Paper vs. Tablet Computers: A Comparative Study using Tangible Flags
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ABSTRACT
Concurrent collaboration is a critical skill for cognitive and social development. Tangible Flags is a system designed to facilitate collaboration and exploration, and bridge the gap between the physical and the digital. The system enables children to tag an item of interest in the real world with a flag, scan the flag, and create a corresponding digital artifact on a tablet computer. Another child can see the flag and its context, scan it, and view and modify the digital artifact in a form of collaboration. This paper describes a study that compares two Tangible Flag systems; a paper system and a tablet computer system. The study identifies several collaborative advantages of using the technology-based system, including increased awareness, more shared experiences, and longer time participating in activities.

Categories and Subject Descriptors
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

General Terms
Design, Experimentation, Human Factors.

Keywords
Children, tangible interfaces, tagging, collaboration, Cooperative Inquiry.

1. INTRODUCTION
A group of children are learning about patterns in their class. They have been asked to look for patterns in their classroom and share them with others. One sees a striped couch and leaves a marker and a note showing the pattern she found. Another child sees the marker and accentuates the pattern with another color.

This is an example of an activity that supports collaboration and exploration, which are essential to the development of young children [17, 19]. While the markers in the example above could easily be paper, they were in fact, digital. Figure 1 illustrates this scenario, showing the context and artifacts made by children using an electronic system – Tangible Flags.

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Figure 1. Context and artifacts made by children using Tangible Flags; top, a striped couch is marked (flagged) and drawn; bottom, another child sees the marker (flag) and adds to the drawing.

Collaboration is a vital part of learning [14]. Vygotsky’s socio-cultural 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 [30]. Peer interaction among children facilitates understanding critical concepts [27]. Explanatory elaboration is an effective means to restructure knowledge [27]. Such collaborative activities are supported for children and the creation of knowledge artifacts can enhance children’s learning [26].

Children in an open, exploratory environment may not work together collaboratively all the time, even when assigned to pairs or teams [25, 29]. As seen in previous research [2, 26], concurrent activity is important in keeping children engaged during collaboration. Concurrent activity or concurrent collaboration occurs when two or more individuals are working together on the same artifact at the same time. When working together, children may not be aware of each other’s discoveries and may not effectively share their knowledge. In order to increase awareness it is necessary to make the actions of an individual obvious [21].

It is necessary that tools providing concurrent access to a shared digital space allow children to seamlessly switch between exploration and artifact creation, independent of their peers’ activities. Such tools enable children to easily integrate their individual work into a joint artifact and can provide incentive to collaborate. In addition, tools should provide children with an awareness of other children’s explorations and artifact creation...
activities while also helping children keep their attention on the real world. 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.

2. TANGIBLE FLAGS

Tangible Flags is a tablet computer-based system developed to enable children to explore physical spaces, place a marker, create an artifact, and explore and make additions to others’ artifacts. This paper reports on a study that examines the differences between the use of the Tangible Flags technology and paper both indoors and outdoors. This paper provides confirming and additional information to the original qualitative study of the Tangible Flag system previously presented to the Interaction Design and Children (IDC) community [6].

Tangible Flags was developed with children using the Cooperative Inquiry co-design method [9]. The concepts and interface are based on the theoretical grounds discussed in the related work, and were developed iteratively by working with children throughout many design sessions. Initial design sessions confirmed that children could use physical flags as an abstraction to embed digital information into their environment. The term Tangible Flags evolved to describe computationally enhanced flags used for this purpose. The literature, our observations, and design team sessions led us to focus on three key concepts for the Tangible Flags technology: attaching tangible flags to the real world, increasing contextual awareness, and supporting concurrent interactions.

The simple interaction of placing a Tangible Flag is an age appropriate activity for young children, as 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 mental connection between the physical and the digital because the child is situated to compare the digital artifact with the real world environment that it represents. Once a Tangible Flag has been scanned, access to the corresponding digital artifact is available through software on a tablet 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.

