Are Tangibles More Fun?
Comparing Children's Enjoyment and Engagement Using Physical, Graphical and Tangible User Interfaces

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ABSTRACT
This paper presents the results of an exploratory comparative study in which we investigated the relationship between interface style and school-aged children's enjoyment and engagement while doing puzzles. Pairs of participants played with a jigsaw puzzle that was implemented using three different interface styles: physical (traditional), graphical and tangible. In order to investigate interactional differences between the three interface styles, we recorded subjective ratings of enjoyment, three related subscales, measured times and counts of behavioral based indications of engagement. Qualitative analysis based on observational notes and audio responses to open interview questions helped contextualize the quantitative findings and provided key insights into interactional differences not apparent in the quantitative findings. We summarize our main findings and discuss the design implications for tangible user interfaces.

Author Keywords
Interface style, enjoyment, engagement, children, play, puzzles, tangible user interfaces.

ACM Classification Keywords
H5.2. User interfaces

INTRODUCTION
Computation has been used to augment children's play in a variety of ways [7,16,17]. A recent trend is the application of tangible user interfaces (TUIs) to children's learning, play-based applications and products (e.g., [4,14,22,23,24, 33]). Much of the research in this area has focused on the development and descriptive analysis of new tangible systems. This research is grounded in implicit assumptions that tangible style interfaces, which rely on direct physical manipulation and support face-to-face collaboration, are more "natural" and thus more enjoyable and engaging for children than desktop environments. However, few empirical studies address these claims [4,14]. Compared to graphical style desktop systems there has been little research that explicitly and systematically explores the advantages of tangible systems. The claims of the benefits of tangible interaction remain speculative. It is unknown how the properties of tangible interaction will contribute to enjoyment and engagement in tangible games for school age children. Understanding these issues will contribute to grounding this technology agenda in empirical studies; inform the development of stronger frameworks for the theory and practice of play-based learning with tangibles; and lead to the development of principles to guide the design of new forms of tangibles.

This paper presents a comparative study exploring how interface style related interaction factors impact enjoyment and engagement in jigsaw puzzle games under a collaborative condition for 132 school-aged children (7-9 years old). The main contribution of the study documented in this paper is that it is the first empirical comparison of physical (traditional), graphical and tangible interfaces for school-aged children. A second contribution is the development of an extensible tabletop prototype, which uses fiducial markers and a camera vision system to track user driven events, such as the connection of two or more puzzle pieces. The third contribution is the set of design recommendations for the development of enjoyable and engaging tangibles.

BACKGROUND
Tangible User Interfaces
Tangible user interfaces and tangible interaction are terms increasingly gaining currency within the human computer interaction community [11]. The last decade has seen a wave of new research concerned with the coupling of the physical and digital worlds. Tangible user interfaces utilize physical representation, manipulation of digital data and offer interactive couplings of physical artifacts with computationally mediated digital information [11]. Many different research projects have studied enabling technologies, usability aspects and various applications of tangible user interfaces (e.g., [10,11,24,31]). Projects utilizing augmented tabletop environments have demonstrated tabletops' potential value (e.g., [2,20]). One major advantage that has been identified with for tabletops is that they can support synchronous co-located collaboration. However, little is known about how and why such environments can be designed to support successful social interactions.

The development of tangible systems specifically targeted to children is also a growing research area. It builds on past research themes, which have explored how technology can enhance learning during child's play; the role technology can and should play in children's lives; and how children can be supported to develop cognitively through augmented play activities. There are many noteworthy studies. For example, Price *et al.* report that interaction with tangibles encourages engagement, excitement and collaboration [18]. Africano *et al.* describe the design and implementation of Ely, a tangible tabletop environment, which supports school-aged children's collaboration [1]. McNerney suggests that, compared to screen-based user interfaces, tangible user interfaces have made computation immediate and more accessible, and that they are appropriate for children learning about computation and scientific exploration [15]. Andersen observes children's emerging understanding of sensors as they explore and play with touchable interfaces [3]. Fernaeus and Tholander present the insight that tangibles are resources for action as well as alternative forms of data representation [8]. Raffle *et al.* argue that manipulating parameters of motion enable children to more deeply explore and analyze sophisticated robotic behaviors [19]. Bohn presents a smart jigsaw puzzle assistant but provides no systematic evaluation [5]. Many of these studies focus on describing the system and provide descriptive summaries of user interactions rather proposing explanations for how and why tangibles might cause particular learning effects. Fails *et al.* made a step towards explanation through a comparative study of the differences between a desktop and tangible game environment for pre-school aged children [7].

