children made additions representative of an object existing in the environment significantly less often than during the second or third activity. In addition, the correlation matrix shows the strongest correlation occurs between the second and third activity. The actual event count totals show that during the first activity, children made drawings of real objects 67% of the time, while during the second and third activity, children made drawings of real objects 83% and 81% of the time, respectively. Further inspection of the data shows that this effect occurred primarily for Tangible Flags and not the paper system. This may be a result of the novelty of using the Tangible Flags system for the first time.

5.11 Limitations

5.11.1 Participant Population

This study was limited by the fact that the participants were all from the same classroom at the Center for Young Children at University of Maryland. Although somewhat ethnically diverse, most or all of these children come from families with an affiliation to the University of Maryland, faculty, staff or students. As such, they do not represent children from a broad cross-section of families. In addition, all the children were either 5 or 6 years old. Therefore the results of this study may be less relevant if applied to children of different ages.

5.11.2 Interface Design

This study was limited by the use of a single interface design for the technology. This interface was not designed to scale for a larger number of users or Tangible Flags and this study does not investigate those issues. Thumbnails for Tangible Flags were presented across the top of the interface. This was chosen in order to reduce potential for obscuration of the thumbnails while a child worked on a page. During the design of Tangible Flags, a number of other placements for the thumbnails have been used and this study does not examine the effects various layouts may have on collaboration. The interface also does not include the deletion tool or the message area used for the interface in the case study, and therefore does not examine the possible effects these may have on collaboration. Finally, flashing thumbnails to provide a visual alert of changed pages was used for the interface in this study. However, the study does not provide detailed insight on how alerts, either visual or audio, may effect collaboration or potentially distract a child.

This study makes a comparison between the Tangible Flag technology run on a tablet PC, and a paper system with approximately the same size, shape and look as the technology. However, it is not a perfect comparison, as the paper system weighed significantly less, did not have the thumbnails across the top, and did not have the pen attached with a string. It is not clear what impact, if any, this may have on the study results. Also, this study gives limited insight into how weight and form factor affected the use of the technology.

5.11.3 Activity Tasks and Environments

This study was limited in that it only examined children's activity patterns for a single, very broad type of task. This task of finding and drawing an object from a broad category (furniture, patterns or structures) was intended to make it simple and straightforward for children to engage in the exploration and creation activities. This choice of task limited the study's insight on how the Tangible Flags affects collaboration on more structured learning tasks. However, it was difficult to develop a more structured task that would also be consistent in both the environments available for this study, a classroom and a playground. Different tasks for each environment would have resulted in limited ability to compare results and drastically reduced the amount of data available for quantitative analysis. It may also have had a substantial impact on many event counts, especially for metrics such as inspection and exists, since a structured task would necessarily be more directed.

The indoor environment used for this study was an unused classroom and the outdoor environment was a playground, sometimes with non-participant children present. It was not logistically feasible to conduct this study in more appropriate learning environments, such as a museum or natural environment. Nor was it one of the primary goals of the study, as it was for the case study detailed in Chapter 4. Therefore, the results of this study may not be representative of the effects that could be expected in different environments. Also, because the presence of non-participant children during the outdoor activity could not be controlled for, it is unknown what impact this may have had on the study results.

5.11.4 Data Collection

This data collection of this study was limited because multiple researchers were involved in interaction with the participants and collecting data. This probably led to increased variability in how children were prompted during the study. It also resulted in slightly differing patterns of using the video camera and asking children questions to capture their intent. Both could have resulted in more variance in the resulting data. It was not possible to conduct this study using a single researcher. Therefore, detailed guidelines for interacting with the participants and capturing video were developed to promote a consistent process regardless of researcher. A pilot study was conducted to practice the guidelines before the actual study.

The data collection was also limited due to the impact of different environments on video capture. The indoor environment sometimes resulted in multiple conversations overlapping on the audio. Glare from sunlight and noise from wind sometimes interfered with video capture in the outdoors environment. There was not sufficient equipment and expertise to improve on the video capture in these conditions. However, the use of multiple cameras helped offset the impact in many cases, capturing several takes on an event that could be compared.

5.11.5 Data Coding

The data coding for this study is limited because it only 25% of the coded data was cross checked for consistency. It was not feasible to have a second researcher code the entire data set. It is also limited because coded metrics were accepted that had a crosscheck consistency as low as 85%. However, the process of checking 25% of the data for consistency enabled the development of well-defined coding guidelines for the remaining 75% of the data as well as excluding the coding of metrics that were inconsistently interpreted.

5.11.6 Quantitative Analysis

The statistical power of the quantitative analysis was limited by the small sample size of 18 children. This reduced the power of all the analyses and may have resulted in a failure to detect a significant effect. The small sample size made testing for interaction effects in GEE problematic.

The small number of participants available also lead to a repeated measures design in order to collect a sufficient amount of data. However, analysis of panel data is more complex than straightforward statistical tests, such as ANOVA, and requires more interpretation of the resulting models. In addition, significance tests for regression models are performed using the Wald z statistic, which is an estimator more appropriate for large samples. For this reason, the GEE significance measures are less robust than those for ANOVA and similar tests.

The GEE analysis was based on the assumption that each child's response was independent of the other children. However, since the children participated in the study in groups of three, this assumption may not be strictly true. It is for this reason that the analysis was restricted to the counts of events that the children could perform independent of another child's activity. This analysis could not be performed on counts of events that required another child's participation, such as collaboration. Without this assumption, the proper way to perform the GEE analysis would be to treat groups as the independent panel and participants within a group as a dependent cluster of data. However, this approach was not used because six groups would not have been a sufficient sample size.

5.11.7 Qualitative Analysis

The qualitative analysis is limited because a single researcher developed the coding scheme for the raw data and interpreted the results of coded data. It was not possible to interview participants after a session due to time constraints, especially since interviewing 5 and 6 year-old children would require additional effort to elicit useful information. Therefore the analysis relied entirely on review and interpretation of the video. The participants' artifacts are also used confirm the analysis when possible. Direct quotes and images of the artifacts are provided to support the conclusions.

Chapter 6: Contributions

My research provides contributions to those interested in either children's education or the research and design of children's technology. While these contributions focus around supporting children's education in open environments, such as field trips, some are also applicable to children's technology in general, especially for collaborative interfaces. These contributions are a result of the iterative development of the Tangible Flags technology done through cooperative inquiry with two different children's design teams, plus two studies conducted using the technology. These two studies provided two different perspectives on supporting children's field trips with technology, one being a case study conducted in an authentic environment and the other being a comparative study that illustrates the impact of Tangible Flags in detail.

6.1 Contributions to Children's Learning and Collaboration

These contributions are of primarily of interest to children's educators or the designers of children's open learning environments, such as museums, parks or field trips. They detail important aspects of supporting children in learning and collaboration while they explore the real world. While they are not specifically tied to the use of technology, they are also still important considerations for designers of children's technology.

6.1.1 Flagging the environment

Placing and discovering flags can enhance young children's interaction with both an open learning environment and with representational artifacts.

In the study detailed in Chapter 5 shows that young children can understand the idea of placing Tangible Flags to mark the environment and can learn to consistently place Tangible Flags on their own during learning activities. The case study in particular showcases a real learning activity in which Tangible Flags were used in an open environment. I observed that children often considered how the environment matched the requirements of a learning activity when placing a Tangible Flag, indicating how placement of flags can promote additional thought about the activity. There were cases of children actively searching for Tangible Flags, sometimes for specific ones. The case study also demonstrated how educators could flag objects to direct children's attention. In both studies, children discovered a large majority of the Tangible Flags placed by others. This indicates how Tangible Flags can provide a point of interest that captures children's attention and can promote awareness of both peer and educator activity. Using Tangible Flags combined with the context of the activity, children were often able to recognize the intent of a creative effort without consulting the original author. They sometimes went on to question a peer's purpose in selecting a particular object. This indicates how Tangible Flags gave children insight into a representational artifact by providing a concrete connection to the environment.

Designers of educational experiences in exploratory environments should not underestimate the importance of providing children with concrete connections between information and the environment. Research has shown that the real world context is important for older children when accessing learning content and creating representations [Rieger and Gay, 1997; Soloway et al., 2001; Parr et al., 2002; Slotta et al., 2002; Metcalf and Tinker, 2004; Rogers et al., 2004]. My research suggests that the physical activity of placing and discovering flags is an age appropriate approach to providing this connection for younger children. It is consistent with research in learning theory [Piaget, 1977b; Papert, 1980] and also further supports existing research that indicates the importance of tangible interaction for children [Resnick et al.; 1998, Stanton et al., 2001; Sluis et al., 2004; Fails et al., 2005]. A key element is children's placement of flags themselves. The decision making involved in placing a flag requires consideration of the environment, within the scope of the learning activity. If children's activity consists only of discovering flags, the implicit task becomes discovering flags, not observing the environment.

6.1.2 Shared spaces and children's asynchronous collaboration

Providing children a shared space where they can easily transition from exploration to creation of a joint artifact creates opportunities for asynchronous collaboration.

Numerous examples in both studies show how children asynchronously built on each other's work. In most cases where children discovered a Tangible Flag, they chose to make an addition to the joint artifact. Examples in both studies also show that children used the context of the Tangible Flag and the activity to make appropriate additions to each other's work. While face-to-face interaction is considered crucial to young children's collaboration [Davidson, 1985; Johnson and Johnson, 1994; Scott et al., 2003], this research demonstrates that children as young as five can effectively participate in asynchronous collaboration when given appropriate tools. However, this is not to suggest that asynchronous collaboration is more effective than face-to-face collaboration. It is important to support both modes when designing collaborative learning tools appropriate for young children [Dimitracopoulou, 2005].

Designers of learning environments must bring together three elements when creating tools for young children's asynchronous collaboration. First, a tool should promote children's awareness of the opportunity to work on a joint artifact. Second, a tool should provide a context for the activity that will enable children to make appropriate contributions. Finally, a shared space for the collaborative effort should to be provided in direct conjunction with the first two supports. While this research was primarily directed towards open, exploratory environment such as outdoor field trips, the indoor portions of the study in chapter 5 indicate these principles are also applicable to more contained environments, such as a classroom. As these principles are primarily cognitive in nature, they should also be extendable to design of desktop software or similar, non-mobile interfaces.

6.1.3 Shared spaces and signatures

Children feel a need for personalizing their contributions to joint artifacts. Distinguishing children's contributions to joint artifacts can also increase awareness *of peer activity. Children collaborating in shared spaces could be provided with individual signatures to fulfill both purposes.*

In my research, children were assigned different ink color in order to distinguish their contributions to joint artifacts and support an awareness of author. Examples show that children recognized the author based on color and sometimes used color as a basis for collaboration. Yet an example also indicated that the use of color for this purpose could limit children's creative efforts. This suggests a different method to distinguish individual contributions might be more appropriate, in order to provide awareness without restricting color choice. Plus, a different mechanism will be necessary for some applications that don't involve drawing or coloring.

Children using the paper system personalized their work by writing their names or adding their own unique symbol. It is interesting to note that children using the Tangible Flags technology almost never personalized their work. A sense of joint ownership may be more intrinsic for digital shared spaces that support concurrent interaction. Regardless, some form of personalized signature can provide awareness as well as being more fun. When designing technology for a shared digital space, children should be given a mechanism to distinguish their individual contribution. Preferably, this signature could be personalized.

6.1.4 Creation, collaboration and engagement

Enabling children to collaborate on the creation of joint artifacts can increase their engagement in a learning activity that involves independent exploration of an open environment.

During the activities in both studies, children operated independently, or in independent teams, on a regular basis. Especially in the case study, this occurred in a large, open area. Yet children's post interview responses indicated that discovering Tangible Flags, viewing other's inputs, and making additions were very enjoyable elements of the activity, given as a feature they liked almost twice as often as learning about nature or using the computer. This indicates that the collaborative and creative elements were strong factors in enjoyment. The comparative study further establishes a correlation between collaboration and engagement. Children using Tangible Flags collaborated significantly more and made significantly more additions, while also participating significantly longer. The study does not establish a cause and effect between creation, collaboration, and participation time; indeed, the effects likely reinforce one another. Yet the technology was designed with supporting collaboration as a primary purpose. Beyond the support of collaboration, the only the use of the computer could attribute to a difference in engagement when compared with the paper system. However, the increased participation of users of Tangible Flags occurred for all the three activities (see Figure 29), suggesting that increased engagement is not a result of the novelty of 'using a computer'.

Giving children the flexibility to explore independently is an important part of a learning experience [Salomon and Perkins, 1998; Stahl, 2000]. Research also indicates that providing tools to encourage children to collaborate is preferable to tools that enforce collaboration [Benford et al., 2000]. Also, interaction with other children and with educators can increase children's engagement. My research extends the importance of creative collaboration to open learning environments where independent exploration is often occurs at the expense of immediate, on the spot collaboration; or alternately, where individual exploration may be restricted because children are assigned to groups and required to work together.

6.2 Contributions to Research in Children's Technology

These contributions are of interest to designers of children's technology. They detail important benefits and considerations for the use of technology to support children's learning and collaboration in open environments.

6.2.1 Enhancing awareness

The Tangible Flags technology increased children's awareness of peer and educator activity and also provides educators with awareness of children's activity. This is especially important when children explore independently but the environment limits communication and awareness. Technology is not required for flagging the environment and providing a shared space for joint artifacts. However, technology enables children to retain artifacts discovered yet continue to explore and can provide immediate feedback of updates to those artifacts. This support is also available to educators without the need to discover flags. Technology can also support communication between separated users and provide users a summary of group activities.

In both studies, children used the Tangible Flags technology to inspect joint artifacts while exploring and the results of the comparative study support the hypothesis of increased awareness. In the case study, the park ranger used the technology to follow the activities of, and communicate with, multiple independently operating groups. The vote summary provided children with an overview of scavenger hunt results in both design sessions and the case study, though it attracted minimal interest during the latter, probably because children were unfamiliar with the interface.

Technology can be used to enhance children's awareness of collaborative activity and also support educators in communicating with children who may be dispersed in an open learning environment. Shared spaces for joint artifact creations are a powerful tool for children's learning (see section 6.1.2) and when provided through a mobile technology, awareness of opportunities to collaborate are greatly increased.

6.2.2 Enhancing collaboration

Tangible Flags technology enabled children exploring open environments to transition from asynchronous collaboration to synchronous collaboration and can result in face-to-face collaboration. There are three key elements to providing this benefit: increased awareness of peer activity, mobile access to a shared space, and concurrent interaction in the shared space.

Children responded to increased awareness of peer activity by accessing joint artifacts more often and participating in more drawing activity. The results of the comparative study show an increase in additions, plus an increase in conversations and joint drawing activity, usually face-to-face. Children also used ink color to recognize who was adding to a joint artifact. The increased collaborative activity combined with concurrent interaction in the shared digital space clearly impacted how children built on joint artifacts together. This can be seen in the comparative study by the increase in overlaid work (see section 5.9.8.1) and in examples of extended collaboration (see sections I.8 and I.9).

Using this process, designers of mobile technology can promote children's face-to-face collaboration in open environments, even when they are initially exploring at different locations. An awareness of changes to a joint artifact combined with immediate access results in children collaborating asynchronously in a shorter time period, as children respond promptly to changes made by others. Use of an author signature, such as ink color, enables children to identify their collaborative partner. Joint drawing activity is further enabled because children can concurrently interact in the shared digital space, each on their own computers. This enables a cycle of prompt asynchronous collaboration to become overlapped and turn into synchronous collaboration. As a result, children naturally seek each other out and meet face-to-face as the collaborative effort becomes synchronized. It is interesting to note that this collaborative interaction cycle was less pronounced during the case study and in the outdoor activity of the comparative study. This indicates that for exploration of larger areas, children may need additional support in seeking out their peers and focusing their collaboration.

Face-to-face collaboration is most likely to suffer when children explore in an open environment, yet it is also a critical element in children's learning [Davidson, 1985; Johnson and Johnson, 1994; Scott et al., 2003]. In the form of Tangible Flags, mobile technology provided the tools necessary for children to easily participate in asynchronous collaboration; awareness, context and concurrent access to a shared space. But more importantly, it leverages asynchronous collaboration into face-to-face collaboration.

6.2.3 Trade-off between awareness, access and focus

When the technology increases children's awareness of peer activity and enables joint activity in a shared space while mobile, more emphasis may need to be given in structuring children's collaborative activities around the learning tasks in order to maintain focus on the real world environment.

In the comparative study, children using the Tangible Flags technology inspected the environment less often than children using the paper system. Although they made more additions to each other's work, these additions were less often representative of an object in the environment. The comparative study indicates that while Tangible Flags promoted more additions, it did not strictly translate into more attention to the environment. Drawing tasks in the comparative study were only given a basic form, enough to set the context without restricting the children's creative efforts. Not surprisingly, the children indulged their natural tendency to interact with their peers and the technology enabled them to become more involved in working on each other's drawings. Because the activity did not provide any structure to help them retain their focus, they also became correspondingly less involved in the real world environment. In the case study, this effect was not observed and the children's joint work was much more relevant to the learning tasks. This can largely be attributed to the focus on the activity provided by the park ranger's questions as well as more specific tasks.

Designers of collaborative technology for learning environments should consider how increased awareness and mobile access might impact children's attention to the learning tasks. While increased collaboration is desirable, it may be necessary to structure collaborative tasks to maintain focus on learning. Of course, open-ended exploration also affords learning opportunities that need not be structured to specific learning tasks. For such applications, increased interaction is generally beneficial.

6.2.4 Usability of the Tangible Flags technology

RFID technology is a usable approach for children to flag the environment and access digital information embedded in Tangible Flags. Combined with appropriate software design, children as young as five used the system to collaborate in the creation of joint artifacts representing knowledge gained in an open learning environment. As more child appropriate mobile devices become commercially available, technology designed around the guidelines of my research will be a practical approach for developing interactive learning environments for children.

Both studies demonstrated that children as young as five could consistently use the RFID reader to scan a Tangible Flag and the children's preference for scanning over GUI access indicates the interaction is very natural for them. Still, children regularly used the GUI to access joint artifacts when not at the location of the corresponding Tangible Flags. The comparative study demonstrated that children were also capable of remembering to place Tangible Flags on their own. Though the tablet computers were somewhat heavy and bulky, children were still willing to carry them around and able to use them. Only a couple of the children's responses in the case study indicated that the computer form factor might have been an issue. Probably more telling was the occasionally dropped, and in one case broken, computer. However, these computers were not designed for children's use or for outdoor environments. Even still, young children used them without too much difficulty in the second study.

The Tangible Flags technology is a practical approach to tools for young children to embed digital information into the real world. RFID is a robust and mature technology that works well for children, as has been demonstrated by this research as well as in other research by the Classroom of the Future project [Montemayor et al., 2004; Fails et al., 2005]. An appropriately designed software interface keeps changes to shared information visible at all times and readily accessible, plus visual alerts can further enhance children's awareness of updates. The form factor of commercially available mobile devices remains a major challenge for designing tools that could find broad acceptance in classroom and other educational environments, such as museums and parks. However, projects such as the One Laptop per Child [www.laptop.org] will likely result in public access to mobile devices that are ergonomically suited to children and rugged enough for their outdoors use. The Tangible Flags technology would benefit from portable computers designed specifically for children's outdoor use.

