Child's Play: A Comparison of Desktop and Physical Interactive Environments

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ABSTRACT
The importance of play in young children's lives cannot be minimized. From teddy bears to blocks, children's experiences with the tools of play can impact their social, emotional, physical, and cognitive development. Today, the tools of play include desktop computers and computer-enhanced physical environments. In this paper, we consider the merits of desktop and physical environments for young children (4-6 years old), by comparing the same content-infused game in both contexts. Both quantitative and qualitative methods are used for data collection and analysis.

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Children, educational applications, games, stories, desktop, physical interactive environments

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

I played some games, then ate lunch, then swam with my cousin, went home to dry off, played some more games, ate dinner, and then played games until bedtime. – a six-year-old girl describing her day's activities

A child's work is play — and they work hard [34,35]. Play is an integral part of children's lives. According to many prominent researchers, as children play, they develop cognitively, socially, and physically [30,34,38,39,22]. They learn via exploration, trial and error, collaboration, experimentation, role-playing, and pretending. This has also been evidenced by the recent strong emphasis on play in the curriculum of U.S. preschools [28].

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Many people have explored how technology can be used to augment child's play [36,37,42,43,44,33]. Our study furthers this research by comparing the use of desktop and physical interactive environments by preschool-aged children (ages 4 to 6). The main contribution of this paper is the first exploratory comparison of desktop and physical environments for preschool-aged children. Desktop interactive environments are characterized by a computer unit, keyboards, mice, and monitors which sit on a surface such as a desk or table; such environments are commonplace in today's society. Physical interactive environments are places where interactive technology is embedded into physical objects [42,43,44,32,31]. These physical interactive environments have sometimes been categorized with ubiquitous computing systems which enable users to perform digital manipulations in everyday environments [33,42]. The main contribution of this paper revolves around the creation of the Hazard Room Game — a game that focuses on teaching children about environmental health hazards. The game includes role-playing story activities with potential hazards such as lead, particulates, pesticides and phthalates.

In developing the Hazard Room Game, we used the methodology of Cooperative Inquiry [13,14]. Cooperative Inquiry adapts ideas from contextual inquiry and cooperative and participatory design to form a methodology that effectively includes children in the design process [13]. In Cooperative Inquiry, the brainstorming process involves sketching ideas to create low-tech prototypes using child friendly art supplies. Child and adult team members also observe technology use and capture activity patterns, using sticky notes, drawing or writing in journals [13, 14]. Typically, methods which involve children as design partners primarily involve the target age children in consulting or participatory roles. Here we also partner with children who are slightly older than the target user age.

Using the ideas designed by our team, we built technologies that supported content-infused story games. The Hazard Room Game consists of two modes: exploring and learning. In the explore mode, children could explore, search and find story elements. In learning mode, children would hear stories emphasizing specific content knowledge — thus the game became a content-infused story game (referenced as

CIS Game hereafter). It should also be noted that although the specific content in the CIS game was environmental health hazards, the technologies we developed are not constrained to this specific domain, but can generalize to any number of content areas, such as teaching children about insects, transportation, safety, or farms.

RELATED WORK

Many people have explored how technology can enhance learning during child's play [23,36,15,33]. The role technology can and should play in the education of young children has fueled much debate among researchers [27,29,31]. Despite this debate, many have successfully ventured into the realm of technologically enhanced educational systems for young children. The main categories of research related to this study are the role of stories in learning, games and gender, desktop applications for children, physical environments, and CIS games. These topics are discussed in the following subsections.

Role of Stories in Learning

There is an Indian Proverb that says: *Tell me a fact and I'll learn. Tell me the truth and I'll believe. But tell me a story and it will live in my heart forever.* [20]

This proverb is supported by a The (U.S.) National Council of Teachers of English (NCTE) Guideline which states that teachers discovered children could easily recall whatever historical or scientific facts they learned through story [11]. Indeed, stories and narrative exploration, are excellent for learning and teaching [20]. Stories meet the diverse needs of children [50], greatly facilitate language learning [25], and help children construct an image of self [10].