To increase awareness, sets of Tangible Flags are color-coded to each child to provide others 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 easily access to digital information using the computer interface instead of the Tangible Flag as the number is also displayed on the Tablet Computer.

2.1 Related Work

An extensive body of research in augmented reality has demonstrated that embedding content in the appropriate context enhances the value of the information as well as augmenting the real environment [12, 22, 31, 33]. Some have used head-mounted displays that are bulky and not suitable for children [11]. Others use mobile devices and headsets that may be more ergonomically suitable for children [1, 12, 33]. All of these tools address only the presentation of digital artifacts, not their creation.

Tools for adults to annotate the real world with digital artifacts enable users to exchange information through the context of the physical space [5, 20]. This research suggests the benefits of user authoring and embedding of pertinent information in an appropriate context, which provides a medium relevant to collaborative activity. 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 approaches can help young children connect digital artifacts with the real, physical environment. Tags have been proposed as an important way to bridge physical and digital worlds [31]; this is the approach we take with Tangible Flags.

2.1.1 Technology for Children’s Learning

Several mobile systems have been developed to support children’s field trips. The Wireless Coyote project [32] 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 [18, 23, 28], particularly for science education. The Ambient Wood project showed the importance of enabling collaboration in context to promote reflection [24] as well as the effectiveness of digitally augmenting of the physical environment to promote awareness [16, 21]. This research indicates that older children can potentially benefit from supporting collaboration in knowledge artifact creation during exploration of open environments.

Participatory simulation research has 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 [8, 15]. While participatory simulations can support collaboration and encourage exploration, research into participatory simulation has not addressed the creation of artifacts.

HyCon Explorer [4] enables children (ages 10-12) to produce their own material related to a learning activity and automatically links child-authored information to the environment via a global positioning system (GPS). Information is displayed to children on mobile devices. When they move to certain locations in the environment, however, no link outside the digital realm is used. Other research using GPS and context-aware systems have 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 [3]. This illustrates the need for direct methods for connecting digital information with the real world.

Some 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 [2]. Research into children’s (age 9 to 11) collaborative interactions indicates that children participate more when they are provided with concurrent multi-user interaction [26]. 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 have in supporting collaboration.
3. COMPARATIVE STUDY

The following study was devised to evaluate the relative merits of the Tangible Flag computer and paper-based systems. While some may think technology is obviously advantageous; for children, many people assume paper is good enough. This paper is intended to address this question, and help tease out the relative differences and advantages. The hypotheses for the comparison were:

H1: Using the technology, children would demonstrate more awareness of each other’s drawing activities.
H2: Using the technology, children would participate in more collaborative activity.
H3: Using the technology, children would participate in the activity longer.
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.

The Tangible Flags software and hardware, as well as the paper system used to evaluate these hypotheses are described below. The experimental methods and procedures, data collection, and analysis methods follow.

3.1 Tablet Computer Version: Software & Hardware

The screen interface, as shown in Figure 2, consists of a thumbnail area which shows all previously scanned flags and a working area where the currently selected flag is edited. The flag thumbnail area is positioned across the top of the screen and has space for 6 thumbnails, two of each color, and the working area for Tangible Flags below. Before a child creates a digital artifact, the main working area is void of any markings except the Tangible Flag number in the upper left corner.

A flag’s thumbnail flashes whenever another user makes an addition to that Tangible Flag. The alert only occurs for the thumbnails of minimized pages, since the page currently displayed in the working area does not display a corresponding thumbnail.

Figure 2. Tangible Flag user interface.

In addition to the tablet pen (which was attached to the computer with a piece of elastic string), the tablets were equipped with an RFID reader. The RFID reader was attached to the top of the tablet (see Figure 3). Each child was also given two Tangible Flags, numbered 1 and 2, with a color matching the RFID scanner cover of their computer. The Tangible Flags client software communicated via wireless with a server. Each child’s digital ink was of the same color as their flags (red, green, or blue).

Figure 3. Tangible Flags hardware: tablet computer, pen, RFID reader (on top of tablet), and two flags (w/ embedded RFID tags).