6.3 Examples of Design Process and Working Technology

The final contributions of my research are examples the design process with children and working technology developed. The design ideas developed during my research will be useful to both the creators of children's learning environments and designers of children's technology. The description of cooperative inquiry design sessions illustrates both the process of generating useful design concepts as well as highlighting the importance of those ideas to children's technology.

The working examples of several interface components will benefit designers of children's collaborative software interfaces. Use of a screen display where all shared content is always visible, even if minimized, supports children's awareness by making changes easily noticed. Visual alerts can further enhance this. Use of a signature, such as pen color, helps children easily identify authors. A message tool that uses pen writing and automatically deletes old messages enables children to easily communicate without worrying about typing, scrolling, or clearing the message space.

Finally, a general client-server library for shared data objects is available to other researchers on the Tangible Flags website [www.cs.umd.edu/hcil/tangibleflags/TangibleFlags.shtml]. This library is written in

C# and the executable runs on Microsoft's .Net framework, therefore it can be used by any software running that framework regardless of development language. This lightweight library is useful for writing simple, flexible clients without requiring design of a detailed data structure for the client-server system. Since it does not guarantee order of data updates to clients, it is mostly useful for applications where data change order is not critical or where the additional overhead to timestamp data changes is minimal. A server application built on this library does not require prior knowledge of client data structure, can be implemented in a single class with a handful of code, and will support many different client applications.

Chapter 7: Future Work

In design session for both my formative research as well as testing the Tangible Flags concepts and implementation, a number of interesting ideas came up. Unfortunately, unless these ideas were central to the work I was currently pursuing, I could not develop them further. In the future, I hope to extend my research in a number of ways.

7.1 Extending to Other Environments

Tangible Flags enables young children to augment a physical environment with joint artifacts created on the spot. This brings the learning benefits of collaboratively constructed representations, which normally occur in the classroom, to the immediate learning experience. However, this does not imply that construction of knowledge representations beyond the immediate experience lack learning benefits. Instead, such activities may become even more powerful learning experiences when building on knowledge artifacts that were created during exploration. It is important to consider how the Tangible Flags technology can be extended to represent these artifacts in a context beyond the immediate experience.

7.1.1 Other Environments and Applications

The concepts behind Tangible Flags have broad application. In addition to a field trip for a classroom, the case study illustrates the use of Tangible Flags technology for a park. Other children's environment could be playground and museums. Other children's applications could be for play and social learning experiences. A wide variety of learning games could be designed around interacting in social space besides scavenger hunts, such as games involving solving puzzles, interactive simulations, and role playing games. Tangible Flags technology may also be appropriate for adult worksites in environmental sciences, archeology, civil engineer, and forensics. Future work will consider how to extend Tangible Flags in such ways.

7.1.2 Multiple Visits and Visitors to a Learning Environment

Many field trips occur at locations such as museums, parks or historical sites that provide educational experiences for a steady flow of visitors. Often these sites may be visited more than once by a given group of students or a classroom may repeat the same visit with a new class of students each year. This can also be true of a natural environment that is regularly used for educational purposes. Knowledge artifacts that are embedded in these environments can be retained for future explorations. Children re-visiting the site can build upon their previous experience and new explorers can access knowledge artifacts left by prior visitors. Via Internet, children in the classroom can also access knowledge artifacts they previously left embedded at the field trip environment. When doing so, they can see how later visitors have built upon their artifacts. This can establish exchange of knowledge between different classrooms that is built around their visits to a physical site.

Tangible Flags can remain from one visit to the next. In this case the Tangible Flags' visual characteristics can be used to distinguish between the different exploration experiences, for instance, a Tangible Flag could include the name of a school, class and year. This approach provides an awareness of the previous visitors' activities enabling children to immediately start building on prior knowledge artifacts. A second approach is to make the prior artifacts embedded at a given spot available only after a child embeds their own artifact at that same spot. Children are provided access to prior artifacts only in reference to their own knowledge artifacts. Either approach may be applicable to a given learning experience, as may be no access to prior visitors' artifacts.

7.1.3 Returning to the Classroom

The Tangible Flags technology can be extend to help support children back in the classroom as they participate in traditional activities to synthesis knowledge gained during a field trip experience. Digital knowledge artifacts created during the field trip can be available during classroom discussions using a desktop computer to retrieve artifacts from the server. Tangible Flags can support the capture of metadata during the field trip, which can help children back in the classroom to correlate knowledge artifacts to the exploration experience. For instance, adult participants can use video or digital cameras to record the children's field trip. After recording any given scene, an adult can use a portable device to scan the Tangible Flags in the scene. Time or sequence information can then be used to create an association between the video recording and the children's artifacts.

With a correlation between video and the Tangible Flags, simple tools can bring the artifacts children create during a field trip back to the classroom. For instance, an application for replaying video or a digital image slideshow could simultaneously present any artifacts associated with Tangible Flags seen in the show. During the group discussions, teachers can directly address the children currently appearing in the show to explain their artifacts. Seeing their own activity at the time of the artifact creation may aid the children in recalling the meaning of their artifacts.

7.2 Optically Coded Tangible Flags

2D optical codes are finding commercial uses and there are standard code formats, such as the International Standards Organization [http://www.iso.org/] standard for Data Matrix (ISO/IEC 12066). A variety of freeware, shareware and commercial software development kits for 2D optical codes are available. Below is an example of a 2D optical code generated using freeware. An application could process a digital image of this page using an algorithm based on Data Matrix and extract the ASCII string "Gene's Artifact".

Gene's Artifact

Figure 31. Data Matrix optical code for the ASCII string "Gene's Artifact".

The algorithms for processing 2D optical codes are not computationally intensive, for instance, CyberCode is a 48 bit code that has been demonstrated to be detectable at 15 frames/second on a 200 MHZ Mobile Pentium MMX [Rekimoto and Ayatsuka, 2000]. This is more than sufficient as human reaction times are normally at least 100 milliseconds [Card et al., 1983]. 2D codes lend themselves well to Tangible Flags because an algorithm can compensate for rotation angle and a non-normal viewing angle. This will be important in creating an interface for children as it provides more flexibility for scanning.

Optically coded Tangible Flags can greatly simplify the capture of field trip metadata using video or digital cameras (see section 7.1.2). Software can automatically extract codes from Tangible Flags that appear in video recordings or digital photographs, and retrieve the appropriate artifacts from the server. A similar system has been developed as a tool for adults to track paper documents and photographs as they move about a physical desktop over time [Kim et al., 2004]. Using such an approach, any digital images from the trip, including cameras operated by the children themselves, can automatically be used to retrieve the artifacts associated with the Tangible Flags in a given scene.

7.3 Interface Extensions

7.3.1 Extending Artifact Creation Tools to Encourage Collaboration

Previous research has investigated technology for encouraging young children's collaboration. Kidpad [Druin et al., 1997; Benford et al., 2000] and Klump [Fahlen et al., 1993; Benford et al., 2000] explored artifact creation using drawing software for multiple users on a single display computer. Children were encouraged to collaborate by interfaces that provided engaging extensions and variations when used collaboratively [Benford et al., 2000]. This approach can be applied to an application built on my framework. If these tools are only available when children are in proximity to a Tangible Flag, this may further encourage face-to-face collaboration in a relevant context.

7.3.2 Advantages of Multiple Display Groupware

Supporting collaborator awareness is a main research area for traditional adult groupware applications [Dourish and Bellotti, 1992; Gutwin and Greenberg, 2002]. The interface design of the Tangible Flags technology has drawn on this research, for instance, by using updated flag thumbnails and flashing alerts to provide awareness to all artifact changes even while children are working on different pages. Another approach to groupware that is appropriate for co-present collaborators is single display groupware [Stewart, 1999]. This research addresses issues of collaborative awareness with a straightforward approach, i.e., users are looking at the same display. Coordination of activity is simplified from that of distributed groupware, because collaborators are co-present and because it fits the model of 'what you see is what I see' (WYSIWIS). The Tangible Flags technology has also drawn on this concept, especially from Kidpad [Druin et al., 1997; Benford et al., 2000], by promoting face-to-face collaboration with children working together in shared workspace for the same Tangible Flag. Even though they each have their own computer, their displays are identical (WYSIWIS) and they can easily talk, look over each other's shoulder and point at the screen. However, because children do each have their own display, there is an option to relax the WYSIWIS condition, which is a common approach for adult groupware applications [Gutwin et al., 1996]. This gives the potential of interface designs that can enhance the benefits of the Tangible Flags technology.

One possibility is an interface design that helps children resolves shared space conflicts. My research has shown that these conflicts can occur. To begin investigating possible solutions based on relaxed WYSIWIS, children on the design team helped evaluated a couple of design approaches in an activity designed to promote conflict. Three interfaces were compared:

- An interface in which users could delete each other's work. This was standard WYSIWIS, but a different delete policy from the interfaces used in the study, where users could only delete their own work.
- An interface where deleting only removed an object from the deleting user's display, but not from other users' displays (relaxed WYSIWIS).
- An interface with where deleting an object did not delete the object from the user's display, but faded the object by making it mostly transparent. Other users' displays were unchanged (relaxed WYSIWIS). A third input control button enabled users to undelete faded objects.

There was not a noticeable difference in the conflict resolution that occurred between the three interfaces; however, this may have been a result of an activity designed to encourage conflict. Some of the children were annoyed to discover that the second interface did not delete objects on other users' displays. Some of the children liked the interface with faded delete, but some did not. Future work will include testing similar interface designs in cooperative activities.

A second possibility with relaxed WYSIWIS is the concept of a private annotation layer in the shared workspace [Ichimura et al., 1993; Shiozawa et al., 1999]. An input control mode could be added that would enable users to make private additions to the shared workspace that would not appear on other users' displays. This could be especially useful for educators to annotate children's field trip project work for grading purposes or further follow up back in the classroom.

7.3.3 Scaling for Larger Numbers of Users

The interface used for the studies conducted in my research was purposely designed with a single layer display of all interface components [Hutchinson, 2006], which meant that any content changes are immediately visible to the user. However, such a design will not scale for a larger numbers of users or greater amount of content. Future interface designs that are to be scalable will probably not be able to display all active content simultaneously and will need to incorporate more tools for supported awareness of collaborative activity [Dourish and Bellotti, 1992; Gutwin and Greenberg, 2002]. However, these interfaces will need to be carefully designed to extend such concepts to children, especially to younger children. Use of Cooperative Inquiry methods would be critical to developing a successful design [Druin, 1999].

7.3.4 Adding Audio Support

Research indicates that children learn better when visual images are combined with audio narrative [Low and Sweller, 2005; Mayer, 2005]. Audio is also an important communication channel for supporting collaboration, providing a different format that may be a more effective than writing for a quick transfer of information. One powerful addition to the Tangible Flags technology would be to add audio support, which could perform several useful functions. For instance, children could record audio to go with their written notes and drawings. This would support asynchronous collaboration and give additional understanding of the context of a Tangible Flag by enabling children to supplement writing and drawing with additional details. In addition, educators could attach audio recordings to Tangible Flags they have placed in the environment (such as in the case study) or add audio to children's notes to ask questions or provide information.

Audio could also be used as an instantaneous communication channel for supporting synchronous collaboration. One mechanism to help organize and direct instantaneous voice would be to create a voice channel for each Tangible Flag. All children viewing a particular flag could talk on an associated channel, without interrupting those working on a different flag. This could help focus voice discussions and direct social interaction around Tangible Flags and their context. It may also enhance the effects of mobile awareness that results in more face-to-face collaboration when children are using the Tangible Flags technology.

7.4 Future Studies

7.4.1 An extended case study involving classroom processes

The case study detailed in Chapter 4 represented a common educational experience for children. However, this study did not represent a field trip environment with a more structured learning experience, such as children visiting from a classroom with more specific learning goals might encounter. Therefore, the case study of Chapter 4 was limited in its ability to study the impact of the Tangible Flags technology on children's learning outcomes. Future work will include a study designed around a classroom curriculum. This will allow for field trip activities and a Tangible Flags interface that is designed around more specific learning content. Such an application can include more structure or roles centered on the content, which has been shown to be important for collaborative learning [Slavin, 1996]. In addition, the study can include observations of classroom activity after the field trip, which will allow more understanding of the impact on learning processes and outcomes.

7.4.2 A comparison study with a location based system

One option I considered for a study was to compare the Tangible Flags concept with a system similar to the research for older children discussed in Chapter 2, i.e., a system that used an intangible connection, such as location awareness, to provide information in context. Because my best available study group was a classroom of kindergarteners, I elected not to do this because I felt a comparison study would likely be very one sided. The learning theory and research for older children detailed in Chapter 2 suggest that such a system would be problematic for kindergarten age children. However, such a study might be very interesting if conducted with older children. Around age 12, children become developmentally more capable of understanding the abstract [Piaget, 1977b]. A study conducted with children in this age range might give more insight into the benefits of tangible or concrete mechanisms for embedding information into the physical world, as well as better guidelines for developing technology for older children.

After word

In conducting this research, I have sought to examine how to keep exploration experiences as the genuinely exciting and motivating activity that lets children naturally do what they do best; explore, question, create and interact with each other. The desired outcome of this research was to understand ways in which technology can help children to learn outside of classroom environments. As can been seen from the body of research, many factors are important to children's learning. Yet while learning in authentic context, creation of an explicit representations, and collaborative activity are all recognized as valuable contributors to a child's cognitive growth, all too often technology designed for children focuses on only one or two aspects at the expense of the others. However, my research shows that even when providing all support for all these factors, technology can still distract children from learning activities. The addition of technology to learning processes requires that such technologies be carefully integrated with learning content and activities. Especially when providing support for collaboration, children's natural social tendencies may result in behaviors that distract from learning. Technology may provide the most learning benefit when structured around specific learning content and balancing support for collaboration with learning activities may be the most challenging part of that. Yet in my studies, support for collaboration was also the primary factor in keeping the children engaged in the learning activities for a longer period. I hope that my research has suggested how technology can provide important learning supports for children, yet also enable their teachers to provide the structure necessary to focus their learning and channel it into the ongoing classroom processes.

Appendix A: Announcement, Letter and Permission Form for Case Study

A.1 Rock Creek Park Program Announcement

2:00PM @ Nature Center. Forest Scavenger Hunt. Join a park ranger, explore a 1/4 mile trail and learn how to find and identify trees and other natural features of the forest. Children may also use an exciting new educational technology designed for field trips and scavenger hunts (technology use weather permitting). For ages 6 and up.

A.2 Parental Letter

Dear Parents,

What are the educational benefits to children using technology? How can technology be used to enhance learning in children? A research team led by Dr. Allison Druin from University of Maryland's Human-Computer Interaction Lab is investigating these research questions. We are developing a new educational technology to support children and their educators, including teachers and park rangers. We hope that this technology can enhance children's learning when they participate in field trips.

We are working directly with the National Park Service to study and improve this technology. The National Park Service has provided us with an ideal setting for this technology, the Forest Walk. Park Rangers have helped combine this popular exploration activity with interactive technology that allows children to create their own documentary of their Forest Walk experience.

We are inviting your child to use this interactive technology during the Forest Walk. As your child explores the Forest Walk trail, he or she will be able to write comments about parts of the Forest that interest him/her and view comments made by the other children participating in study. In addition, afterwards we would like you and your child to participate in a group discussion of the experience to help us improve the use of this technology in the National Parks. Your child will get to participate in a fun and unique experience while helping our research team to better understand how to design technology for the National Parks and other educational experiences.

This technology is not a commercial product; it is being developed as part of the University of Maryland's research into educational technology for children. The technology is developmentally appropriate and safe for children to use and there is no known risk associated with using the technology. While it does use wireless networking, there is no connection to the Internet.

Your child's participation in this research is entirely voluntary. You may accompany and interact with your child during the study. You or your child may choose to discontinue participation at any time. If your child does not participate in the study, he/she may still participate in the Rock Creek Park's Forest Walk.

Your child's name will not be used in any description of this study. Data on your child's use of the technology will be collected, but only associated with your child by age and gender. For research purposes, your child may be videotaped, audio taped, or have digital photos taken of him/her while using the technology. These recordings may be used in articles submitted for publication in research journals, *but under no circumstances will any personally identifying information about your child be associated with a recorded image.* Your child's information may be shared with representatives of the University of Maryland, College Park or governmental authorities if your child or someone else is in danger or if we are required to do so by law.

Dr. Allison Druin at the University of Maryland, College Park, is conducting this research. If you have any questions about the research study itself, please contact Dr. Druin at the phone number or email below. If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: **Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (e-mail) irb@deans.umd.edu; (telephone) 301-405-0678.**

Thank you,

Dr. Allison Druin, Principal Investigator
Human Computer Interaction Lab (HCIL)
3159 AV Williams Bldg., University of Maryland
College Park, MD 20742
(301) 405-7406
allisond@umiacs.umd.edu

A.3 Parental Permission Form

Interactive Field Trip Technology at Rock Creek National Park

I give permission for my child, ____,
to participate in using the interactive field trip technology during today's Forest Walk activity at Rock Creek National Park. My child will be helping the National Park Service and University of Maryland's research team under Dr. Druin to develop new educational technologies for children.

_______________________   _____________________________   _____________

Parent Name   Parent Signature
Date

I give permission for my child to be videotaped for research purposes while using the interactive field trip technology during today's Forest Walk activity at Rock Creek National Park. I understand that my child's name will not be associated with his/her picture at any time.

__________________________________   ___________

Parent Signature   Date

Child's age: ___________
Child's gender: ___________

Parental Contact Information:

Parent Name: ____

Phone Number: ____

Email Address: ____

Appendix B: Parental Questionnaires for Case Study

B.1 Parent Pre-Questionnaire

The purpose of this questionnaire is to collect some basic demographic information on the participants.

Basic information (please fill out one line for each child participating):

	Child's Age	Child's (School) Grade	Child's Gender		Returning participant	
1)	__________	_________________	M	F	Yes	No
2)	__________	_________________	M	F	Yes	No
3)	__________	_________________	M	F	Yes	No
4)	__________	_________________	M	F	Yes	No

How often do your children use a computer at home?

Child 1)

more than once a day once a day a few times a week once a week or less

Child 2)

more than once a day once a day a few times a week once a week or less

Child 3)

more than once a day once a day a few times a week once a week or less

Child 4)

more than once a day once a day a few times a week once a week or less

Tell us a bit about your past visits to the National Parks, such as which parks you like to visit and how often you visit a national park.

(Filled out by researcher) Family Assigned to Team Color: ________________

B.2 Parent Post-Questionnaire

The purpose of this questionnaire is obtain an assessment of your child's use of the technology from a person very qualified to do so; you! Feel free to write on the back if needed.

1) What part of this experience was easy for your child(ren)? Please tell us why.

2) What part of this experience was hard for your child(ren)? Please tell us why.

3) What suggestions can you give us to make this experience more rewarding and beneficial for your child(ren)?

4) How much difference do you think the technology made in your child(ren)'s experience at the park? Please tell us the reasons why.