Because stories are such a powerful teaching tool, many systems have been developed to foster story creation and sharing. A few of these technologies in particular seem to form a bridge between the physical and desktop environments. These systems use a desktop to create, and a stuffed animal for sharing and reviewing previously created stories. SAGE [4,48] and Rosebud [17] developed at the MIT Media Lab and PETS developed at the University of Maryland [40] are three such examples. Hazard Room Game also uses stories as the teaching mechanism; however, it uses them in a much more directed manner than the aforementioned systems.

Games and Gender

Games are an integral part of child's play. Children love games [22]. Their "games" do not necessarily have to be the goal oriented games that adults generally play. Children's games not involving technology often have more to do with repetitive, simple activities as in *Simon Says* or *Hide-and-Go-Seek* [18].

Games can also be used for educational purposes. Renowned educator John Dewey has described the educational principles for teaching as: engaging children in a fun and playful environment, imparting educational content, and ideally sparking interest in learning more about the subject [12]. Indeed this is the purpose behind the Hazard Room Game.

In research on games, there is also a lot of discussion about gender differences — especially for children [10,22,18]. Much of the computer game research addresses an apparent designer bias towards male users and a corresponding interest imbalance tending towards males being more interested. Researchers have found that there are many reasons for this disparity between the genders when it comes to games. This imbalance however has been countered by games targeted specifically for girls [49,10]. In more general game research, psychologists have noted that for young children, the organized games of girls are simpler in their rule structure than are the games of boys, and require a lesser amount of physical skill. They also note that boys play games in larger groups. Also relevant to the CIS Games is psychologists' assertion that girls seem to be slightly ahead of the boys in their ability to initiate fantasy play without the benefits of realistic props [22]. This is applicable to the Hazard Room Game in the physical environment because it uses props. Inkpen, et. al. also show gender differences in collaborative interaction — boys take, and girls relinquish control of the mouse [24].

Desktop Environment

The traditional desktop environment has been employed for educational purposes since its inception. Although the desktop offers a great deal of software that drill or test children on subject matter, one of the early software tools for children which employs a different approach and has been conceptually influential is Logo [36]. Logo and its descendant StarLogo [41], as well as the relatively new Squeak [47], are educational platforms and programming environments that can lead to exploring the conceptual worlds of math, science and more. When using these environments, children usually start from example, and then manipulate and make changes to discover new mathematical and scientific concepts in action as they build new programs. These technologies support the educational approach called *constructionism*, which suggests children build as part of their educational process, and by doing so, can build their own conceptual models of the world around them [36,37]. A more traditional perspective of explorative educational approaches such as *constructionism* is called *discovery learning*. *Constructionism* and/or *discovery learning* (depending on your point of view) also play an important role in narrative storytelling systems, which have been implemented for both physical and desktop environments. Examples of some of the open-ended desktop narrative storytelling applications include: Hayes-Roth Improvisational Puppet system [21], MOOSE Crossing [7], StoryBuilder [2], and Renga [8,9]. Although not the focus of this paper, CIS games could conceivably be built by children to teach other children. By the same constructionist premise of narrative storytelling applications, children would learn while creating and then be able to share that knowledge when others play their CIS game.

Physical Environments

Ubiquitous computing has become a popular paradigm that enables computational accessibility in everyday settings [16,26,19,15]. Recently this technology has been employed to aid the teaching of young children [42,43,44,32,33,1]. Typically, physical educational environments are revered as a more natural, explorative environment for young children, since children generally play with and learn in physical environments. Several physical, educational learning applications emphasize narrative storytelling, which as discussed above [33,1,5]. An example of narrative storytelling environments is StoryRooms, which enables children to create a story with technological icons and physical props [32,33]. The child programs using physical objects a sequence of actions that correlate with their story, thus facilitating sharing, collaboration and reproduction.

Desktop vs. Physical Environments

Desktop and physical educational environments have been shown to aid learning [36,37,33,32,41,1], however, most studies stop there. To our knowledge there has been no study comparing desktop and physical environments for children. Researchers have studied different desktop collaborative configurations [45,47]. There have been many studies on how desktop environments can enhance learning [36,41,43]. Physical environments have asserted theoretical advantages on the grounds that children interact better in the physical world than in the two-dimensional space of the desktop [33]. Others still have attempted to bridge the gap by having physical and desktop components [17,4,48]. There is extensive literature about each individual environment, but it appears as though direct comparisons have been avoided. Herein we investigate the desktop and physical educational environments in direct comparison in the domain of young children's learning.