3.2 Paper Version: Materials

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, in order to best mimic the look of the screen on the Tablet computer (see Figure 4). The paper’s color matched the marker color and the pages were numbered 1 and 2 with black ink in the upper left corner. The paper flag would remain at the marked location and other children could see the flag and come closer to view the artifact.

Figure 4. Paper version of Tangible Flags.

3.3 Methods

Eighteen children (ages 5 and 6) participated in this study. Nine were boys; nine were girls. The children were assigned to one of six groups with three children per group. 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 gender type was assigned to use the Tangible Flags technology and one group of each gender type was assigned to use the paper system. 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 each doing 3 activities apiece). These three activities all had a similar structure but each had a different content goal. The activities were conducted in the same order for every group. The three activities were: (A1)
furniture (training), (A2) patterns, and (A3) structures. Activities 1 and 2 took place in a classroom that was unused on study days in the pre-school the children attended; activity 3 took place on the school’s playground. These activities were developed based on the curriculum of the pre-school.

The first activity (A1) was a training activity in which the children found and drew pictures of furniture in a classroom with no other children. Various furniture found by the children included tables, chairs, desks, bookcases and other classroom items. During this activity, for both the groups using the paper and technology version of Tangible Flags, researchers were free to help children with any questions without strictly following guidelines for prompting. During this training activity, researchers encouraged children to interact, including prompting them to find and add to each other’s drawings, showing them how to use the technology or paper, and making suggestions that helped children to discover pages.

For the second activity (A2) the children looked for patterns. The children found patterns in floor tiles and carpet, pillows and cushions, tablecloth, cabinets and cubicles, and various other classroom objects. For the third activity (A3) the children looked for structures on a fenced, outdoor playground. Children found numerous play structures: the school, the maintenance shed, nearby buildings outside the school fence and even the fence itself. During the second and third activities, researchers followed specific guidelines on when and how to prompt children to find pages and make additions to drawings.

Before each session, the children were instructed to look for and draw objects of a certain type within a designated area. The children were asked to find a few example objects in the hallway prior to proceeding to the designated area to ensure that they understood the content of the activity. The children were asked to create a drawing of the target object and 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. They could 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 stop at any time.

A researcher was assigned to each child for the duration of the activity. Researchers followed written guidelines for helping children and giving appropriate prompts. Each researcher also operated a video camera to capture the child’s activity and asked questions about the child’s activities in order to elicit detailed explanations. After the child finished with the activity, the researcher would ask her a few standardized questions designed to elicit information about the experience. After 20 minutes any children still participating in the activity were asked to finish their current drawing and answer the questionnaire.

3.4 Data Collection and Coding

Video of children’s system usage and interactions with one another, the artifacts they created, and post questionnaires were collected, coded, and analyzed. For the paper system, the physical drawings were used; for the Tangible Flags technology the server logged the digital artifact creation including timestamps for every addition to the artifact. The post questionnaire was administered verbally and included questions on how many flags of each color the participant found and made additions to.

Video data was coded by two raters using a set of defined criteria. All of the fields listed below were used in the analysis and had an inter-rater reliability in excess of 80%. The hypotheses corresponding to each item are indicated in parentheses. For more information on these criteria, see the dissertation work of the first author [7].

- Number of times a child:
  - Interacted with a page (H1)
  - Reviewed a page (H1)
  - Made an addition to a page and whether it was on top or inside the drawing already on the page (H2)
  - Returned to the physical location of a page (H1)
  - Inspected the environment while drawing (H4)
  - Drew something from the environment (H4)

- Recall of number of pages seen and changed (H1)
- Number of location and addition prompts (H1, H2)
- How long the child participated and an average of how long the child spent on each page (H3)

Additional collaborative, qualitative metrics analyzed were the number of times a child:

- Drew with another child nearby (co-located)
- Drew with another child while they were not nearby (distributed)
- Talked about what to draw with another child
- Watched what another was doing nearby (co-located)

Additional metrics specific only to the computer-based version were:

- Accessed a flag just using the graphical user interface
  - Walked to a flag after accessing it on the GUI
  - Walked to a previously discovered flag and accessed it via the GUI (not scanning it)
- Scanning a flag that had previously been discovered

3.5 Data Analysis

The data collected was analyzed using generalized estimating equations (GEE) – an extension of the general linear model of statistical regression for modeling correlated data [10]. Three binary explanatory variables were used to distinguish the participants in the study (participant’s gender, mixed gender group, paper/technology). Two dummy variables were created as binary explanatory variables in order to analyze the effect of the different activities (training, indoors/outdoors).