Appendix C: Researcher Guidelines for Case Study

Setup process

1. Know the starting spot for your team
2. Use the demo version to pre-place a flag (not your team's color)
    a. Shut down the demo client
    b. Turn off the RFID
    c. DO NOT shut down the demo server
3. Checklist for starting
    a. Your team's tablet
        i. Start demo version as we form into teams
        ii. Also turn on and initialize the RFID
    b. Your team's bag of flags and nametags
    c. Clipboards (and pens) with questionnaires for parents
    d. A notepad and pen for yourself and video camera for your assistant
    e. A walkie-talkie to call me if you have problems. Leave the volume down unless you need it.

Demo process

1. Split into teams, assign team leaders
2. Team leaders write team color on questionnaire and hand one questionnaire per family to a parent
3. Tell parent to fill out FIRST PAGE ONLY and put their name at the top.
4. Ask the kids if they are experts in TEXTURE, COLOR, SHAPE or SIZE
5. Assign jobs to the kids and give them the nametag with their job
    a. Give COLOR or SIZE to the younger children
6. Show demo version of the software to the children in your team
    a. Find something interesting and place a flag
    b. Vote for the features that describe your object
    c. Hand the computer to a kid and prompt them to describe an aspect that fits their job ("do you think the bark is rough or smooth? Can you write that here?")
    d. Walk to a pre-place flag and scan it, pointing out that it is another team's flag
    e. Show them what is on the flag
    f. Vote for features on that flag (or have a kid do it)
    g. Ask another kid to answer a question (related to their job)
7. Shut down demo client and server
8. Start study version of software and initialize the RFID
9. Collect clipboards from parents and set on ground or give to another researcher
10. Move your team to your starting point

Study process

1. Tell parents to place an asterisk on a page if they help a child with writing.

2. Prompt the team as necessary but note when doing so (by FLAG)
3. Encourage children to look for things other teams have not found (total votes can be seen in bottom right corner)
4. On video, try to capture the children's interactions with each other and the environment. Also try to get some shots of their use of the tablet (showing screen if possible)
5. Take note of children's actions that indicate:
    a. Inquiry into the environment
    b. Collaboration within or between teams (or ranger)
    c. Elaboration on what they are learning
    d. How the Tangible Flag and/or software is involved in the action
6. Put one child in charge of collecting your team's flags at the end
7. Back in the Nature Center, hand out the questionnaire clipboards to the parents again.

Appendix D: Transcripts and Examples for Case Study

Example 1: Red girl

Initial part of tape is missing, but researcher asked all groups the same question: *"Do you know what the different color writing means?"*

Red girl: *(Initial part of response missing, but she answered correctly and was asked "why?"). "Because we are on different teams and the team, I think, is the same color."*

Researcher: *"That's right. So who's black?"*

Red girl: *"The ranger?"*

Researcher: *"Yup, the ranger."*

Example 2: Blue girl

Researcher: *"Do you know what the different color writing means?"*

Blue girl: *"No."*

Researcher: *"What color is your writing?"*

Blue girl: *"Blue.*

Researcher: *"Do you see any other color writing?"*

Blue girl: *"Well, I just saw a little bit of black."*

Researcher: *"Who do you think the black is?"*

Blue girl: *"You?"*

Researcher: *"No."*

Blue girl: *"Ranger?"*

Example 3: Green boy

Researcher: *"Do you know what the different color writing means?"*

Green boy: *(No response).*

Researcher: *"Do you see the different color writing on here? What color is your writing?"*

Green boy: *"Black."*

Green girl parent: *"We're green."*

Researcher: *"The ranger is black."*

Appendix E: Parental Permission Form and Letter for Comparative Study

Fall 2005
Dear Parents:

What kinds of technology enhance learning in young children? What are the educational benefits to young children using technology? These research questions are being investigated by a research team led by Dr. Allison Druin of the Human Development department of the College of Education and the Human-Computer Interaction Lab. We are developing new, educational technologies for children and would like permission for your child to play with and help to create these new technologies.

Our research team of faculty, staff, and students in human development, education, computer science, engineering, art, and children who work with us in our lab are designing these technologies. The technologies are not commercially available, so your child will have the opportunity to experience cutting-edge technologies.

As our research team develops new technologies throughout the semester, we would like permission to ask your child to play with and to help develop these technologies. All technologies will be developmentally appropriate and safe for the children. The children will play with and help design the technologies in the classroom, the great room, or one of the research rooms. We believe that there could be many benefits to your child, including acquiring new technology skills, enhancing his/her creative problem-solving skills, and perhaps having a lot of fun. None of these benefits are promised by the researchers, but have been seen in other children who have been a part of similar experiences. In addition, it is hoped that the work of this research will enhance technologies that can better serve children in their learning and play.

Children will be asked if they would like to participate and may choose not to at any time. Your child's participation in this study is voluntary and goes beyond normal participation in school activities. Your child may choose not to participate at any time, without it affecting your child's status at the Center for Young Children. Your child's name will not be used in any description of these studies. For research purposes, your child may be videotaped, audio taped, or have digital photos taken of him/her while using the technologies. These recordings may be used at conferences or in articles submitted to research journals to share our findings with other researchers, but your child's name will not be associated with any images.

If you are willing to give permission for your child to participate, please sign the attached permission slip and return it to the folder by the front desk at the CYC. You may learn more about our research projects through our website at http://www.cs.umd.edu/hcil/kiddesign/. If you have any questions, please contact the principal investigator, Dr. Allison Druin, at allisond@umiacs.umd.edu or 301-405-7406.

Thank you,

Dr. Allison Druin, Principal Investigator,
Human-Computer Interaction Lab (HCIL)
3159 AV Williams Building
University of Maryland, College Park

Technology Exploration

I give permission for my child, ____________________________________ to participate in playing with and helping to create new educational technologies developed by Dr. Druin's research team at the University of Maryland.

Child's Birthdate: _____________________________

_____________________________ _________________________ _______
Parent Name Parent Signature Date

Phone Number: ___________________________

Email Address: ___________________________

For questions, please contact:
Dr. Allison Druin, Principal Investigator,
Human-Computer Interaction Lab (HCIL)
3159 AV Williams Building
University of Maryland, College Park 20742
301-405-7406
allisond@umiacs.umd.edu

Technology Exploration

I give permission for my child, ___________________________________ to participate in playing with and helping to create new educational technologies developed by Dr. Druin's research team at the University of Maryland.

________________________ _____________________________ ___________

Parent Name | Parent Signature | Date

I give permission for my child to be videotaped for research purposes while playing with and helping to create the technologies, understanding that my child's name will not be associated with his/her picture at any time

__________________________ ____________

Parent Signature | Date

Child's birthdate: __________________________

Phone Number: __________________________

Email Address: __________________________

For questions, please contact:
Dr. Allison Druin, Principal Investigator,
Human-Computer Interaction Lab (HCIL)
3159 AV Williams Building
University of Maryland, College Park 20742
301-405-7406
allisond@umiacs.umd.edu

Appendix F: Participant Post Questionnaire for Comparative Study

Name and Group	Assigned Color and Technology	For the two colors besides you child's own, ask the first two questions for one color and the second two questions for the other color.	Activity 1 Answers	Activity 2 Answers	Activity 3 Answers
Child Name and Group	Red Paper	How many GREEN papers did you find? How many GREEN papers did you add something to? How many BLUE papers did you find? How many BLUE papers did you add something to? Did you find all the papers? Did you add something to all the papers?			
Child Name and Group	Green Paper	How many RED papers did you find? How many RED papers did you add something to? How many BLUE papers did you find? How many BLUE papers did you add something to? Did you find all the papers? Did you add something to all the papers?			
Child Name and Group	Blue Paper	How many RED papers did you find? How many RED papers did you add something to? How many GREEN papers did you find? How many GREEN papers did you add something to?			

		Did you find all the papers?			
		Did you add something to all the papers?			
Child Name and Group	Red Tangible Flags	How many GREEN flags did you find?			
		How many GREEN flags did you add something to?			
		How many BLUE flags did you find?			
		How many BLUE flags did you add something to?			
		Did you find all the flags?			
		Did you add something to all the flags?			
Child Name and Group	Green Tangible Flags	How many RED flags did you find?			
		How many RED flags did you add something to?			
		How many BLUE flags did you find?			
		How many BLUE flags did you add something to?			
		Did you find all the flags?			
		Did you add something to all the flags?			
Child Name and Group	Blue Tangible Flags	How many RED flags did you find?			
		How many RED flags did you add something to?			
		How many GREEN flags did you find?			
		How many GREEN flags did you add something to?			
		Did you find all the flags?			
		Did you add something to all the flags?			

Appendix G: Researcher Guidelines and Prompts for Comparative Study

This study will run in 1 hour blocks on Tues. and Thurs., 10:30 at the CYC until Mar. 10th. I will need three researchers each time (two others besides myself). I am counting on Mona Leigh on Tuesdays and Sante both Tues. and Thurs. up through Feb. 24th. Jerry will be off on Tues. unless absolutely needed. Sabrina will be helping out as needed as well.

Goal of Study

The study will compare two technologies for children to take notes. One technology is Tangible Flags and the other is paper. I've set up the paper to resemble the Tangible Flags as closely as possible. Children will use either paper or flags to mark places where they have drawn pictures or written notes around the area (either indoors or outdoors). Children can also look at and draw/write on each other's pictures. The goal is to see how children interact with each other using paper and Tangible Flags. I am looking at two specific aspects of interaction.

<u>Awareness</u>: I want to capture how much awareness children have that the other children have created pages of drawings or notes. Do they know where the other children have been? Do they see where others' have placed their papers or flags? How well do they keep track of them? Do they 'get' that they can go look at these? Do they 'get' the association between drawings/notes displayed on the computer and flags?

<u>Collaboration</u>: I want to capture how much the children build on each others' pages. Do they add to each others' pages? Do they return to pages to see if others' have added anything? Do they add to their own pages again (maybe after others' have)?

Within these two aspects, researchers need to carefully follow a procedure for directing or prompting children. I want to emphasize that the goal IS NOT to see if they figure out the technology on their own. Giving them instruction on using Tangible Flags is fine. Where we need to be careful is in suggesting/directing children to find papers/flags and in suggesting/directing children to add to each others' pages. These things need to follow a clear procedure (given in prompt section below).

Teams

Children will be split into 6 teams of 3 children each. 3 teams will use paper for the entire study and 3 teams will use the technology. Each team will complete 3 activities over the course of the study, for a total of 18 activities. This means we need to do 2 per CYC session (and 3 a couple times if we can). Six of these activities will be outside, so we need to take advantage of nice days when we get them (need 3 good outdoor days).

Activities

In each activity, each child will create two pages. They will also look for others' pages and add to these pages. Children with paper will have 2 slates and a marker. Children with the technology will have a tablet PC and 2 flags. You may carry objects for children when asked, returning them when asked or as opportunity arises.

The first activity the children do will be a training/instruction session where the children will look for a simple class of objects (probably furniture in the great room). In this activity, researchers should *pro-actively* engage the children to look for each others' pages and to add to each others' pages. During this activity, teams using the technology need to have the features explained and *should be encouraged to explore technology features as much as possible*. Please use the prompts outlined below, but do not worry about pausing or following the specific order. Instead, go with the flow, keep the children engaged and try to get them to do many different things

ESPECIALLY, emphasis the *flag area* for children using Tangible Flags, so they can learn to look at flags there as well as in the physical space.

REMEMBER: Be very free with prompting during the training activity!

The second and third activities will be non-training sessions. During these activities, you will still give the children prompts to look for and create pages. However, *the prompts need to be delivered in a regular and paced manner*, starting with the lower level prompts and working up. *Always answer questions about use of the technology* (or aid a child having problems). One of the non-learning activities will be outdoors, where the children look for structures and the other will be indoors (great room), where the children look for patterns.

Interference

It is very likely that we will have children from other classrooms when we are working outdoors. Please be on the alert for other children touching or moving papers and flags. Watch for this and stop it as quickly as possible. If non-study child moves a paper/flag, move it back (ask your study child if you don't know where it was). Non-study children may also distract the study children. Tell them you are working and ask them to go play when this happens. Be firm.

Prompts

The following are the guidelines for giving prompts during the drawing activity. They are arranged in sections matching the general order in which children will do things. All pauses should be about 5 seconds (1 Mississippi, 2 Mississippi …).

A) Doing their first page:

Children should be guided to find their first subject away from the other children. Be insistent. Prompt the child if they are hesitant at choosing their first subject or hesitant to start drawing or writing:

- Ask neutral questions:
  - "What do you see that has/is a pattern/structure?"
- Respond to the child's gestures with questions:
  - "What is that?"
  - "How would you draw or write about that?"
- Prompt them to draw:
  - "What can you draw or write about it?"
  - "What do you like about it?"
- Do **NOT** use specific objects in asking questions
  - **NOT**: "Is *such and such* a (pattern/structure)?"
- Do **NOT** use gestures or point at possible choices.

Always help children with spelling if requested. You may offer to help spell if they seem stuck. "Do you need help spelling?".

B) Remind children to place their paper/flag when done.

- Make sure they do not forget to place the paper/flag
  - "Where would you like to place your paper/flag?"
- Do NOT gesture or make suggestions about location or placement. Allow the child to choose even if it will be hard to see. If the child asks if a certain location or placement is good, say "yes".
- If a child moves a paper/flag when working with it, ask them to put it back where they found it. Do **NOT** correct them if they put it back in the wrong place.

C) Every time a child finishes with a page (their own or another's):

Present these two choices every time a child finishes working on or inspecting a page.

- Do you want to look at a paper/flag or make a new one?

Continue this until the child creates their second page.

- If children try to place their second paper/flag at the location of their first paper/flag, ask them to place it somewhere away from the other paper/flag.
- If children want to place their second paper/flag at the location of another child's paper/flag, that is fine.

After the second page, just say "Let's look for other papers/flags." until the child decides or indicates that they would like to quit. Then take the child to the hall outside the Blue Room and ask the post-questions on the clipboard. Then return the child to the Blue Room.

D) If the child decides to look for a paper/flag:.

Use these descriptive prompts to help children locate a paper/flag. Continue giving prompts until the child finds a paper/flag, moving on to the next prompt each time you get a non-positive response. Give the level 1 prompt once, then the level 2 prompt once, etc. Children may respond to prompts either verbally or with gestures.

- Pause after any non-positive response (verbal or gesture)
- Ask next level of prompt if child has not started moving after pause
- Do **NOT** provide any prompts when a child is moving unless they are going very slow.
- If a child gives a positive response, or points at a paper/flag, ask:
  "Would you like to go look at it?"
- If a child doesn't want to look at a paper/flag, go back to part (C) above.

- **LEVEL 1**: Pause after the child responds to part (C) above:
  - "Do you see any papers/flags?"
- **LEVEL 2**: Pause for the child responds to level 1:
  - "Let's walk around and look for papers/flags."
  - TF ONLY add: "or do you want to look at any of these?" (Indicate flag area)
- **LEVEL 3:** Pause for the child responds to level 2:
  - Gesture in the broad direction of the nearest page and ask "Let's look over there."
  - TF ONLY: if child wants to look for a page in the flag area, gesture in the direction of the specific flag and ask above question.
- **LEVEL 4**: Pause for the child to react to level 3. If the child still does not find a paper/flag:
  - Point at the nearest paper/flag and ask "Let's go look at this one"
  - TF ONLY, when looking for a flag from the flag area, point out that flag.

E) When a child has found an existing paper/flag:

Use these descriptive prompts to help children add to an existing page. Ask each level prompt if the child does not take the appropriate action on their own initiate.

- If a child takes the indicated action, skip that prompt and move to the next.
- If a child gives a negative response to a prompt, go back to section (C) above, looking for a page.
- While a child is drawing or writing, ask questions about their work. See videotaping section below.
- If a child answer with a positive response but does not take any action:
  - You may help with the technology if needed.
  - You may give prompts to help them start. See section (A), on first page.

- **LEVEL 1**: Pause after the child discovers the paper/flag. If they do not look at it (scan the flag, pick it up or get close to it), ask:
    - "Do you want to look at it?"
- **LEVEL 2**: Pause after the child looks at it. If they do not start drawing or writing, ask:
    - "What would you like to add to it?"
        - If the child responds with a verbal response of what they want to add but does not start, tell them, "Ok, you can add that."
- **LEVEL 3:** Pause after the child stops drawing or writing. If they do not resume, ask:
    - "Do you want to add anything else?"

Example: Fred finds a flag. Before the pause is over, he scans the flag and looks at the picture. This was the level 1 action, so you skip this prompt. After Fred looks at it for the duration of a pause, you ask the level 2 prompt, "What would you like to add to it?". Fred starts drawing. You ask him about his drawing while videotaping. Fred stops drawing and runs off to look around before you finish pausing for the level 3 prompt. When Fred stops, you now ask the section C) question (unless he has found another page already, then you start another section E).

Videotaping

There are two purposes for the video tape. First is to capture the prompts when you give them children. SPEAK CLEARLY. I have to code all this video.

Second is to capture the child' intent about their drawing or writing. ALWAYS ask the child questions about their work, both on their own pages and when working on others' pages. Try to find out what the child has done and why. Do not go into much detail, just get the big picture. Get on camera WHEN YOU OR A CHILD GESTURES so I can see what is pointed at.

- "What does this writing say?"
- "What did you draw?"
- "Why did you draw this?" (You may gesture)
- "What is this part?" (You may gesture)
- Do **NOT** guess at or conjecture about the drawing!
    - **NOT:** "Is that a *such and such*?"

You may not always manage to have the video tape in the right place at the right time, if you miss something, narrate very briefly to the camera what happened (e.g., "Fred pointed at the slide")

Appendix H: Coding Forms and Guidelines for Comparative Study

H.1 Initial Coding Form

Child: ____________ Adult: ________________ Color: ________ Group: ____ Tech: __________

Tape Number and Date: ______________________ **Start Time on Tape: _________________**

Flag Color and Number: ______________________ **Finish Time on Tape: ________________**

After finishing a page -- Part C Instructions:

Record prompts if they vary from the standard and record any responses from the child. Place numbered notes for unusual events (and place a number with the relevant prompt).

Standard Prompt: "Do you want to look at a paper or make a new one?"

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Notes:

Creating new page -- Part A Instructions:

Record prompts and any responses from the child. Note if the child inspects the environment before drawing or while drawing. Note picture and page placement. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for as necessary.

New page color and number: ______________________________

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Does child inspection environment?

Describe Picture:

Describe Placement (# of prompts):

Children's Interactions:

Notes:

Looking for page -- Part D Instructions:

Record prompts if they vary from the standard prompt and record any responses from the child. Describe whether a child moves directly to a page or wanders while searching. Note time and page color/number if the child misses a page. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for unusual events with number in appropriate field.

Child's Search Mode (Direct or Wandering): ____

Time: __________ Level 1 Prompt ("Do you see any papers/flags?") ________________________

Time: __________ Level 2 Prompt ("Let's walk around and look for papers/flags.") ___________

Time: __________ Level 3 Prompt ("Let's look over there.") _______________________________

Time: __________ Level 4 Prompt ("Let's go look at this one.") ____________________________

Missed (Flag/Time): ____

Children's Interactions:

Notes:

Adding to a page -- Part E Instructions: **Page Color and Number: _______________________**

Record prompts if they vary from the standard and any responses from the child. Note if the child inspects the environment before drawing or while drawing. Describe picture and page placement. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for unusual events.