Content-Infused Story Games

The concept of content-infused story games (CIS Games) is not necessarily new but builds upon other story game technologies [17,40,4,48]. Its basic premise is that games and stories can be combined to educate children. In CIS Games, stories are used directly to indirectly teach particular content. Because of their generality, CIS Games can be effectively implemented in both desktop and physical environments.

Many of the aforementioned approaches, both in desktop and physical environments, use creative story narrative as the educational mechanism. These systems implement constructive methods [36]. Although we support these open-ended approaches, we also believe there is a need for directed learning. CIS Games are a mechanism for teaching directed material using prefabricated stories.

From a pedagogical standpoint, CIS Games use most of the recommended effective approaches as designated by The National Research Council. The four it specifically employs are: direct instruction, teaching through play, teaching through structured activity, and computers [6]. The other two are: engagement with older peers and child-initiated instruction. Both of these could be incorporated into CIS games — the former, by including multi-age dyads, and the latter by allowing the children to dynamically create their own CIS Games.

HAZARD ROOM GAME

The CIS Games we created were the product of a long evolution involving 35 children (ages 4-11) over an 18-month period. The specific target audience for these technologies was young children, ages 4-6. In developing the structure with children, we focused on environmental health hazards as the educational content. The hazards that were covered in the game were lead, particulates, pesticides and phthalates. The game was designed to be engaging as well as teach the children about what dangers the hazards pose and how to avoid them. This domain was chosen due to the recent need for such information in the Washington D.C.-area where lead in drinking water had been a common occurrence. To develop the appropriate content we partnered with the Children's Environmental Health Network (CEHN), a non-profit organization concerned with public education and policy development on these issues.

The Hazard Room Game was implemented in both desktop (Figure 1) and physical interactive environments (Figure 3). Both environments use the same game structure. The game consists of stories about each hazard. The stories contain information about the hazard and what is the appropriate action to take in each situation. Stories were broken into three different segments. Each segment is associated with a prop and a sound segment. For example: "You get an apple / You wash the apple because the apple can have pesticides on it. Pesticides make you sick / You eat the apple". In this story, the potential hazard is pesticides. Three props are used to help tell the story: an apple, a sink, and a mouth. Each prop corresponds to a sound segment as delineated by the '/' above.

The same props (or pictures of the same props), the same hazards, and the same stories are used in both desktop and physical implementations of the Hazard Room Game. In both implementations, the props were located in the same manner around the periphery of the space, real or virtual. The placement of the props was designed to encourage children to explore the whole area during each turn.

During the game, teams take turns filling two different roles: the *I Spy* team and the *Finder* team. The *I Spy* team helps the *Finder* team locate the props for the current hazard story in a random order. They do this by verbally giving an initial clue (e.g. "I spy with my little eyes, something red"), followed by locational clues (e.g. "you're getting warmer/colder") for each prop. The *Finder* team explores the room, finding each prop, and depositing them in a special area defined as the *Story Corner*. Once all three props are collected for a story, all players hear the full story. The *Finder* team then sequences the props in the order they were mentioned in the story. The technology then notifies the children whether they sequenced the props correctly by responding, "That story is correct". If not, the children listen to the story and order the props until the sequence is correct. Correct ordering of the props is indicated by the order the props occurred in the story. For example, in the apple story the correct ordering is: apple, faucet, mouth. This same game flow is used in both the desktop and physical implementations of the game.

Desktop Game

In the desktop Hazard Room Game, the two teams are connected via the Internet. The “room” in the desktop version is a window that occupies the full screen of the computer (see Figure 1). Each team has their own computer, which is not visible by the other team. The *Finder* team navigates the play area by using the arrow keys which moves a representation of their team (e.g. the red and blue dotes in Figure 1). Locational clues are given by the *I Spy* team via warmer/.colder buttons on the keyboard. These clues indicate whether the team is warmer (closer) or colder (further) from the currently sought prop. As soon as the *Finder* team navigates over the object they are looking for, the object automatically moves (via animation) to the story corner. Once all objects are found, sequencing is performed in the story corner which is zoomed in to fill the full screen (see Figure 2, *Left*).