4. RESULTS AND DISCUSSION

The analysis of the data confirmed H1, H2, and H3, while H4 was refuted. As mentioned previously, researchers followed scripted guidelines for prompts. There was not a significant difference in the number of location or addition prompts given to children while using Tangible Flags versus the paper system, which mean the significant differences found between the systems were not due to the number prompts given.

4.1 Effect on Awareness (H1)

There were two significant differences between the paper and technology implementations of Tangible Flags in the area of awareness. First, children using the Tangible Flags technology interacted with significantly more pages than children using the paper system (C_P=254, C_T=193; IRR=1.562; p=0.004). And, second, children using the electronic version had both significantly better recall of the number of pages they found (C_P=47, C_T=31; IRR=13.384; p=0.001) and significantly better recall of how many they added to (C_P=46, C_T=25; IRR=15.922; p=0.002).
There was no significant difference in the number of times children using Tangible Flags technology returned to the physical location of a page versus children using the paper system. This helps confirm H1, as even though there were more page interactions with the technology, there were fewer (though not significantly so) returns to the physical location. This correlates to children using the GUI to return to pages they previously scanned.

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 ascertained the original author's intent quite often–sometimes from a drawing as simple as a square. There was no significant difference between the paper and technology in how children flagged the environment.

These findings confirm H1; that using the technology-based Tangible Flag system, children were more aware of each other's drawings.

4.2 Effect on Collaboration (H2)
Several collaborative advantages of the Tangible Flags system were confirmed. Children using the Tangible Flags technology made significantly more additions to pages than children using the paper system (T_F=182, C_P=117; IRR=1.581; p=0.03). 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 (61). The number of page interactions in which children did not make an addition was the same for both systems (22 for each). This suggests that most of the increased page interactions that occurred with Tangible Flags resulted in additions.

There are more cases of children conversing and drawing simultaneously on the same page when using the technology (see Table 1). Only two children drew on a page at the same time with the paper system, whereas all but two did using the technology version. Conversations between children were more common when using the technology, occurring 1.69 times more frequently. This could be related to the number of page interactions, indicating there may not be an increased rate of conversation per page, but more opportunities to interact due to more page interactions. The number of cases when children watched each other work was relatively equal for the two systems (T_F=37, T_P=30).

Table 1. Count of co-located/distributed drawing cases while using paper and technology Tangible Flag systems, by activity and group; only technology can be distributed (*due to data loss of a participant, the numbers may be slightly lower).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Boy Group</th>
<th>Girl Group</th>
<th>Mixed Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Paper</td>
<td>Tech</td>
<td>Paper</td>
</tr>
<tr>
<td>A1</td>
<td>0</td>
<td>10/4</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>0</td>
<td>0/2</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>0</td>
<td>0/0</td>
<td>6</td>
</tr>
</tbody>
</table>

Children using the Tangible Flags technology overlaid their additions (see Figure 6 and Figure 7 for technology/paper examples) to existing work on the page significantly more often than children using the paper system (T_F=166, T_P=45; IRR=16.190; p=0.000) (see Figure 5). 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 this increase would be a result of the increase in additions; however, this dramatic increase cannot be explained by an increase in additions alone. This is clarified by looking at when the children did not overlay their illustrations. For children using the paper system, 72 of 117 additions were not overlaid, compared with only 16 of 182 for children using the Tangible Flags technology. 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 without overlays. The increased number of overlays instead can be attributed to two factors. First, children sometimes promptly switched to a page in the GUI after noticing another child had made an addition. Second, the increase in joint drawing activity likely resulted in a tendency for children to mark on each other's work. This effect would be amplified as children could concurrently interact in the shared digital space without interacting in the same shared physical space required by the paper system.