Time: __________ Level 1 Prompt ("Do you want to look at it?") ___________________________

Time: __________ Level 2 Prompt ("What would you like to add?") ________________________

Time: __________ Level 3 Prompt ("Do you want to add anything else?") ____________________

Repetition or Original: ___________________Separate or Addition: _____________________

Does child inspection environment?

Describe Picture:

Describe Placement (# of prompts):

Children's Interactions:

Notes:

H.2 Inter-rate Reliability Check Coding Form

Child: ____________ Adult: ________________ Color: ________ Group: ______ Act: __________

Tape Number and Date: ______________________ Start Time on Tape: _________________

Flag Color and Number: ______________________ Finish Time on Tape: ________________

After finishing a page -- Part C Instructions:

Record prompts if they vary from the standard and record any responses from the child. Place numbered notes for unusual events (and place a number with the relevant prompt).

Standard Prompt: "Do you want to look at a paper or make a new one?"

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Notes:

Creating or Adding to a page -- Part A&E Instructions:

Record prompts if they vary from the standard and any responses from the child. Note if the child inspects the environment before drawing or while drawing. Describe picture and page placement and count placement prompts. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for unusual events.

New Page: YES or NO Previously Added: YES or NO

Time: __________ Level 1 Prompt ("Do you want to look at it?") ___________________________

Time: __________ Level 2 Prompt ("What would you like to add?") ________________________

Time: __________ Level 3 Prompt ("Do you want to add anything else?") ____________________

Time: __________ Other Prompt: ____

Time: __________ Other Prompt: ____

Repetition/Original: _____________ Separate/Addition: ________________ Exists: YES or NO

Does child inspection environment: BEFORE DURING

Describe Picture:

Describe Placement (# of prompts):

Children's Interactions:

Notes:

Looking for page -- Part D Instructions:

Record prompts if they vary from the standard prompt and record any responses from the child. Describe whether a child moves directly to a page or wanders while searching. Note time and page color/number if the child misses a page. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for unusual events with number in appropriate field.

Child's Search Mode (Direct or Wandering): ____

Time: __________ Level 1 Prompt ("Do you see any papers/flags?") ________________________

Time: __________ Level 2 Prompt ("Let's walk around and look for papers/flags.") ___________

Time: __________ Level 3 Prompt ("Let's look over there.") ______________________________

Time: __________ Level 4 Prompt ("Let's go look at this one.") ___________________________

Other Flags Passed, Missed or Inspected:

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Time: __________ Flag:___________ Has Added: YES or NO Glance/Inspect: YES or NO

Children's Interactions:

Notes:

Interactions after last page of session:

H.3 Post Inter-rate Reliability Check Coding Form

Child: ____________ Adult: ________________ Color: ________ Group: ______ Act: __________

Tape Number and Date: ______________________ Start Time on Tape: _________________

Flag Color and Number: ______________________ Finish Time on Tape: ________________

After finishing a page -- Part C Instructions:

Record prompts if they vary from the standard and record any responses from the child. Place numbered notes for unusual events (and place a number with the relevant prompt).

Standard Prompt: "Do you want to look at a paper or make a new one?"

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Time: __________ Prompt: ____

Notes:

Creating or Adding to a page -- Part A&E Instructions:

Record prompts if they vary from the standard and any responses from the child. Note if the child inspects the environment before drawing or while drawing. Describe picture and page placement and count placement prompts. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for unusual events.

New Page: YES or NO Previously Added: YES or NO GUI Access: _____

Time: __________ Level 1 Prompt ("Do you want to look at it?") ___________________________

Time: __________ Level 2 Prompt ("What would you like to add?") ________________________

Time: __________ Level 3 Prompt ("Do you want to add anything else?") ____________________

Repetition/Original: _____________ Separate/Addition: ________________ Exists: YES or NO

Does child inspection environment: BEFORE DURING NOT THERE

Describe Picture:

Describe Placement (# of prompts):

Collaboration Style: ASYNCH CO-LOCATED DISTRIBUTED

Children's Interactions:

Notes:

Looking for page -- Part D Instructions:

Record prompts if they vary from the standard prompt and record any responses from the child. Describe whether a child moves directly to a page or wanders while searching. Note time and page color/number if the child misses a page. Take note of any interactions with other children (child's name and words/actions). Place numbered notes for unusual events with number in appropriate field.

Child's Search Mode (Direct or Wandering): ____

Time: __________ Level 1 Prompt ("Do you see any papers/flags?") _______________________

Time: __________ Level 2 Prompt ("Let's walk around and look for papers/flags.") ___________

Time: __________ Level 3 Prompt ("Let's look over there.") ______________________________

Time: __________ Level 4 Prompt ("Let's go look at this one.") ___________________________

Other Flags Looked at:

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Time: ________ Flag:_________ Has Added: Y or N Glance Inspect GUI Access

Children's Interactions:

Notes:

Interactions after last page of session:

H.4 Inter-rate Reliability Check Results

Flag additions

Purpose:

Coders recorded the color and number of a page every time a child added to a different page. A single coding sheet is used represent each and every page record and includes a variety of information (see attached coding sheet). The purpose is to create a sequential record of a child's interaction with the pages, with one sheet per addition to a page.

Validation: 97%

Coders agreed on 115 out of 118 cases. The 3 cases where the coders did not agree occurred when the children were using the technology. With the technology, children could switch views to a different page and make an addition while moving around. Because of this, the interaction was not always captured on video, or captured very briefly. Fortunately, interaction data logged by the technology use can be used to verify all Tangible Flag interactions. In the case of paper, the child's additions occurred while stationary and were well captured on video (hence, no disagreement between coders for paper).

In 6 cases for children using the technology, one coder put quick interactions with a different page via the GUI on the same sheet with another, more significant interaction. While this represented a deviation from the coding process, it is simple to verify using the interaction data logged by the technology. Such quick interactions did not occur with children using paper.

Start and stop times

Purpose:

The primary purpose of the timing information is for locating interesting events. Since the elapsed time for an interaction consists of both the time spent looking for a flag and the time spent working on a flag, its use for analysis is limited. The only meaning likely to be derived from this measure is to see if children spent more total time on the activities using either technology or paper.

Validation: 92%

A start time and a stop time were recorded for each page interaction. Coders agreed on timing in 108/118 cases. Coder timing was compared using the stop time recorded for each interaction. Stop times 5 seconds or less apart were marked as an agreement. 5 seconds was chosen somewhat arbitrarily, but seems a reasonable amount of time for the coder to make a decision that an interaction has ended, pause the tape and record the time. 3 of the inconsistent cases are a result of the 3 cases where the flag interaction did not agree. The remaining 7 cases are a result of a different opinion of when one interaction ended and another began and are not much more than 5 seconds apart in these cases.

Prompts:

Purpose:

A standard set of prompts was used by the researchers when conversing with the children during the activities. These prompts were given at the start of searching for a page, during the page search, and when interacting (adding) to a page. In addition to these standard prompts, the researchers were allowed to ask the children questions about what they were doing (e.g., "what are you drawing?") and to answer questions or make suggestions concerning the use of the technology or the activity process (i.e., "do you see any patterns you would like to draw?"). These questions and comments are considered *descriptive* and will not be used in quantitative analysis.

Prompts will form a significant part of the quantitative analysis. Number and level of prompts given will be used to determine if children had more awareness of the pages and if they elaborated more easily on their drawings.

Validation: 85%

Coders agreed on prompts in 196 out of 230 cases.

There were 3 types of disagreements:

<u>Miss</u> one of the coders did not record a prompt recorded by the other coder

<u>Level</u> coders assigned the prompt at different levels (parts D & E)

<u>Type</u> what one coder recorded as a prompt the other coder recorded as a different type of prompt or as a descriptive comment.

There were 17 cases where a coder missed a prompt. Missed prompts resulted from a variety of reasons. Some missed prompts were considered to be descriptive (and repetitive) by one coder and not recorded. Some missed prompts occurred when two prompts were spoken together by the researcher and one coder called it a single prompt and the other called it two. The most critical missed prompts where those where a part D or E was missed, because this will impact the quantitative analysis. This occurred 8 times. Of those 8, two cases were non-standard prompts that one coder considered a descriptive comment. One case was two prompts run together that were coded as a single prompt by one coder. Three cases were repeated prompts (not occurring at the same time) that one coder did not record both times. One case occurred at the end of the session (the child did not interact with any more flags). One case was simply missed by a coder.

There were 11 cases where coders' classified prompts as different types. In two cases, coders differed whether a prompt was a Part C prompt or a Part D Level 2 prompt. These two prompts are similar. In 9 cases, one coder recorded as a prompt what the other recorded as a descriptive comment. Of these, 5 were either Part C prompts or recorded separately as 'other' prompts and so do not effect quantitative analysis. The other 4 were non-standard prompts that were interpreted as a Level prompt by one coder and as a descriptive comment by the other.

There were 6 cases where coders assigned a prompt with a different Level in Parts D or E. One case was two prompts run together and placed at a single Level by one coder and split into two levels by the other coder. One case was a non-standard Part C prompt was taken as a Part D prompt, one coder as a Level 1, the other as a Level 2. Four cases were non standard prompts that were interpreted as differing Level by the coders.

This suggests the following guidelines during the remainder of the coding:

- Review all non-standard prompts a second time.
- Split all run together prompts into separate prompts based on transcript only, not timing.
- Be careful to record all repeated prompts.
- Distinguish between the very similar Part C and Part D, Level 2 prompts based on previous prompts for that flag interaction. If no Part C or Part D, Level 1 has yet occurred, call these prompts as Part C.
- Remove the 'other' prompt field from the coding sheet to remove the potential ambiguity in recording prompts versus descriptive comments.

Validation on subsets of prompts:

Part C:	79/93 = 85%
Part D all Levels:	68/81 = 84%
Part E all Levels:	49/56 = 88%
Part E, L1 & L2:	26/32 = 84%

Inspects the environment:

Purpose:

Coders noted if a child inspected the environment either immediately prior or while they were adding to a page. This measure is designed to help gauge if a child's addition is grounded in the environment. Are they finding something real and relevant to add to the drawing?

Validation: 88%

Coders agreed in 98 out of 111 cases.

This was a subjective decision in cases when the camera angle did not show the child's face. The difference in coding occurred in these cases. For the remainder of the coding, it will be considered inspection if a child looks away from the page, except when looking at another child.

Placement:

Purpose:

Placement is used to see if and how children used the placement of the page to help indicate the subject of the drawing.

Validation: 96%

Coders agreed in 107 out of 111 cases.

Coder described the original placement of each page. Coders counted any prompting by the researcher for the child to place the page. Coders noted if the child moved an existing page. The 4 cases when the coders did not agree were either a difference in counting placement prompts or failure to record the placement or movement of a page.

Repetition/Original:

Purpose:

This measure is to determine if the child repeated another child's drawing when adding to a page or added something new to the drawing. Original additions are considered to be more collaborative, if they exist in the environment (see **Exists** measure below).

Validation: 87%

Coders agreed in 73 out of 84 cases.

In 6 cases, the child added a new feature to a drawing, for instance, adding more stripes to a pattern. One coder called the new feature original and the other called it a repetition. In 4 cases when it was unclear what the child was adding, one coder made a guess and the other left the coding sheet blank. In 1 case, a child added a drawing of another object that was of the same type as the one already on the page; one coder called it repetition and the other original.

This suggests the following guidelines during the remainder of the coding:

- If what the child is adding is in doubt, no entry will be recorded.
- Object of a similar type will be called as an original if a second object exists, otherwise as repetition.
- In the case of adding features that have already been added previously, these will be called as repetition. Features not previously added by any child are original.

Separate/Addition:

Purpose:

This measure is to determine if the child is adding features to build on the object already drawn by another child or if the child is adding their drawing in a separate space on the page. Additions are considered to be more collaborative, if they exist in the environment (see **Exists** measure below).

Validation: 88%

Coders agreed in 74 out of 84 cases.

In 6 cases, one coder called objects that existed in the environment as additions when added to a different space on the drawing. In 2 cases, one coder called an object that was added on top of another object in the space as separate because the real object was separate from the first in the real world. In 1 case a coder was uncertain and left the field blank and in 1 case a coder made a mistake in calling an addition as separate.

This suggests the following guidelines during the remainder of the coding:

- Separate or addition will not be based on whether an object exists or if it is placed in the drawing differently that its position in the real world.
- Addition will refer to any drawing that overlaps or lies within the bounds of an existing drawing. Otherwise the drawing is considered separate.

Exists:

Purpose:

In the cases of Repetition/Original and Separate/Addition measures, whether the object exists or not helps the measure to be decided based on objective criteria instead of trying to gauge a child's intent. Combined with the above two measures this gives a more objective determination. This measure was added after the original inter-reliability coding had been conducted. The coders reviewed the coding sheets (which includes a description of the child's drawing) to determine if what the child drew actually existed. In cases where the description was not clear, the coders reviewed the video.

Validation: 93%

Coders agreed in 103 out of 111 cases.

In 4 cases, one of the coders was unsure and the other coder guessed. In 4 cases, a feature was added and the coders did not agree that the feature existed. This was stripes added to a pattern. Vertical stripes were added to a drawing of an object that had only horizontal stripes (or vice versa).

This suggests the following guidelines during the remainder of the coding:

- If what the child is adding is in doubt, no entry will be recorded.
- If a feature generally exists then any representation of it is considered to exist even if it is incongruent with the real world (e.g., stripes are stripes and if the object has stripes, they count as existing regardless of direction).

Mode:

Purpose:

Direct or Wandering is an indication of whether a child has a clear idea where they are headed or what they are looking for. Moving directly to a page previously visited could indicate that a child has a clear idea where the page is physically located. Moving directly to a not yet discovered a page could indicate that a child has a clear idea what area has been previously unexplored. If a child backtracks while looking for a page, then it is wandering mode. If the child always moves into a new direction while looking for a page, it is direct mode.

Validation: 83%

Coders agreed in 70 out of 84 cases.

In 4 cases one coder was unsure and did left the field blank and the other coder made a guess. In 10 cases, the coders differed. This is a somewhat subjective measure, though in many of the differing cases, the child interacted significantly with other child or inspected pages without making additions.

This suggests the following guidelines during the remainder of the coding:

- If the case is border line, no entry will be recorded.
- If a child interacts with another child or stops at another page, the mode will be considered as wandering.

Other Flags:

Purpose:

Coders record number and color and time for each page a child interacts with but does not make an addition to. The goal is to note the child's awareness of other pages and when a child decides not to add to a page or check on a page to see if it has changed.

Validation: 71%

Coders agreed in 77 out of 108 cases.

The bulk of the errors occurred because the camera often did not or only briefly captured a nearby page. Coders had to rely on their knowledge of the placement of the pages in the area, which also changed with time. The children seldom seemed to notice these pages which were on the periphery of the video.

In order to capture some useful insight, this was re-coded using only flags that the children noticed or interacted with. Coder decided if a child noticed a page at least briefly and was judged using similar criteria to **Inspects the environment** above. If the child noticed the page, the coder also decided if the child inspects the page, by gauging if the child looked at the page closely enough and long enough to determine what drawing was on it. Using these coding criteria the new results were:

Pages noticed:

Validation: 84%

Coders agreed in 53 out of 63 cases. In 10 cases, the coders differed on whether a child noticed a page or not. There is no clear way to remove the subjective element in judging this measure.

Pages inspected:

Validation: 81%

Coders agreed in 35 out of 43 cases. However, the major difference occurred in the case of paper. With technology, to inspect a page requires that a child scan a flag or click on the GUI to access the page. Therefore it is very clear when a child inspects a page. Breaking down the coding inter-reliability for each type of technology suggests that this measure may not be accurate in the case of paper.

Paper validation:	13 out of 19 cases = 68%
Tangible Flags validation:	22 out of 24 cases = 92%

H.5 Coding Guidelines used Post Inter-rate Reliability Check

Flag additions:

Once sheet for every time changes are made to a different page.
Verify tech version from data.

Stop times:

New interaction begins, determined by either researcher prompt, or in the case that child' makes a mark after prompt, from the end of the last mark.

Prompts:

Descriptive comments (not coded as prompts, but noted):

- Technology help or prompting ("do you remember how to ..?")
- Questions about child's activity ("what are you looking for?", "what are you drawing?")

Guidelines:

- review all non-standard prompts
- assign prompts based on how closely transcript matches prompt (not by order)
- split run together prompts into separate prompts based on transcript only (not timing)
- be careful to record all repeated prompts
- distinguish Part C and Part D, lvl 2 based on previous prompts for that flag. If no part C or part D, level 1, classify as Part C.

Inspects:

Considered inspection if child looks away from the page, except when looking at another child.

Placement:

Describe placement and count prompts by researchers.

Repetition/Original:

- When in doubt, record no entry
- Object of similar type = original if a second object of that type exists, otherwise repetition.
- Adding features previously added = repetition. Features not previously added by ANY child = original.

Separate/Addition:

- Addition refers to any drawing that overlaps or lies within the bounds of an existing drawing.
- Between unclosed lines or shapes is considered inside the bounds.
- Separate vs. addition not based of object's existence or position in the real world.

Exists:

- When in doubt, record no entry
- If feature generally exists, any representation of it exists (even if incongruent with real word). i.e, stripes are stripes, and exist regardless of direction

Mode:

- When in doubt, record no entry
- Any backtracking = wandering
- If child interacts with another child or stops at a page/flag, mode = wandering

Flags Looked At:

Note if child looks at a page/flag. Distinguish between a glance and inspection. Note use of GUI to access page.

Collaborative interaction type:

Mark one per interaction sheet. Indicate if children collaboratively draw or only discuss or watch each other.

Asynchronous
Synchronous

- collocated
- distributed

Appendix I: Transcripts and Examples for Comparative Study

I.1 Example of carrying paper page around

Example 1: Group1, Activity 2, Red boy (see Figure 32).

[To researcher, when moving his paper for the first time]
"This is mine. I'm going to put it in a better place so I can draw a pattern."

[To researcher, when he starts carrying the paper around]
"I'll keep this one and draw every single pattern that I found."

[When another boy (Group 1, Blue) asks him: "Any papers here?"]
(Shows the paper he is carrying) "This is my keep it handy paper."

Figure 32. The "keep it handy paper" page that the red child carried around during much of an activity.

I.2 Examples of paper pages providing context

Example 2: Group 1, Activity 1, Page Green 1 (see Figure 33).

Researcher: *"What do you think the other drawing was, that was on there?"*

Boy, Group 1, Red: *"That." (Points at couch)*

Figure 33. Photograph of child indicating that a paper drawing represents nearby couch.

Example 3: Group 2, Activity 3, Page Green 2 (see Figure 34).

Researcher: *"What do you think this is?"*

Girl, Group 2, Red: *"The slide."*

Figure 34. Photograph of child indicating that a paper drawing represents the slide.

Example 4: Group 3, Activity 3, Page Green 1 (see Figures 35 and 36).

Researcher: *"What do you think it is?"*

Girl, Group 3, Red: *"The tire swing." (Points at tire swing)*

Figure 35. Photographs of the red child indicating that a paper drawing represents the tire swing (left), and making an addition to the page (right).

Figure 36. Photographs of paper page near tire swing (left), and final drawing on page at end of session (right).