Figure 1 — Screenshot of the desktop Hazard Room Game.

Once sequencing is completed correctly, the teams switch roles, so each have alternate opportunities to be the *I Spy* and *Finder* teams.

Figure 2 — *Left*: Screenshot of desktop story corner during sequencing; *Right*: Close-up of physical story corner

The desktop Hazard Room Game was built for the Windows platform using the Piccolo Toolkit [3] to enable quick development of a game that included interactive zooming and animation. The game, being a two-teamed game, was designed for two computers that could share a TCP/IP socket for communication.

Physical Game

Similar to the desktop version, the *Finder* team starts out in the center of the physical play area (shown in Figure 3). Teammates navigate by holding hands (to avoid teams separating and thus being near different props) and walking around the play area. Once an item is found, the team places it by the story corner, where the sequencing bins are located. A close-up of the story corner is shown on the right of Figure 2. Similar to in the desktop version, the children perform sequencing by placing the props inside the story bins.

The physical Hazard Room Game uses radio frequency identification (RFID) readers and tags. Each prop has an RFID tag associated with it; each story bin has an RFID antenna and controller that is connected serially to a wireless modem (BlackMagic [32]) that was engineered, built and tested in our lab. The wireless communication for each bin communicates to a Windows computer that has a Java application that orchestrates the correct sequencing and the playing of the sound clips.

Figure 3 — Photo of the physical Hazard Room Game.

EXPERIMENT AND ANALYSIS

To compare the desktop and physical environments the hazard stories were divided into two sets, Set A consisting of lead and phthalates, and Set B, particulates and pesticides. The sets were chosen to be similar in ease of learning by Daniel Schwarz, the former Director of CEHN and a content expert. The quantitative analysis showed no effects by hazard set, demonstrating that this was achieved.

The study participants were children ranging in age from 4 to 6. None of these children had ever seen the technologies to be tested, nor were they among the design team that helped develop the technologies. Eight teams of two children each were randomly selected. The random selection was constrained to have a boy and a girl on each team, to counterbalance gender effects [24]. Two teams were then randomly assigned to a group, forming four different groups. Each group used one environment (desktop or physical) with either hazard Set A or B, for a session. They then used the other environment with the other hazard set in another session a few days later. The experimental design therefore was a two-by-two, fully counterbalanced cross with hazard set (A or B) and application type (Desktop or Physical), for a total of four treatments. Each treatment involved two teams of two children. Each treatment consisted of two sessions. Each session consisted of two hazards with each hazard having a story for each team, resulting in four stories per session.

During each session four adult moderators were present, one for each child present. Each moderator administered the pre and post tests one-on-one with a child. During the sessions, there was a main facilitator (who explained procedures [e.g. how to play the game] and moderated discussion), one person video taping, one taking notes, and another monitoring the technology.

The metrics of comparison were twofold: qualitative and quantitative. The quantitative metrics were measured via identical pre and post tests administered before and after each session. Since the sample size was small, we anticipated that the qualitative measurements would be more revealing. As such the quantitative analysis was performed to provide descriptive statistics to accompany the qualitative findings. The qualitative analysis is based on notes and video coding of questions asked by adult researchers after each, correct story sequencing.

Quantitative Analysis

The quantitative analysis consisted of scoring the pre and post tests and evaluating the difference between each participant. The tests consisted of six multipart questions which were administered verbally; the duration of the tests took approximately one to two minutes. The first four questions gave scenarios similar to those in the stories and asked the children what they would do and why they would do it. For example, recall the apple story from the Hazard Room Game. Each child was asked: "What should you do with an apple before you eat it?", and then "Why should you {initial response} before you eat the apple". For the last two questions, the child was asked which of a list of items could have the potential hazard. For example, "Which of these could have pesticides on it? … Water … Pacifier … Apple … Plastic Toy … Carpet". A response was awaited after each item was read.

The tests were then scored and the differences between participants' pre and post tests were used for analysis. For scoring the first four questions equal points were awarded for each of the three-part questions. The last questions were awarded a point for a correct answer and a half a point deduction for a false positive. With this scoring scheme, a completely correct test had a score of 16. Thus the largest possible difference between pre and post tests was 16. The differences between participants' pre and post tests were then used for analysis.