![Figure 5. Graph showing percentage of additions that were overlaid (x-axis); per child, per session (y-axis).](image)

Examples show how children used context to asynchronously make appropriate additions to a joint artifact. In both the paper and technology systems, children made additions that complemented or enhanced the existing work. This was likely the result of their understanding of what object a drawing was intended to represent. The effect was further enhanced by the use of the Tangible Flags technology. When using Tangible Flags technology, children often went beyond adding another object to a drawing, and instead added features to an object already represented on the page (see Figures 1, 2, and 6). Examples also show that children using Tangible Flags technology collaborated on a joint artifact over an extended period, building on each other’s additions (see Figure 6).

These outcomes reveal that the technology version exhibited increased indicators of collaboration, including more page additions, more communication between collaborators, and more overlaid additions to the artifacts. The technology supported the transition between synchronous and asynchronous collaboration; it also supported face-to-face collaboration. We believe the three key elements to providing this benefit are: increased awareness of peer activity, mobile access to a shared space, and concurrent interaction in the shared space.
4.3 Effect on Engagement (H3)
Children using the Tangible Flags technology participated in the overall activities for a significantly longer time than children using the paper system (M_TF=15:57, M_p=10:57; RC=5.069 minutes; p=0.000). There was no significant difference between the average times per page interaction for children using either system. The statistical model predicts children would spend approximately five minutes more participating in the technology based implementation than on the paper version. The data shows that children using the paper system spent an average of 96 seconds per page interaction, while those using the technology spent an average of 107 seconds per page interaction. This indicates that the increased page interactions observed in the technology version did not affect the time spent per page interaction.

4.4 Effects of Focus and Environment (H4)
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 (T_TF=54%, T_p=85%; IRR=0.282; p=0.010). This was most apparent during the first activity (the training activity where the children identified furniture). Children using Tangible Flags also inspected the environment significantly less often than children using the paper system (T_TF=67%, T_p=89%; IRR=0.207; p=0.000). We believe this is partially due to the children’s ability to color on the same page at the same time as other children, as well as to referencing previously scanned pages directly from the GUI. The technology facilitated contextualizing drawings, and also allowed additions and modifications to a single drawing simultaneously, which was hard to do in the paper condition. We believe this created a situation in which children’s creative efforts were less restricted. In this manner, the technology enabled them to become more involved in working on each other’s drawings.

The results of the study point to some key differences between the paper and technology implementations of Tangible Flags. The study identifies several collaborative advantages of using the technology-based system, including: increased awareness, more shared experiences, and longer time participating in activities. Another difference is that individual ownership of the drawings...
was more prominent with paper. This may be an advantage for the technology version as the tool is to encourage multi-child collaboration so any indication of joint ownership (e.g. children did not individually label pages) could be viewed as positive.

Tangible Flags technology demonstrates how mobile technology can promote children's face-to-face collaboration in open environments. Awareness of changes to a joint artifact coupled with immediate access results in children collaborating asynchronously in a shorter time period and encourages responses to changes made by others. Concurrent collaborative drawing is further enabled because children interact in the shared digital space, on their own, individual devices. This cycle of prompt asynchronous collaboration can overlap and turn into synchronous collaboration. As a result, children naturally seek each other out and collaborate face-to-face.

We believe the Tangible Flags system illustrates how tagging technologies (such as RFID) are an effective approach to help children understand the link between the physical and digital worlds and to support collaboration in open environments. Children as young as five years old used the system to flag the environment, and access, elaborate and share digital information. This research suggests some practical approaches for developing interactive learning environments for children including mobile device applications. As mobile device usage expands further to children, this research illustrates advantages of using today's technology over the traditional technology of paper - the primary advantage being that of supporting collaboration.

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7. REFERENCES