I.3 Examples of context and asynchronous collaboration with paper system

Example 5: Group 1, Activity 1, Page Green 2 (see Figures 37 and 38).

Researcher: *"What did you draw there?"*

Boy, Group 1, Red: *"That." (Points at spray bottle on counter)*

Researcher: *"Oh, the spray bottle?"*

Boy, Group 1, Red: *"Yeah."*

Figure 37. Photographs of the red child indicating the spray bottle he is adding to a paper drawing (left), and drawing the spray bottle on the page (right).

Figure 38. Photographs of a paper page near on table near counter with spray bottle (left), and the final drawing on the page at the end of the session (right).

Example 6: Group 3, Activity 3, Page Green 1 (see Figures 36 and 39).

Researcher: *"What are you drawing?"*

Boy, Group 3, Blue: *"The dormitory."*

Figure 39. Photographs of the blue child adding drawing of a dormitory to a drawing of a tire swing on a paper page (left), and the dormitory in the background of the tire swing, from the perspective of the paper page (right).

I.4 Example of context and synchronous collaboration with paper system

Example 7: Group 1, Activity 1, Page Green 2 (see Figure 40).

Boy, Group 1, Blue: *"What are you drawing?"*

Boy, Group 1, Green: *"This." (Points at table)*

Boy, Group 1, Blue: *"Are those the little cups?" (Points at drawing)*

Boy, Group 1, Green: *"Yeah and those are the forks and [unintelligible]." (Points at drawing)*

Boy, Group 1, Blue: *"You going to draw the napkins?"*

Boy, Group 1, Green: *"Yeah."*

Figure 40. Photograph of two children discussing a drawing on a paper page.

I.5 Example of concurrent interaction with paper system

Example 8: Group 2, Activity 3, Page Green 2 (see Figure 41).

Girl, Group 2, Blue: *"I'm going to draw the slides and then the sky and the clouds and the sun."*

Girl, Group 2, Red: (*Speaking to girl, Group 2, Blue) "Stop [Blue girl's name], I got here first."*

Girl, Group 2, Blue: *"Well, we both can work on it."*

Researcher: (*Speaking to girl, Group 2, Blue) "[Blue girl's name], what are you drawing?"*

Girl, Group 2, Blue: *"I'm drawing the sun."*

Researcher: (*Speaking to girl, Group 2, Red) "[Red girl's name], what are you drawing?"*

Girl, Group 2, Red: *"The window."*

Figure 41. Photographs of two children working together on a paper page.

I.6 Examples of Tangible Flags providing context

Example 9: Group 4, Activity 1, Page Blue 1 (see Figure 42).

Researcher: *(Prompts child to scan a Tangible Flag) "Now what do you see?"*
Boy, Group 4, Green: *"A table."*

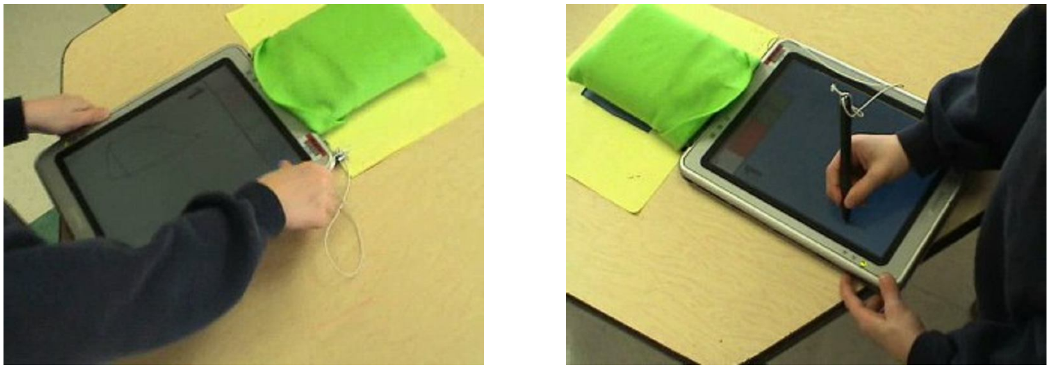

Figure 42. Photographs of a child scanning a Tangible Flag (left), and adding to the page using the computer (right).

Example 10: Group 5, Activity 3, Page Red 2 (see Figure 43).

Girl, Group 5, Blue: *(Scans flag) "Oh, I know what it is, it's the house."*

Figure 43. Photographs of a child running to a Tangible Flag (left), and scanning it (right).

Example 11: Group 6, Activity 2, Page Blue 1 (see Figure 44).

Researcher: *"What do you think that is?"*

Girl, Group 6, Green: *"It's a piano because it was right there." (Touches flag)*

Figure 44. Photograph of a child indicating that a Tangible Flag page represents the piano because of the placement of the flag.

I.7 Examples of context and asynchronous collaboration with Tangible Flags

Example 12: Group 4, Activity 1, Page Red 2 (see Figure 45).

Boy, Group 4, Activity 1: *(Takes down Tangible Flag and scans it.) "Ok."*

Researcher: *"Ah! What do you think that is?"*

Boy, Group 4, Activity 1: *"The shelf thing." (Points).*

Researcher: *"Oh, you think it's the shelf thing. What are you going to add?"*

Boy, Group 4, Activity 1: *"More boxes."*

Figure 45. Photographs of a child taking a Tangible Flag down to scan it (top left), indicating that the page represents the shelves (top right), and putting the Tangible Flag back (bottom).

Example 13: Group 5, Activity 1, Page Red 1 (see Figures 46 and 47).

Girl, Group 5, Green: *(Scans flag) "What is this a picture of?"*

Researcher: *"Hmm, I don't know, what do you think it is a picture of?"*

Girl, Group 5, Green: *"Oh, the cabinets and this."*

Researcher: *"What is it?"*

Girl, Group 5, Green: *"The cabinets and this."*

Researcher: *"The cabinets and what else?"*

Girl, Group 5, Green: *(Gestures at countertop).*

Researcher: *"The cabinets and the counter? What are you drawing?"*

Researcher: *(Brief pause) "What are you adding there, [girl's name]?"*

Girl, Group 5, Green: *"The cup."*

Researcher: *"Which cup?"*

Girl, Group 5, Green: *(Points at cup).*

Girl, Group 5, Green: *(Draws some more) "That's the water bottle."*

Researcher: *"The water bottle?"*

Girl, Group 5, Green: *"One of them."*

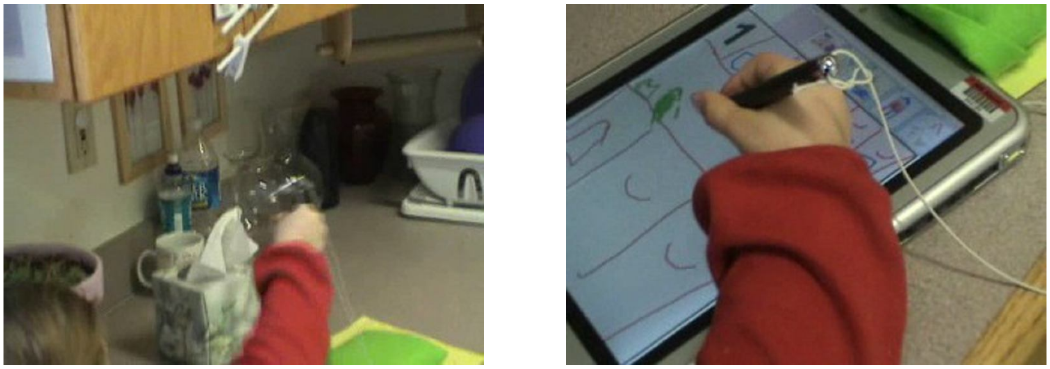

Figure 46. Photographs of the green child indicating that a Tangible Flag page represents the countertop (left), and adding a drawing of a cup and water bottle to the page (right).

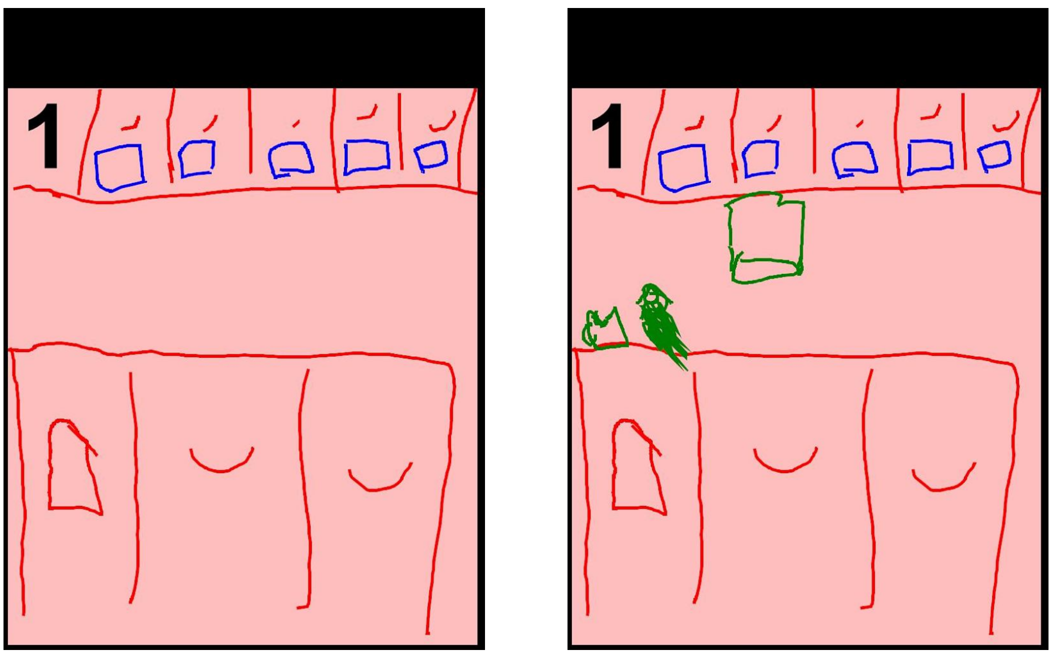

Figure 47. Screen shots of the page before the green child adds a drawing of a cup and water bottle (left), and after (right).

Example 14: Group 6, Activity 1, Page Red 2 (see Figures 48 and 49).

Girl, Group 6, Green: *(Scans flag) "Picture of the bookcase."*

Researcher: *"You think that is a picture of the bookcase?"*

Girl, Group 6, Green: *"I think."*

Researcher: *"Why do you think that is a picture of the bookcase?"*

Girl, Group 6, Green: *"Because that's right there." (Points at flag)*

Girl, Group 6, Green: *"And I'm drawing books on it."*

Figure 48. Photographs of the green child scanning a Tangible Flag (left), and indicating that the page represents the bookcase (right).

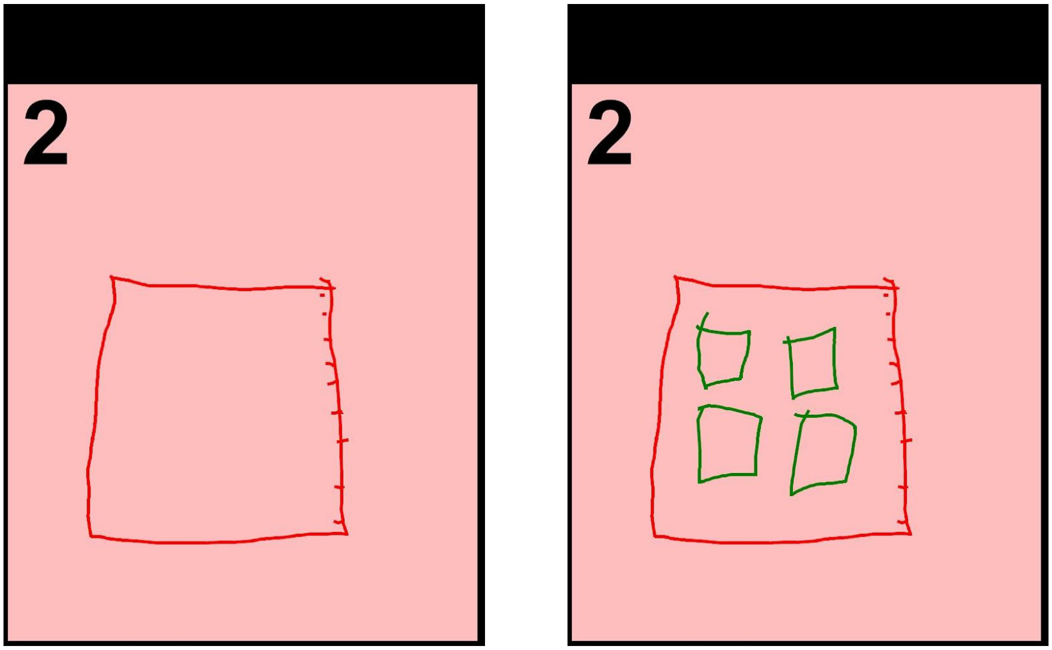

Figure 49. Screenshots of the page before the green child adds a drawing of books (left), and after (right).

I.8 Example of extended asynchronous collaboration with Tangible Flags

Example 15: Group 6, Activity 2, Page Red 1 (see Figures 50 through 54).

[11:22:20 AM]

Researcher: *"Do you see any patterns?"*

Girl, Group 6, Red: *(Points at couch).*

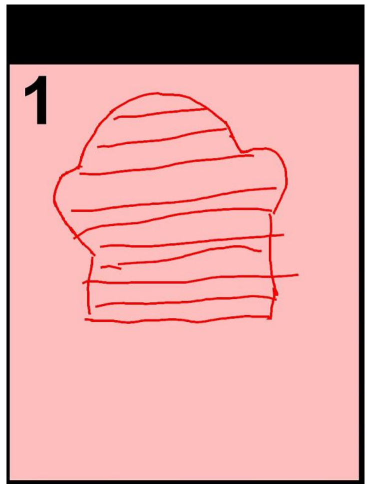

Figure 50. Photograph of the Red 1 Tangible Flag on the couch (left), and a screen shot of the Red 1 page after the red child's initial drawing (right).

[11:25:13 AM]

Researcher: *"Do you want to look around for somebody else's flag?"*

Girl, Group 6, Green: *"Uhhuh." (Walks over to Red 1).*

Girl, Group 6, Green: *"That is definitely a pattern." (Scans Red 1).*

Researcher: *"What's definitely a pattern?"*

Girl, Group 6, Green: *"This." (Points to couch). "The chair."*

Researcher: *"What are you adding?"*

Girl, Group 6, Green: *"More stripes."*

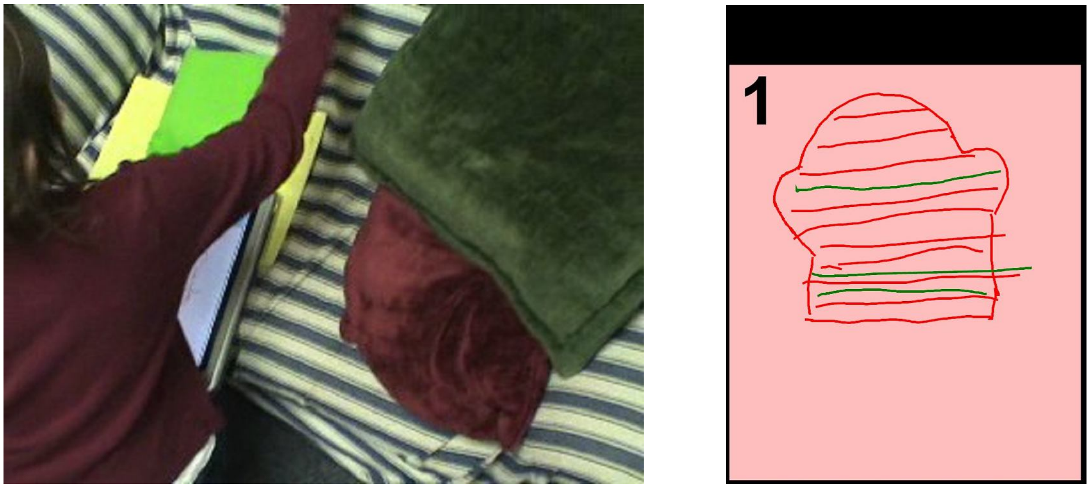

Figure 51. Photograph of the green child indicating that the Red 1 page represents the couch (left), and a screen shot of the Red 1 page after she adds stripes (right).

[11:25:55 AM]

Researcher: *"So, do you want to look for another pattern or do you want to look for somebody else's flag?"*

Boy, Group 6, Blue: *"Let's look for somebody else's flag." (Walks over to Red 1).*

Boy, Group 6, Blue: *"Oh, look, over here. Let's see what this thing is." (Scans Red 1). "Oh, cool."*

Researcher: *"What would you like to add to that?"*

Boy, Group 6, Blue: *"I don't really know, I'll just add stuff."*

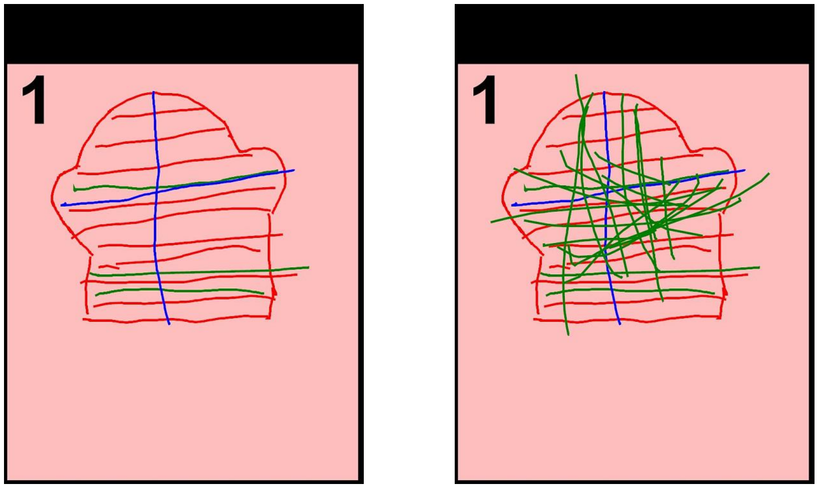

Figure 52. Screen shots of the Red 1 page after the blue child adds 'stuff' (left), and after the red child adds 'more stripes' (right).