The most important comparison we hoped to make was between the desktop and physical environments. As expected, none of the quantitative results were statistically significant due to the small sample size. Given the effect size that was observed between the desktop and physical interactive environments, the power analysis exposed that at least one hundred participants would be necessary to obtain significance. Such a large study was infeasible due to lab resources, thus necessitating qualitative analysis. The descriptive statistics will be used in concert with the qualitative observations to illustrate their correlation.

Another factor that could have impacted the quantitative analysis was our quantitative measurement — the pre and post tests. A measurement analysis showed that there was a small positive correlation on the pre tests (~0.49) and only slightly more on the post test (~0.73). The small correlation on the pre test was expected, as the children guessed, however, we hoped the correlation would be higher on the post test. We feel the reliability of the pre and post tests could be increased by lengthening it slightly and adding more redundancy. This would not impact the children too much, because the test could still be completed in two to four minutes if it were doubled in size.

Qualitative Analysis

The qualitative analysis was based on notes and video taken during verbal discussion between adult researchers and the children after each correct story sequencing. Adult researchers used these two prompts to initiate discussion:

- "Tell me the story in your own words.", and
- "What did the story teach you?"

Coding Procedures

After reviewing notes and video of these qualitative discussions, a coding scheme was developed. The coding scheme for each story included the number of times adults verbally prompted the children for a response for each of the above discussion prompts, as well as coding behaviors of each child throughout the discussion. A prompt consisted of an additional question or comment from an adult facilitator that had the intention of eliciting a response from a child participant. Each prompt was separated either by a response from the children or a pause of 5 or more seconds.

For each child within a story, video evaluators made five observations:

- Whether or not the child gave a verbal response
- How many times the child communicated "I don't know" either verbally or non-verbally (e.g. such as shrugging their shoulders)
- The depth of response as defined by:
    1. Incorrect or no response

2. Rote or slightly reworded, or just identifying the sequence of props
3. Processed or mostly reworded
4. A processed response including the causal effect (e.g. "You should wash the apple before you eat it because it might have pesticide on, which could make you sick.)

- A frequency of the interaction types (pointing or touching of props) to identify which happened most frequently
- A subjective interest level for the child on a scale of one to five, where one is very disinterested, and five, very interested

Findings

To establish reliability of the coding scheme, three different evaluators coded 25% of the stories on video. The inter-rater reliability was 79%. The subjective interest question had the highest variability among the raters; in fact, only 40% of the responses were exactly the same among all three raters. The average standard deviation for each rating was 0.37 meaning that mostly what occurred was that one rater chose a rating that was one off of the other two. Having correlated a high percentage of exact answers and verifying the consistency of the qualitative measures, one researcher then coded the rest of the video.

Table 1 — Summary of the qualitative coding averages

	Desktop	Physical	Winner
# Prompts	3.58	2.75	Physical
Story	1.96	1.67	
Learn	1.63	1.08	
# Responded	0.86	0.75	NA
# Don't Know			Physical
By person	0.30	0.23	
Total	0.39	0.28	
Answer Depth	1.87	2.25	Physical
Interaction (# Point; # Touch)	8; 0	3; 11	NA
Subj. Interest	2.66	3.09	Physical

The results of the coding yielded several advantages for the physical environments over the desktop environments. Specifically, there are four measures that indicate advantages for the physical environments (as can be seen in Table 1). First, the number of prompts necessitated by the facilitators was fewer in the physical environment. Second, the answer depth increased in the physical. Third, the number of "I don't know" responses was reduced. Fourth, the average subjective interest was higher in the physical than it was in the desktop case. These four measures collectively suggest that these children may have been more engaged and that they qualitatively learned more in the physical environment than in the desktop environment. Table 1, shows all of the results, the first three measurements (# prompts, # responded and # don't know) seem to be correlated as do the last three (answer depth, interaction, and subjective interest). If there were no disparity between the desktop and physical environments, then the first three would be correlated with the last three, but instead they are negatively correlated, meaning that more prompts yielded more "I don't know"s than good answers in the desktop environment. These qualitative results agree with the descriptive quantitative statistics where the mean score differential between pre and post tests was greater in the physical (3.63) than in the desktop application type (2.69).

Some gender differences were apparent in our overall findings. The most marked gender distinction was manifest in the type of responses given by girls and boys. Boys tended to respond with rote responses, mimicking the stories almost word for word, but leaving out the causal effects. This was witnessed in observing many segments where the boys simply stated the ordering, but the girls would reword the story when prompted to tell the story in their own words. The qualitative results dramatically illustrate this finding as the boys received rote depth ratings (code number two above) almost four times more than the girls did (15:4). Conversely, girls tended to respond with full causal depth (code number four above) twice as much as the boys did (15:8).

Gender differences were also evident when analyzing the data by environment. The girls verbalized more, as the boys pointed and touched the props considerably more both in the physical and desktop environments. The aggregate ratio of male to female point and touch interactions was 9:2. Not surprisingly touching the props occurred more in the physical environment, although some children did point at the computer screens as they explained the stories in the desktop environment. In the physical environment, the ratio of touching the props again favored the boys, echoing the overall ratio of 9:2.

The quantitative descriptive statistics also pointed to a gender difference, which was not distinguished in the qualitative analysis. Comparing the difference between pre and post tests, the girls performed better on the physical (4.63) than on the desktop (2.19), whereas the boys were about the same on both physical (2.63) and desktop environments (3.19). This difference was not observed as strikingly in the qualitative results. Only minimal benefits (less than 10% improvement) were observed in average depth and average engagement (using average interaction and subjective interest).

LESSONS LEARNED

Throughout the process of developing and testing the Hazard Room Game, we learned a number of lessons about interactive environments for children's CIS games. We present these lessons below as suggested guidelines for others building similar technology with young children.

Physical environments may have empirical advantages over the desktop environment

Our qualitative analysis showed the physical environment to have several advantages over the desktop environment. These were interest, engagement, and understanding in the physical environment as suggested by the decrease in the of "I don't know" responses and facilitator prompts and the increased depth of response. This suggests that embedding technology in the physical world, rather than simply presenting them with traditional desktop applications, may be beneficial to young children.

Gender may effect the types of interaction with the different environments

Although our qualitative study did not yield significant or authoritative differences by gender and application type, the observational data suggests that such differences may exist. Differences in processing (rewording versus rote recitation of stories), interaction (boys tended to point and touch more in both environments), and interest (although both showed greater interest in the physical environment, girls seemed more interested in general, and much more interested in the desktop than the boys) suggest disparities between the genders. We suggest further investigations into the differences that may exist between gender and educational, computational environments for young children, as this may greatly benefit early childhood education.

Comparing desktop and physical environments is difficult and requires multiple metrics

Given the scarcity of published materials comparing the relative merits of desktop and physical interactive environments, direct comparisons appear to de difficult. For our study, we chose CIS games as a basis for comparison because it is an effective learning method that could be implemented comparably in both physical and desktop environments. Also in our study, we used both quantitative and qualitative measurements in concert which enabled us to suggest stronger implications than we could make with either individually. Although we found some interesting differences, further research is necessary to fully understand the trade-offs between desktop and physical environments.

CONCLUSIONS AND FUTURE WORK

Although we observed many interesting trends, the results must be interpreted with caution. The small sample size limited the analyses. Despite the small sample size, the high correlation of several, different measurements indicating advantages for physical environments over desktop environments implies there may be an overall advantage to physical environments. We suggest more research in this interesting area of computing with younger children.

Several ideas for future work in this area include conducting larger longitudinal studies. A larger sample size, a longer test, and a longitudinal study in which children are asked the test questions at a later time (to test retention) will help address the limitations of this study due sample size. A larger sample is also needed to better understand the relationship between gender and application type (desktop and physical environments). In the future, we would like to ask children similar test questions in a real-life physical environment, instead of a short verbal test. By acting out the story, instead of just responding to verbal questions, the testing results may lead to a better understanding of the advantages and disadvantages of desktop and physical interactive environments for young children.

In conclusion, our findings are a springboard for continued comparative research on desktop and physical educational environments for young children. Better understanding the relative merits of these environments can help answer the polemic question of the role each have in child's play!

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