[11:26:52 AM]

Girl, Group 6, Green: *(Accesses Red 1 with GUI). "He added something. Its [Blue boy's name], because its blue."*

Researcher: *"So [Blue boy's name] added something because it's the blue?"*

Girl, Group 6, Green: *"Umhum." (Walks to Red 1 Tangible Flag, does not add).*

[11:27:40 AM]

Girl, Group 6, Green: *(After interacting with Blue 2, walks to Red 1 and scans).*

Girl, Group 6, Green: *(Draws one stripe, uses GUI to switch to Green 2) "And that's there." (Switches back to Red 1 to add more stripes.)*

Researcher: *"What are you adding?"*

Girl, Group 6, Green: *"More and more stripes."*

[11:30:40 AM]

Girl, Group 6, Green: *(After interacting with other Flags, walks to Red 1 and scans).*

Researcher: *"What are you adding?"*

Girl, Group 6, Green: *"Bigger." (Gestures at arm rest).*

Researcher: *"Bigger?"*

Girl, Group 6, Green: *"So the arms can be bigger."*

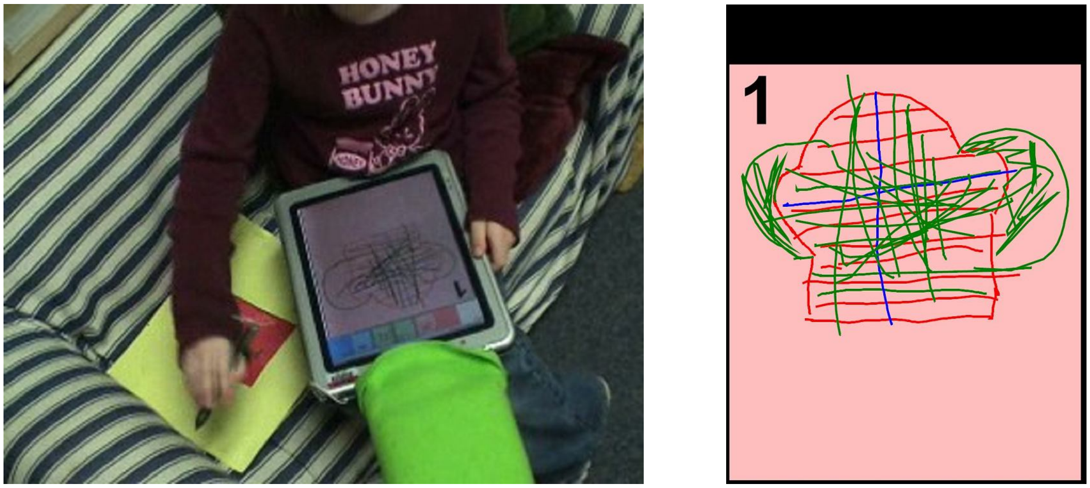

Figure 53. Photograph of the green child indicating the arm rest of the couch (left), and a screen shot of the Red 1 page after she adds the arm rests (right).

[11:33:30 AM]

Researcher: *"Do you want to look for other papers?"*

Boy, Group 6, Blue: *(Walks over to Red 1 and scans it).*

Researcher: *"What's on there?"*

Boy, Group 6, Blue: *"I'm going to make some [unintelligible]."*

Researcher: *"What are you making?"*

Boy, Group 6, Blue: *"Lightning."*

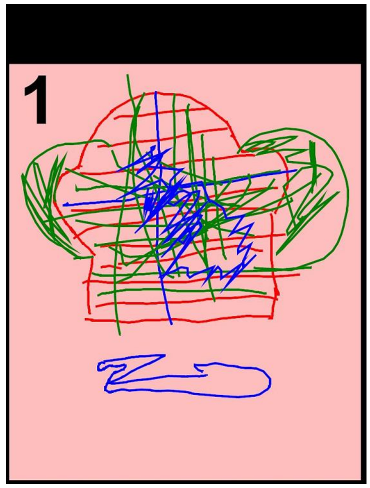

Figure 54. Screen shot of the Red 1 page after the blue child adds lightning.

I.9 Examples of extended and concurrent collaboration with Tangible Flags

Example 16: Group 4, Activity 1, Page Red 2 (see Figures 55 through 58).

[11:20:50 AM]

Boy, Group 4, Blue: *(Sets computer on table and looks at GUI.) "I'll have to add something. Oh, a flasher!" (Uses GUI to switch to Red 2).*

Researcher: *"A flasher, huh?"*

Boy, Group 4, Blue: *"See, [Green boy's name] is doing that." (Points at screen).*

Researcher: *"Yeah, he is, huh?"*

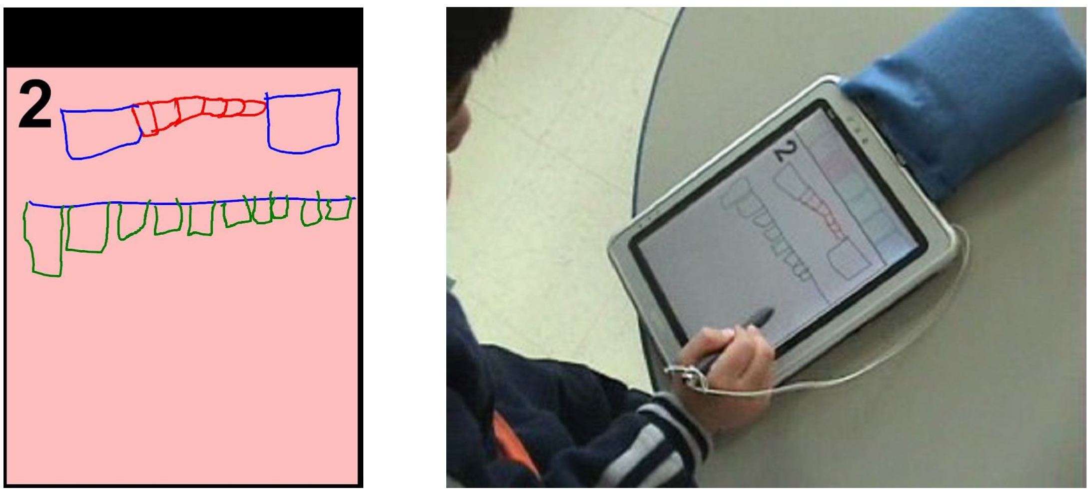

Figure 55. Screen shot of the Red 2 page after the blue child selects its flashing thumbnail (left), and a photograph of the blue child indicating that the green child is adding to the page (right).

Boy, Group 4, Blue: *(Additional strokes from Green boy appear). "More!" (Blue boy adds to drawing).*

Researcher: *"What are you adding there?"*

Boy, Group 4, Blue: *"I don't know. Something."*

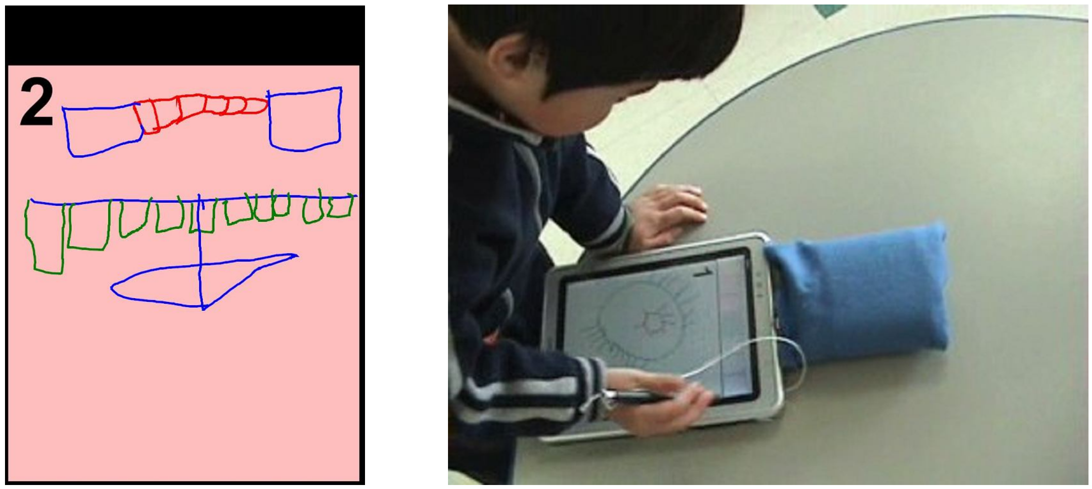

Figure 56. Screen shot of the Red 2 page after blue child adds ‘something’ (left), and photograph of blue child indicating where he is looking for ‘flashies’ (right).

Boy, Group 4, Blue: *(Looks around). “Oh yeah, I wanted to add that.” (Uses GUI to switch to Green 1 and makes an addition).*

Boy, Group 4, Blue: *(Gestures at screen). “I’m looking for some flashies.”*

Researcher: *“You’re looking for some flashies, huh?”*

Boy, Group 4, Blue: *“I’d better go back.” (Picks up computer and walks to join other two boys).*

Figure 57. Photographs of two children comparing the same page on their screens (left), and all three children working at the same location, but not always on the same page (right).

Boy, Group 4, Blue: *"Hey [Red boy's name], [Green boy's name] I came back over to see you."*

Boy, Group 4, Red: *"Did you see mine? I'm at the same one as you, [Blue boy's name], green 1."*

Boy, Group 4, Blue: *"I want to do this one. I'll do the red one." (Picks up Red 1 from nearby table and scans it).*

Boy, Group 4, Red: *"Which red one? Have you found the Red 1?" (All three boys start to work at table, but switch around between pages using the GUI).*

Boy, Group 4, Blue: *"Oh, flashing!"*

Boy, Group 4, Red: *"That means somebody else is doing something."*

Boy, Group 4, Blue: *"Nobody is doing it."*

Researcher: *"That means somebody added something."*

Boy, Group 4, Blue: *"How are they doing that? Oh, [Green boy's name] is doing that." (Boys work together, switching between flags with the GUI).*

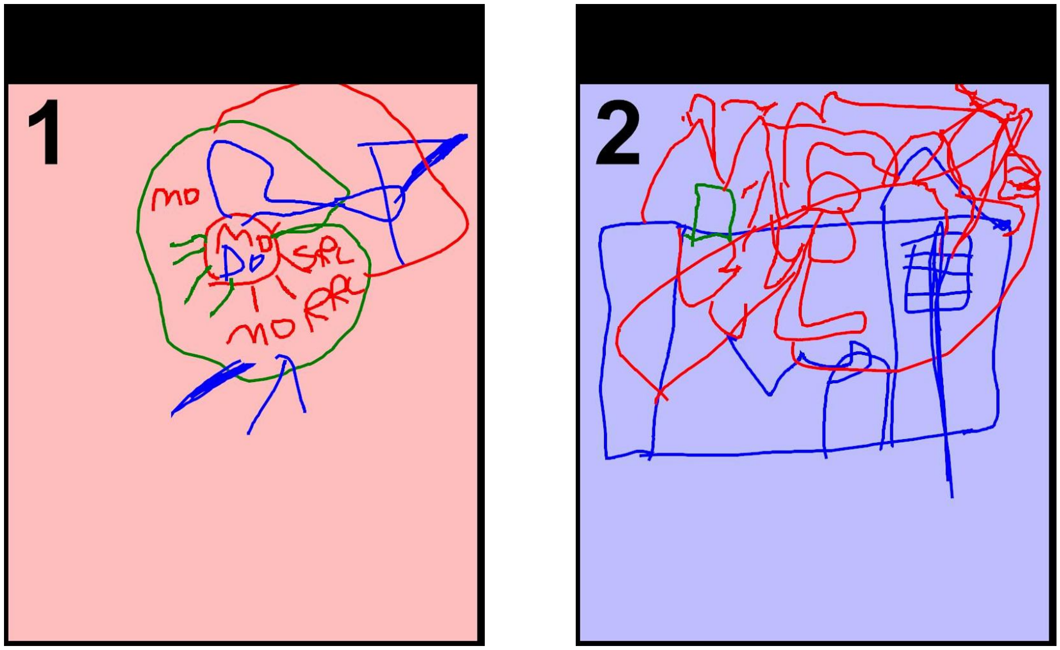

Figure 58. Screen shots of the Red 1 page (left), and the Blue 2 page (right), after all three children work together.

Example 17: Group 5, Activity 2, Page Blue 1 (see Figures 59, 60, and 61).

[11:27:28 AM]

Girl, Group 5, Blue: *(Creates drawing of tiger puppet, places flag on floor).*

[11:31:43 AM]

Girl, Group 5, Green: *(Keeps looking up while drawing).*

Researcher: *"What are you looking at, there, [girl's name]?"*

Girl, Group 5, Green: *"[Blue girl's name]'s" (Names the original creator)*

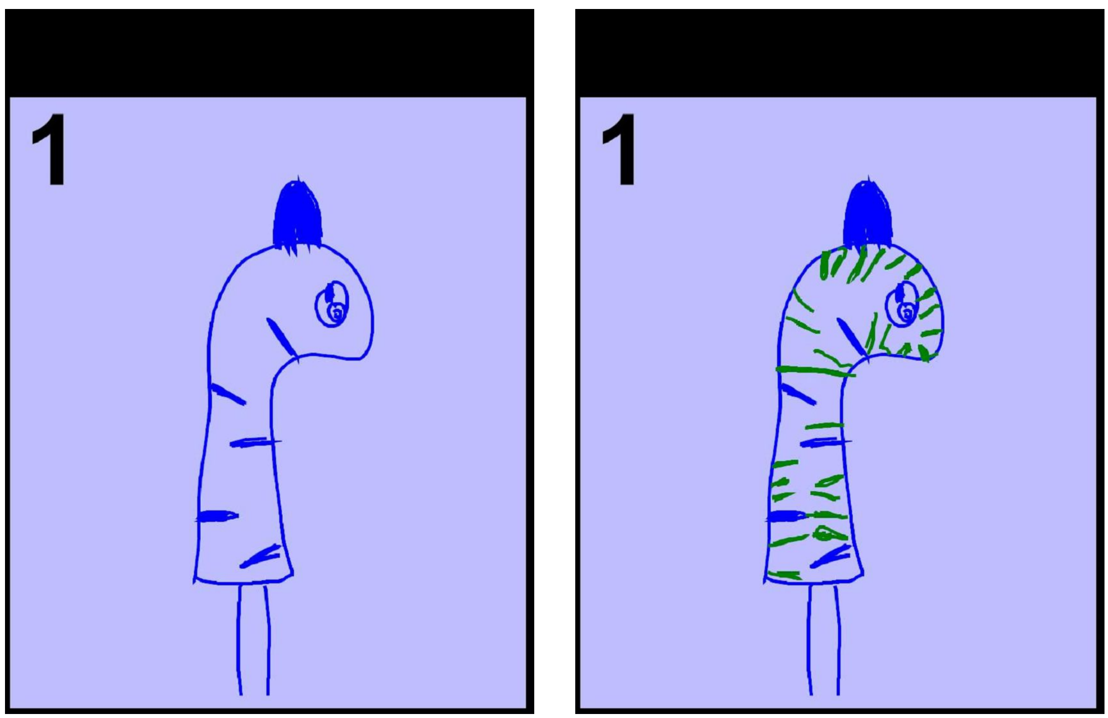

Figure 59. Screen shots of the Blue 1 page after the blue child's initial drawing (left), and after the green child makes her first addition (right).

[11:36:50 AM]

Girl, Group 5, Red: *(Scans flag) "What is it?"*

Researcher: *"I don't know, what do you think it is?"*

Girl, Group 5, Red: *"I think it's that tiger." (Points at tiger puppet)*

Researcher: *"What are you adding?"*

Girl, Group 5, Red: *"The hair. Right there." (Points at mane of tiger puppet)*

Researcher: *"The hair? Ah, the furry part, yeah."*

[11:46:23 AM]

Girl, Group 5, Green: *(Accesses page with GUI from another location and adds to mane, tail, eye and stripes. She draws on top of portions done by the other two girls).*

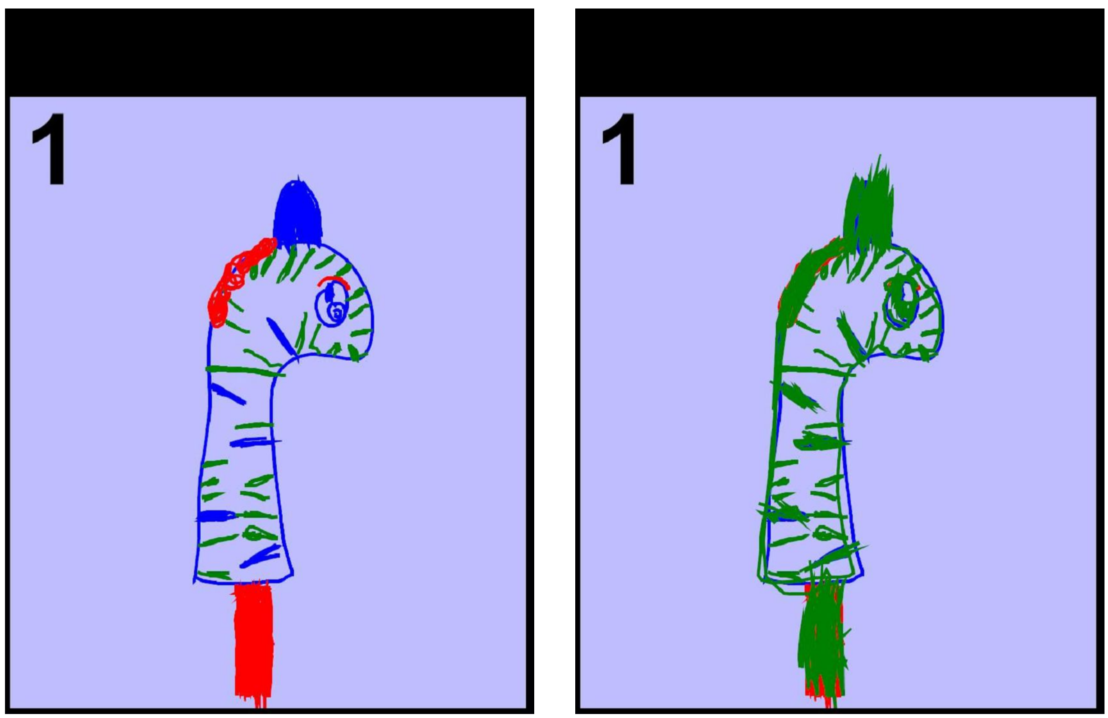

Figure 60. Screen shots of the Blue 1 page after the red child makes her first addition (left), and after the green child makes her second addition(right).

[11:48:08 AM]

Girl, Group 5, Blue: *(Accesses page with GUI from another location).*

Girl, Group 5, Blue: *"Hey, [unintelligible] added to my tiger."*

Girl, Group 5, Blue: *(Starts drawing) "Let's see, add more stripes. I'm putting in the eye."*

Girl, Group 5, Blue: *(Picks up computer and starts walking)*

Researcher: *"Do you want to look at another flag?"*

Girl, Group 5, Blue: "Yeah." *(Moves a short distance and stops) "I'm going to keep adding to the tiger, actually."*

[11:48:46 AM]

Girl, Group 5, Red: *(Accesses page with GUI from another location and starts to draw).*

Girl, Group 5, Blue: *"[Red girl's name]?" (Calls to Group 5 Red girl)*

Researcher: *"[Red girl's name]?" (Calls to Group 5 Red girl)*

Girl, Group 5 Red: *"Um hmm?"*

Girl, Group 5 Blue: *"Are you doing the tiger?"*

Girl, Group 5 Green: *"What?"*

Girl, Group 5 Blue: *"Are you doing the tiger?"*

Girl, Group 5 Green: *"No."*

Girl, Group 5 Red: *"Yeah."*

Girl, Group 5 Blue: *"Hey, [Red girl's name]! Now, I'm going to put on more stripes. This is one colorful tiger."*

Researcher: *"It sure is a colorful tiger."*

(Red and Green girls giggle while Red girl scribbles on drawing).

Girl, Group 5 Green: *"That was [Red girl's name]."*

Researcher: *"What are you laughing at?"*

Girl, Group 5 Blue: *"They're coloring onto this just to mess it up."*

Girl, Group 5 Green: *"[Red girl's name] is messing up [Blue girl's name]'s picture."*

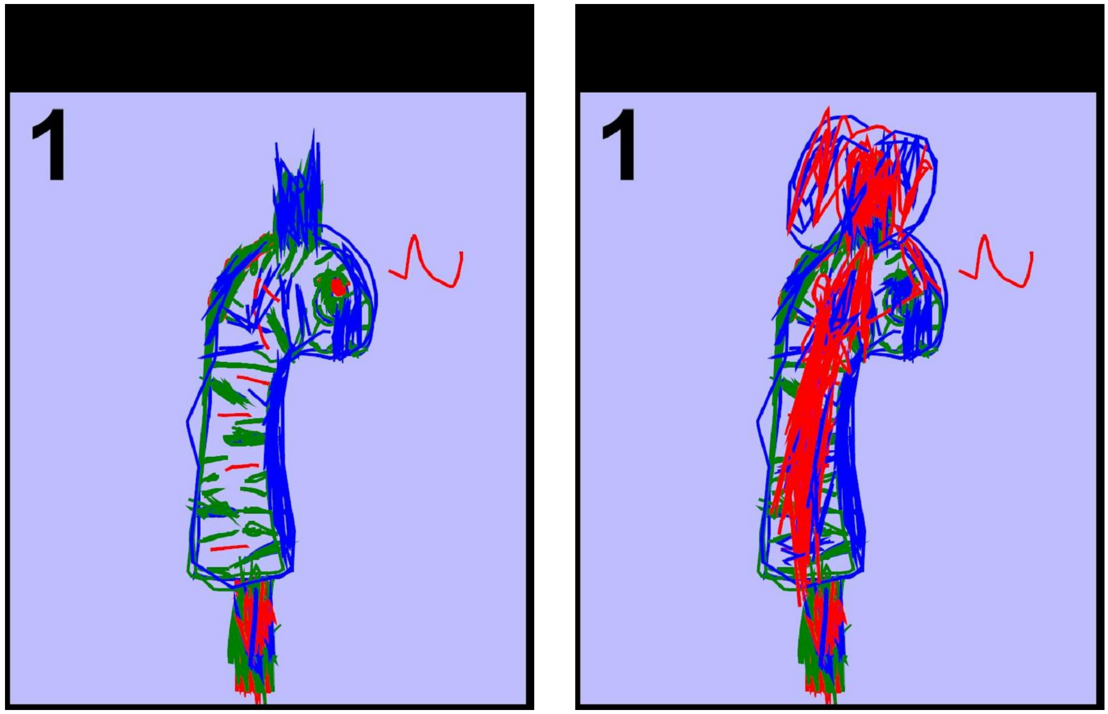

Figure 61. Screen shots of the Blue 1 page when the blue and red child first start to draw concurrently (left), and the final result after the joint activity becomes a conflict (right).

Example 18: Group 5, Activity 2, Page Red 2 (see Figures 62 and 63).

Girl, Group 5, Blue: *(Scans flag while Red girl is working on the page nearby) "I do not know what this is."*

Researcher: *"Well, any idea?"*

Girl, Group 5, Blue: *"Oh, the curtains."*

Researcher: *"You think it's the curtains? Why do you think it's the curtains?"*

Girl, Group 5, Blue: *"Because it has lines on it. And I can see [Red girl's name] adding to it."*

Girl, Group 5, Red: *"It's not the curtains, it's that." (Points at a poster on the wall). "It's a pattern, green, red, green, red, green, red."*

Girl, Group 5, Blue: *"I will make the green." (Starts adding lines on her tablet) "Even though it's blue."*

Girl, Group 5, Red: *"In between, in between. I don't see you adding." (Giggles)*

Girl, Group 5, Blue: *"That's because I'm not done yet." (Pause) "There's the green and there's the red."*

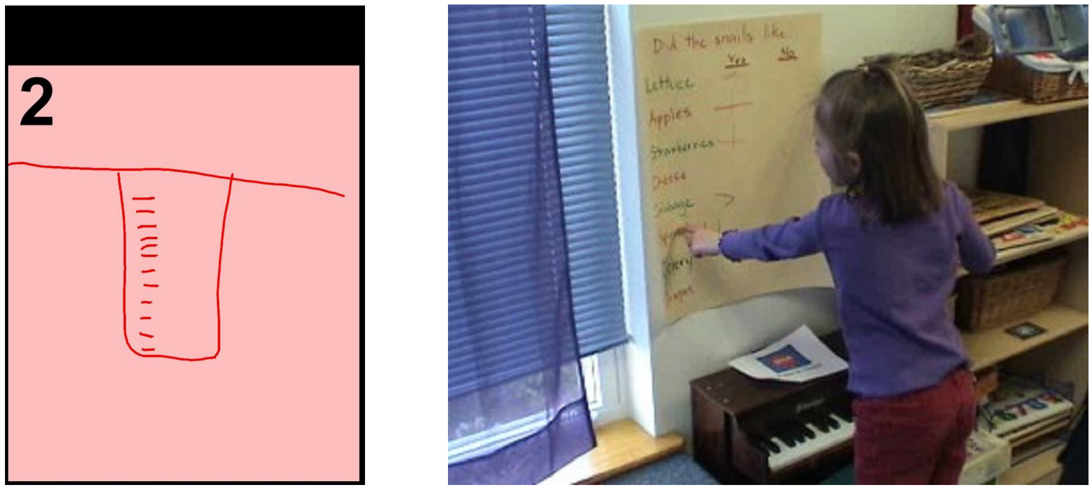

Figure 62. Screen shot of the Red 2 page after the red child's initial drawing (left), and the red child indicating to the blue child the poster her drawing represents (right).

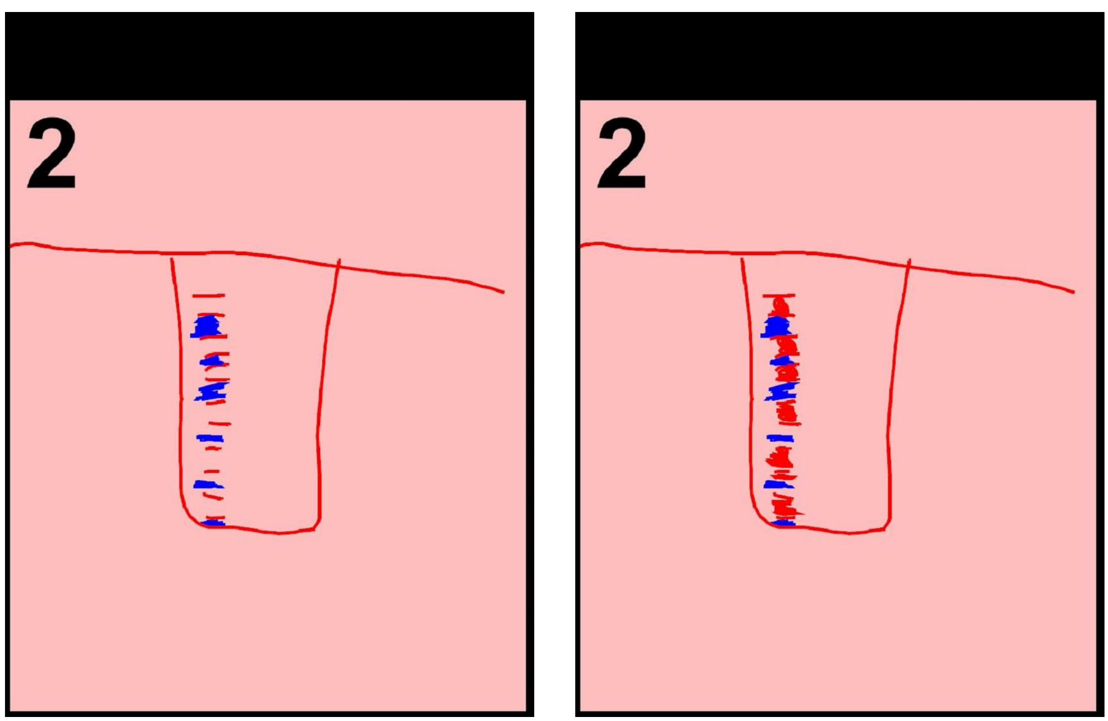

Figure 63. Screen shots of the Red 2 page after the blue child adds the 'green' lines (left), and after the blue and red child work on it concurrently (right).

I.10 Example of remote synchronous collaboration with Tangible Flags

Example 19: Group 4, Activity 2, Page Blue 1 (see Figure 64).

[11:34:57 AM]

Boy, Group 4, Blue: *(Walking past green boy at Blue 1 flag.) "Hey, you found mine! I'm checking what your doing on it. I have to make sure when its flashing." (Goes elsewhere to look for patterns).*

[11:35:44 AM]

Boy, Group 4, Blue: *(Looking for patterns.) "I can't find any. I wonder what [Green boy's name] is doing."*

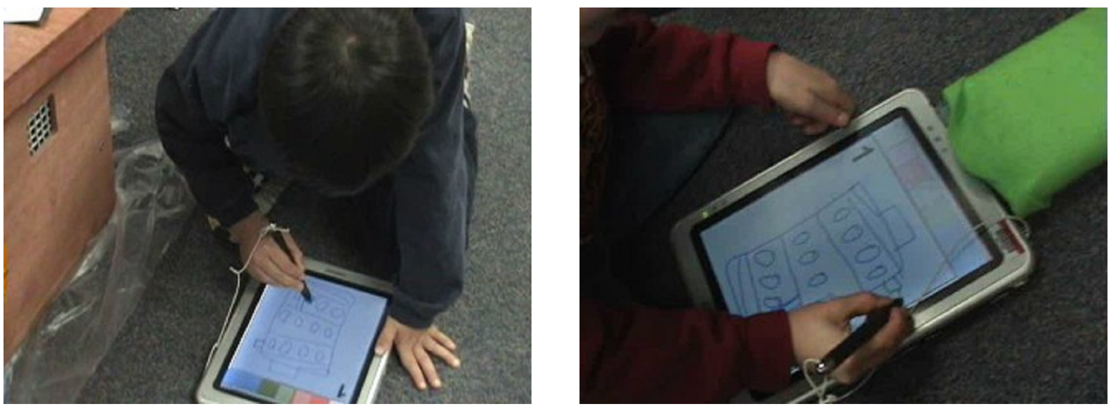

Figure 64. Photographs of the blue child adding to the Blue 1 page (left) concurrently with the green child (right), who is at a different location.

I.11 Miscellaneous Examples

Example 20: Group 1, Activity 1, Page Red 2 (see Figure 65).

Boy, Group 1, Red: *“Ahha!” (Spots Blue 2, runs over to it, and makes an addition.) “I don’t see any stars.” (Looks around). “Where are they?” (Star was already on page).*

Figure 65. Photograph of the red child looking around the environment for a star (seen at the top of the page in blue).

Example 21: Group 2, Activity 1, Page Blue 1 (see Figure 66).

Researcher: *”Do you see any papers over here?”*

Girl, Group 2, Green: *“I see [Blue girl’s name]’s.”*

Figure 66. Photograph of the green child looking at a blue paper.

Example 22: Group 3, Activity 1, Page Red 1 (see Figure 67).

Boy, Group 3, Blue: *(Watching Green boy work on Red 1). "I did that one." (Watches some more). "What are you drawing?"*

Boy, Group 3, Green: *(Points) "That thing, silly."*

Boy, Group 3, Blue: *"The chair?"*

Boy, Group 3, Green: *(Points) "That thing, silly."*

Boy, Group 3, Green: *(Still pointing) "Helicopter."*

Boy, Group 3, Blue: *"The helicopter? That's not furniture."*

Figure 67. Photographs of the green child indicating to the blue child a helicopter he added to the page (left), and the page showing the helicopter (right).

Example 23: Group 3, Activity 2, Page Blue 2 (see Figure 68).

Researcher: *"Do you want to go look for another paper, or look for a pattern?"*

Boy, Group 3, Blue: *(No response, starts drawing a new page, Blue 2).*

Researcher: *"What are you drawing there?"*

Boy, Group 3, Blue: *(Points dots at bottom of book cover).*

Researcher: *"Ah, cool, looks great."*

Boy, Group 3, Blue: *(Counting dots on book cover).*

Boy, Group 3, Blue: *(Counting segments on his drawing).*

Figure 68. Photographs of the blue child indicating the pattern from a book that he is drawing on a page (left), counting the dots on the pattern (center), and counting the dots on his drawing (right).

Example 24: Group 6, Activity 2, Page Green 1 (see Figure 69).

Girl, Group 6, Green: *“[unintelligible]”*

Researcher: *“What’d you say?”*

Girl, Group 6, Green: *“I’m watching him draw.” (Points at screen).*

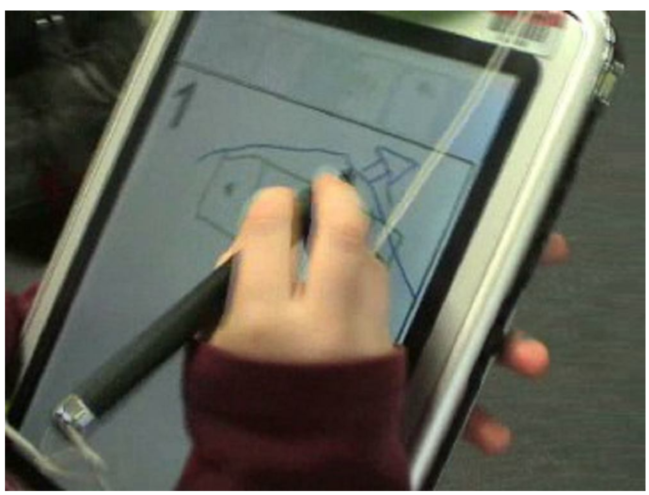

Figure 69. Photograph of green child indicating the blue child’s drawing on a page as it occurs.

Bibliography

1. Phones with Eyes. *Economist*, March 12, 2005.

2. Abowd, G.D., Atkeson, C.G., Hong, J., Long, S., Kooper, R. and Pinkerton, M. (1997). Cyberguide: A Mobile Context-Aware Tour Guide. *Wireless Networks, 3* (5), 421-433.

3. Baecker, R. and Small, I. (2000). Animation at the Interface. In Laurel, B. ed. *The Art of Human-Computer Interface Design*, Addison-Wesley, 251-267.

4. Bauer, P. and Mandler, J. (1990). Remembering What Happened Next: Very Young Children's Recall of Event Sequences. In Fivush, R. and Hudson, J. eds. *Knowing and Remembering in Young Children*, Cambridge University Press, New York, New York, 9-29.

5. Bederson, B.B. and Boltman, A. (1999). Does Animation Help Users Build Mental Maps of Spatial Information? In *Proceedings of the 1999 IEEE Symposium on Information Visualization* IEEE Computer Society, 28-35.

6. Bederson, B.B., Grosjean, J., and Meyer, J. (2004). A Toolkit design for interactive structured graphics. In *IEEE Transactions on Software Engineering, 30* (8), IEEE Computer Society, 535-546.

7. Bellamy, R.K.E. (1996). Designing Educational Technology: Computer-Mediated Change. In Nardi, B. ed. *Context and Consciousness: Activity Theory and Human-Computer Interaction*, MIT Press, Cambridge, MA, 123-146.

8. Bellotti, V. and Bly, S. (1996). Walking Away from the Desktop Computer: Distributed Collaboration and Mobility in a Product Design Team. In *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work*, (Boston, Massachusetts, United States), ACM Press, 209-218.

9. Benford, S., Bederson, B.B., Akesson, K.-P., Bayon, V., Druin, A., Hansson, P., Hourcade, J.P., Ingram, R., Neale, H., O'Malley, C., Simsarian, K.T., Stanton, D., Sundblad, Y. and Taxen, G. (2000). Designing Storytelling Technologies to Encouraging Collaboration between Young Children. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (The Hague, The Netherlands), ACM Press, 556-563.

10. Benford, S., Rowland, D., Flintham, M., Drozd, A., Hull, R., Reid, J., Morrison, J. and Facer, K. (2005). Life on the Edge: Supporting

Collaboration in Location-Based Experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Portland, Oregon, USA), ACM Press, 721-730.

11. Bouvin, N.O., Brodersen, C., Hansen, F.A., Iversen, O.S. and Norregaard, P. (2005). Tools of Contextualization: Extending the Classroom to the Field. In *Proceedings of the 2006 Conference on Interaction Design and Children*, (Boulder, Colorado), ACM Press, 24-31.

12. Burrell, J. and Gay, G. (2002). E-Graffiti: Evaluating Real-World Use of a Context-Aware System. *Interacting with Computers*, *14* (4), 301-312.

13. Card, S.K., Moran, T.P. and Newell, A.P. (1983). *The Psychology of Human-Computer Interaction*. Erlbaum, Hillsdale, NJ.

14. Cheverst, K., Davies, N., Mitchell, K. and Friday, A. (2000). Experiences of Developing and Deploying a Context-Aware Tourist Guide: The Guide Project. In *Proceedings of the 6th Annual International Conference on Mobile Computing and Networking*, (Boston, Massachusetts, United States), ACM Press, 20-31.

15. Chipman, G., Druin, A., Beer, D., Fails, J.A., Guha, M.L. and Simms, S. (2006). A Case Study of Tangible Flags: A Collaborative Technology to Enhance Field Trips. In *Proceedings of the 2006 Conference on Interaction Design and Children*, (Tampere, Finland) ACM Press, 1-8.

16. Cole, H. and Stanton, D. (2003). Designing Mobile Technologies to Support Co-Present Collaboration. *Personal Ubiquitous Computing*, *7* (6), 365-371.

17. Colella, V. (2000). Participatory Simulations: Building Collaborative Understanding through Immersive Dynamic Modeling. *Journal of the Learning Sciences*, *9* (4), 471-500.

18. Convertino, G., Neale, D.C., Hobby, L., Carroll, J.M. and Rosson, M.B. (2004). A Laboratory Method for Studying Activity Awareness. In *Proceedings of the Third Nordic Conference on Human-Computer Interaction*, (Tampere, Finland), ACM Press, 313-322.

19. Creswell, J. (1998). *Qualitative Inquiry and Research Design: Choosing among Five Traditions*. SAGE Publications, Thousand Oaks, CA.

20. Danesh, A., Inkpen, K., Lau, F., Shu, K. and Booth, K. (2001). Geneytm: Designing a Collaborative Activity for the Palmtm Handheld Computer. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Seattle, WA), ACM Press, 388-395.

21. Davidson, N. (1985). Small-Group Learning and Teaching in Mathematics: A Selective Review of the Research. In Slavin, R.E., Sharan, S., Kagan, S., Hertz-Lazarowitz, R., Webb, C. and Schmuck, R. eds. *Learning to Cooperate, Cooperating to Learn*, Plenum, New York, NY, 211-230.

22. Dimitracopoulou, A. (2005). Designing Collaborative Learning Systems: Current Trends & Future Research Agenda. In *Proceedings of the 2005 Conference on Computer Support for Collaborative Learning: Learning 2005: The Next 10 Years!*, International Society of the Learning Sciences, (Taipei, Taiwan), 115-124.

23. Dix, A. and Uden, L. (2000). Iconic Interfaces for Kids on the Internet. In *IFIP World Computer Congress*, (Beijing, China).

24. Dourish, P. and Bellotti, V. (1992). Awareness and Coordination in Shared Workspaces. In *Proceedings of the 1992 ACM Conference on Computer-Supported Cooperative Work*, (Toronto, Ontario, Canada), ACM Press, 107-114.

25. Downs, R. and Liben, L. (1993). Mediating the Environment: Communicating, Appropriating, and Developing Graphic Representations of Place. In Wozniak, R. and Fischer, K. eds. *Develoment in Context: Acting and Thinking in Specific Environments*, Lawrence Erlbaum Assc., Hillsdale, NJ, 155-181.

26. Driver, R., Asoko, H., Leach, J., Mortimer, E. and Scott, P. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher*, *23* (7), 5-12.

27. Druin, A., Stewart, J., Proft, D., Bederson, B. and Hollan, J. (1997). Kidpad: A Design Collaboration between Children, Technologists, and Educators. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Atlanta, Georgia, United States), ACM Press, 463-470.

28. Druin, A. (1998). *The Design of Children's Technology*. Morgan Kaufmann, San Francisco, CA, USA.

29. Druin, A. (1999). Cooperative Inquiry: Developing New Technologies for Children with Children. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems: the CHI is the limit*, (Pittsburgh, Pennsylvania, United States), ACM Press, 592-599.

30. Drury, J., Damianos, L., Fanderclai, T., Kurtz, J., Hirschman, L. and Linton, F. (1999). Methodology for Evaluation of Collaborative Systems, National Institute of Standards and Technology. Retrieved from http://zing.ncsl.nist.gov/nist-icv/documents/methodv4.htm

31. Everitt, B.S. (1995). The analysis of repeated measures: a practical review with examples. *The Statistician*, *44* (1), 113-135.

32. Fahlen, L.E., Brown, C.G., Stahl, O. and Carlsson, C. (1993). A Space Based Model for User Interaction in Shared Synthetic Environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Amsterdam, The Netherlands), ACM Press, 43-48.

33. Fails, J.A., Druin, A., Guha, M.L., Chipman, G., Simms, S. and Farber, A. (2005). Child's Play: A Comparison of Desktop and Physical Interactive Environments. In *Proceedings of the 2005 Conference on Interaction Design and Children*, (Boulder, Colorado), ACM Press, 48-55.

34. Farber, A., Druin, A., Chipman, G., Julian, D. and Shomashekar, S. (2002). How Young Can Our Design Partners Be? In *Proceedings of the 2002 Participatory Design Conference*, (Malmo, Sweden), 272-276.

35. Feiner, S., Macintyre, B. and Seligmann, D. (1993). Knowledge-Based Augmented Reality. *Commun. ACM*, *36* (7), 53-62.

36. Feiner, S. (1999). The Importance of Being Mobile: Some Social Consequences of Wearable Augmented Reality Systems. In *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality*, 145-148.

37. Fischer, K., Bullock, D., Rotenberg, E. and Raya, P. (1993). The Dynamics of Competence: How Context Contributes Directly to Skill. In Wozniak, R. and Fischer, K. eds. *Develoment in Context: Acting and Thinking in Specific Environments*, Lawrence Erlbaum Assc., Hillsdale, NJ, 93-117.

38. Flavell, J.H. (1985). *Cognitive Development*. Prentice-Hall, Englewood Cliffs, NJ.

39. Grant, W. (1996). Wireless Coyote: A Computer-Supported Field Trip. *Communications of the ACM*, *36* (5), 57-59.

40. Guha, M.L., Druin, A., Chipman, G., Fails, J.A., Simms, S. and Farber, A. (2004). Mixing Ideas: A New Technique for Working with Young Children as Design Partners. In *Proceedings of the 2004 Conference on Interaction Design and Children: Building a Community*, (College Park, MD), ACM Press, 35-42.

41. Guha, M.L., Druin, A., Chipman, G., Fails, J.A., Simms, S. and Farber, A. (2005). Working with Young Children as Technology Design Partners. *Commun. ACM*, *48* (1), 39-42.

42. Gutwin, C., Roseman, M. and Greenberg, S. (1996). A Usability Study of Awareness Widgets in a Shared Workspace Groupware System. In *Proceedings of the 1996 Acm Conference on Computer Supported Cooperative Work*, (Boston, Massachusetts, United States), ACM Press, 258-267.

43. Gutwin, C. and Greenberg, S. (2002). A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work, 11* (3), 411-446.

44. Hardin, J.W. and Hilbe, J.M. (2003). *Generalized Estimating Equations*. Chapman & Hall/CRC, Boca Raton, FL.

45. Höllerer, T., Feiner, S. and Pavlik, J. (1999). Situated Documentaries: Embedding Multimedia Presentations in the Real World. In *Proceedings of the 3rd IEEE International Symposium on Wearable Computers*, IEEE Computer Society, 79.

46. Hsi, S. (2004). I-Guides in Progress: Two Prototype Applications for Museum Educators and Visitors Using Wireless Technologies to Support Informal Science Learning. In *Proceedings of the 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'04)*, IEEE Computer Society, 187.

47. Hutchinson, H. (2005). Children's Interface Design for Searching and Browsing. *University of Maryland HCIL Technical Report HCIL-2005-32*. Retrieved August 4th, 2006 from http://hcil.cs.umd.edu/trs/2005-32/2005-32.pdf.

48. Ichimura, S., Kamita, T. and Matsushita, Y. (1993). A Pilotcard-Based Shared Hypermedia System Supporting Shared and Private Databases. In *Proceedings of the Conference on Organizational Computing Systems*, (Milpitas, California, United States), ACM Press, 59-68.

49. Inkpen, K., McGrenere, J., Booth, K.S. and Klawe, M. (1997). The Effect of Turn-Taking Protocols on Children's Learning in Mouse-Driven Collaborative Environments. In *Graphics Interface 1997*, (British Columbia, Canada), A K Peters, 138-145.

50. Inkpen, K. (1999). Designing Handheld Technologies for Kids. *Personal Technologies, 3* (1), 81-89.

51. Ishii, H. and Ullmer, B. (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Atlanta, Georgia, United States), ACM Press, 234-241.

52. Jaccard, J. (1983). *Statistics for the Behavioral Sciences*. Wadsworth Publishing, Belmont, CA.

53. Johnson, D. and Johnson, R. (1994). *Learning Together and Alone: Cooperative, Competitive, and Individualistic Learning.* Allyn & Bacon, Needham Heights, MA.

54. John-Steiner, V. and Mahn, H. (1996). Sociocultural Approaches to Learning and Development. *Educational Psychologist, 31 (3)*, 191-206.

55. Kim, J., Seitz, S.M. and Agrawala, M. (2004). Video-Based Document Tracking: Unifying Your Physical and Electronic Desktops. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology*, (Santa Fe, NM, USA), ACM Press, 99-107.

56. Klemmer, S.R., Newman, M.W., Farrell, R., Bilezikjian, M. and Landay, J.A. (2001). The Designers' Outpost: A Tangible Interface for Collaborative Web Site. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, (Orlando, Florida), ACM Press, 1-10.

57. Lave, J. and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press, Cambridge, UK.

58. Leontiev, A.N. (1978). *Activity, Consciousness and Personality*. Prentice Hall, Upper Saddle River, NJ.

59. Liskov, B. (1991). Practical Uses of Synchronized Clocks in Distributed Systems. In *Proceedings of the Tenth Annual ACM Symposium on Principles of Distributed Computing*, (Montreal, Quebec, Canada), ACM Press, 1-9.

60. Loh, B., Radinsky, J., Russell, E., Gomez, L.M., Reiser, B.J. and Edelson, D.C. (1998). The Progress Portfolio: Designing Reflective Tools for a Classroom Context. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Los Angeles, California, United States), ACM Press/Addison-Wesley Publishing Co., 627-634.

61. Low, R. and Sweller, J. (2005). The Modality Principle in Multimedia Learning. In Mayer, R.E. ed. *The Cambridge Handbook of Multimedia Learning*, Cambridge University Press, New York, NY, 147-158.

62. Luff, P. and Heath, C. (1998). Mobility in Collaboration. In *Proceedings of the 1998 ACM Conference on Computer Supported Cooperative Work*, ACM Press, 305-314.

63. Mandryk, R.L., Inkpen, K.M., Bilezikjian, M., Klemmer, S.R. and Landay, J.A. (2001). Supporting Children's Collaboration across Handheld

Computers. In *CHI '01 Extended Abstracts on Human Factors in Computing Systems*, (Seattle, Washington), ACM Press, 255-256.

64. Marshall, P., Price, S. and Rogers, Y. (2003). Conceptualising Tangibles to Support Learning. In *Proceedings of the 2003 Conference on Interaction Design and Children*, (Preston, Engalnd), ACM Press, 101-109.

65. Mayer, R.E. (2005). Principles for Managing Essential Processing in Multimedia Learning: Segmenting, Pretraining, and Modality Principles. In Mayer, R.E. ed. *The Cambridge Handbook of Multimedia Learning*, Cambridge University Press, New York, NY, 169-182.

66. Mazalek, A., Davenport, G. and Ishii, H. (2002). Tangible Viewpoints: A Physical Approach to Multimedia Stories. In *Proceedings of the Tenth ACM International Conference on Multimedia*, (Juan-les-Pins, France), ACM Press, 153-160.

67. Metcalf, S. and Tinker, R. (2004). Probeware and Handhelds in Elementary and Middle School Science. *Journal of Science Education and Technology*, *13* (1), 43-49.

68. Montemayor, J., Druin, A., Farber, A., Simms, S., Churaman, W. and D'Amour, A. (2002). Physical Programming: Designing Tools for Children to Create Physical Interactive Environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Changing our World, Changing Ourselves*, (Minneapolis, Minnesota, USA), ACM Press, 299-306.

69. Montemayor, J., Druin, A., Chipman, G., Farber, A. and Guha, M.L. (2004). Tools for Children to Create Physical Interactive Storyrooms. *Computer Entertainment*, *2* (1), 12-12.

70. Nelson, L., Ichimura, S., Pedersen, E.R.n. and Adams, L. (1999). Palette: A Paper Interface for Giving Presentations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: The CHI is the Limit*, (Pittsburgh, Pennsylvania, United States), ACM Press, 354-361.

71. van Oers, B. and Wardekker, W. (1999). On Becoming an Authentic Learner: Semiotic Activity in the Early Grades. *Journal of Curriculum Studies, 31* (2), 229-249.

72. Oosterholt, R., Kusano, M. and Vries, G.D. (1996). Interaction Design and Human Factors Support in the Development of a Personal Communicator for Children. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Common Ground*, (Vancouver, British Columbia, Canada), ACM Press, 450-457.

73. Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books, New York, NY.

74. Papert, S. (1991). Situating Constructionism. In Harel, I. and Papert, S. eds. *Constructionism*, Ablex Publishing, Norwood, NJ, 1-12.

75. Parr, C.S., Jones, T. and Songer, N.B. (2002). Cybertracker in Biokids: Customization of a PDA-Based Scientific Data Collection Application for Inquiry Learning. In *Keeping Learning Complex: The Proceedings of the Fifth International Conference of Learning Sciences*, Erlbaum, 574-575.

76. Patten, J. and Ishii, H. (2000). A Comparison of Spatial Organization Strategies in Graphical and Tangible User Interfaces. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments*, (Elsinore, Denmark), ACM Press, 41-50.

77. Pea, R.D. (1993). The Collaborative Visualization Project *Commun. ACM 36* (5), 60-63

78. Piaget, J. (1977a). The Growth of Logical Thinking from Childhood to Adolescence. In Gruber, H. and Voneche, J. eds. *The Essential Piaget*, Basic Books, New York, New York, 405-444.

79. Piaget, J. (1977b). Structuralsim and Dialectic. In Gruber, H. and Voneche, J. eds. *The Essential Piaget*, Basic Books, New York, New York, 775-779.

80. Pinelle, D. and Gutwin, C. (2003). Designing for Loose Coupling in Mobile Groups. In *Proceedings of the 2003 International ACM SIGGROUP Conference on Supporting Group Work*, (Sanibel Island, Florida, USA), ACM Press, 75-84.

81. Pinelle, D., Gutwin, C. and Greenberg, S. (2003). Task Analysis for Groupware Usability Evaluation: Modeling Shared-Workspace Tasks with the Mechanics of Collaboration. *ACM Transactions on Computer-Human Interaction*, *10* (4), 281-311.

82. Price, S., Rogers, Y., Stanton, D. and Smith, H. (2003). A New Conceptual Framework for Cscl: Supporting Diverse Forms of Reflection through Multiple Interactions. In *Designing for Change in Networked Learning Environments. Proceedings of the International Conference on CSCL 2003*, (Bergen, Norway), Springer, 513-522.

83. Rabe-Hesketh, S. and Everitt, B. (2003). *A Handbook of Statistical Analysis Using Stata*. Chapman & Hall/CRC, Boca Raton, FL.

84. Rekimoto, J. and Nagao, K. (1995). The World through the Computer: Computer Augmented Interaction with Real World Environments. In

Proceedings of the 8th Annual ACM Symposium on User Interface Software and Technology, (Pittsburgh, Pennsylvania, United States), ACM Press, 29-36.

85. Rekimoto, J., Ayatsuka, Y. and Hayashi, K. (1998). Augment-Able Reality: Situated Communication through Physical and Digital Spaces. In *Second International Symposium on Wearable Computers*, (Pittsburgh, PA), IEEE Computer Society, 68-75.

86. Rekimoto, J. and Ayatsuka, Y. (2000). Cybercode: Designing Augmented Reality Environments with Visual Tags. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments*, (Elsinore, Denmark), ACM Press, 1-10.

87. Resnick, M., Martin, F., Berg, R., Borovoy, R., Colella, V., Kramer, K. and Silverman, B. (1998). Digital Manipulatives: New Toys to Think With. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, (Los Angeles, California, United States), ACM Press/Addison-Wesley Publishing Co., 281-287.

88. Rieger, R. and Gay, G. (1997). Using Mobile Computing to Enhance Field Study. In *Proceedings of CSCL '97*, (Toronto ON), 215-223.

89. Rogers, Y. and Price, S. (2004). Extending and Augmenting Scientific Enquiry through Pervasive Learning Environments. *Children, Youth and Environments*, *14* (2), 67-83.

90. Rogers, Y., Price, S., Fitzpatrick, G., Fleck, R., Harris, E., Smith, H., Randell, C., Muller, H., O'Malley, C., Stanton, D., Thompson, M. and Weal, M. (2004). Ambient Wood: Designing New Forms of Digital Augmentation for Learning Outdoors. In *Proceedings of the 2004 Conference on Interaction Design and Children*, (College Park, MD), ACM Press, 3-10.

91. Roschelle, J. and Pea, R. (2002). A Walk on the Wild Side: How Wireless Handhelds May Change Cscl. In *Proceedings of CSCL 2002*, (Boulder, CO), 51-60.

92. Salomon, G. and Perkins, D.N. (1998). Individual and Social Aspects of Learning. *Review of Research in Education*, 1-24.

93. Scaife, M. and Rogers, Y. (1996). External Cognition: How Do Graphical Representations Work? *International Journal of Human-Computer Studies*, *45* (2), 185-213

94. Scardamalia, M. and Bereiter, C. (1994). Computer Support for Knowledge-Building Communities. *Journal of the Learning Sciences*, *3* (3), 265-283.

95. Scott, S.D., Mandryk, R.L. and Inkpen, K.M. (2003). Understanding Children's Collaborative Interactions in Shared Environments. *Journal of Computer Assisted Learning*, *19* (2), 220-228.

96. Shiozawa, H., Okada, K.I., and Matsushita, Y. (1999). Perspective Layered Visualization of Collaborative Workspaces. In *Proceedings of the International ACM SIGGROUP Conference on Supporting Group Work*, (Phoenix, Arizona, United States), ACM Press, 71-80.

97. Simonoff, J.S. (2003). *Analyzing Categorical Data*. Springer-Verlag, New York, NY.

98. Slavin, R. (1996). Research on Cooperative Learning and Achievement: What We Know, What We Need to Know. *Contemporary Educational Psychology*, *21* (1), 43-69.

99. Slotta, J.D., Clark, D.B. and Cheng, B. (2002). Integrating Palm Hand-Held Technology into the Web-Based Inquiry Science Environment (Wise). In *Proceedings of Computer Supported Collaborative Learning (CSCL) Conference 2002*, (Boulder, CO), 542-543.

100. Sluis, R.J.W., Weevers, I., van Schijndel, C.H.G.J., Kolos-Mazuryk, L., Fitrianie, S. and Martens, J.B.O.S. (2004). Read-It: Five-to-Seven-Year-Old Children Learn to Read in a Tabletop Environment. In *Proceeding of the 2004 conference on Interaction Design and Children: Building a Community*, (College Park, MD), ACM Press, 73-80.

101. Soloway, E., Norris, C., Blumenfeld, P., Fishman, B., Krajcik, J. and Marx, R. (2001). Log on Education: Handheld Devices Are Ready-at-Hand *Communications of the ACM*, *44* (6), 2001, 15-20.

102. Stahl, G. (2000). A Model of Collaborative Knowledge-Building. In *Proceedings of the Fourth International Conference of the Learning Sciences*, (Ann Arbor, MI), Erlbaum, 70-77.

103. Stake, R. (1995). *The Art of Case Study Research*. SAGE Publications, Thousand Oaks, CA.

104. Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., O'Malley, C., Wilson, J. and Pridmore, T. (2001). Classroom Collaboration in the Design of Tangible Interfaces for Storytelling. In *Proceedings of SIGCHI '01*, (Seattle, WA), ACM Press, 482-489.

105. Stewart, J., Bederson, B.B. and Druin, A. (1999). Single Display Groupware: A Model for Co-Present Collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: The Chi Is the Limit*, (Pittsburgh, Pennsylvania), ACM Press, 286-293.

106. Venger, L.A. (1986). *The Development of Cognitive Abilities in Early Education*. Pedagogika, Moscow.

107. Vygotsky, L.S. (1978). *Mind in Society*. Harvard University Press, Cambridge, MA.

108. Wood, D., Wood, H., Ainsworth, S. and O'Malley, C. (1995). On Becoming a Tutor: Toward an Ontogenetic Model. *Cognition and Instruction*, *13* (4), 565-581.

109. Zimmermann, A. and Lorenz, A. (2003). Listen: Contextualized Presentation for Audio-Augmented Environments. In *Proceedings of the 11th GI-Workshop on Adaptivity and User Modeling in Interactive Systems (ABIS2003),* (Karlsruhe, Germany), Wittig, Frank[Hrsg.], 351 - 357.

110. Zucchini, W. (2000). An Introduction to Model Selection. *Journal of Mathematical Psychology, 44* (1), 41-61.

111. Zurita, G., Nussbaum, M. and Shaples, M. (2003). Encouraging Face-to-Face Collaborative Learning through the Use of Handheld Computers in the Classroom. In *Lecture Notes in Computer Science*, Springer-Verlag, Berlin, 193-208.

112. Zurita, G., Nussbaum, M. and Shaples, M. (2003). Encouraging Face-to-Face Collaborative Learning through the Use of Handheld Computers in the Classroom. In *Lecture Notes in Computer Science*, Springer-Verlag, Berlin, 193-208.