Enjoyment and Engagement

Enjoyment and engagement are integral and prerequisite aspects of children's playful learning experiences. They are the two primary dependent variables evaluated in this research study. The conceptual definitions of enjoyment and engagement set the scope and meaning of the terms within this research study. Each is a complex construct which may be derived from physical, social and cognitive theories.

There are many conceptualizations of enjoyment. For example, Davis presents a causal theory of enjoyment [6]. The basic premise is that an object of enjoyment causes the subject to experience pleasure by causing concurrent beliefs, which satisfy desires concerning the experience itself. In the domain of children's play and learning, an alternate conception is necessary. Self-determination theory (SDT) is a macro-theory of human motivation concerned with the development and functioning of personality within social contexts [26]. SDT relates enjoyment (during social activities) with intrinsic motivation. The construct of intrinsic motivation describes natural inclination toward spontaneous interest and exploration that is essential to cognitive and social development, and represents a principal source of enjoyment [26]. Since we are interested in children's social play, a conception of enjoyment based on intrinsic motivation is relevant. The Intrinsic Motivation Inventory (IMI) is a validated multidimensional measurement instrument based on SDT [25]. It was designed to measure participants' subjective experiences related to enjoyment and interest in activities conducted in laboratory experiments by measuring intrinsic motivation. The IMI questionnaire is easy to customize to any activity. The simplicity of design and language made it an appropriate choice, with slight modification, for school age children as demonstrated by Verhaegh *et al.* in their evaluation of children's enjoyment using a tangible tabletop game developed by Philips Research [32]. The IMI is a questionnaire that uses a seven point Likert scale. In addition to a measure of *Enjoyment and Interest*, it has five related subscales. Three of the subscales were pertinent to our study. *Perceived Competence* was predicted to be positively correlated to enjoyment. *Perceived Choice* and P*erceived Pressure and Tension*, were included to provide a measure of the impact of the artificial nature of a lab study. Perceived choice was predicted to be positively correlated to enjoyment. Perceived pressure and tension was expected to be negatively correlated to enjoyment.

Engagement has been commonly conceptualized as a kind of mindfulness requiring cognitive effort and deep processing of new information [28]. This conceptualization is relevant for children's play since a dominant function of play is learning. Learning requires engaged attention. Some researches have operationalized engagement as the amount of time spent on and off a particular task [1]. For studies involving children, Hanna *et al.* suggest that observing frowns and yawns are more reliable indicators of lack of engagement than children's responses to questions [9]. Read *et al.* propose that engagement could be measured by observing the occurrence of a set of behaviors including: smiles, laughing, concentration signs, excitable bouncing, positive vocalization, and that lack of engagement could be measured through behaviors including: frowns, signs of boredom (ear playing, fiddling) shrugs, and negative verbalization [21]. In order to avoid the biases of subjective measures, engagement was operationally defined in this study as the amount of participants' on-task activity time (given a viable alternate activity) and the number of starts and completions of the puzzle.

Collaboration

Another variable of interest related to enjoyment and engagement is collaboration. Children communicate and learn through social interaction and imitating one another. In this way they acquire new knowledge and hone their ability to collaborate with others. Inkpen *et al.* found that children exhibit a significantly higher level of engagement and activity when working alongside each other [12]. Sluis *et al.* suggest that a collaborative environment is more likely to elicit increased intrinsic motivation [30]. Working together in small groups is shown to increase children's enjoyment, engagement and motivation [12,29]. Based on the assumption that a collaborative, co-located condition is ecologically valid and would enhance children's enjoyment and engagement for all interface styles, a paired collaboration situation was chosen for our study design as detailed below.

METHODOLOGY

Study Design

In order to investigate how interface style affects children's enjoyment and engagement, we designed an experimental comparison of school-aged children's enjoyment and engagement on three interfaces for solving jigsaw puzzles. Jigsaw puzzles were chosen as they represent a familiar playful activity that is undertaken socially, requires cognitive effort, utilizes physical manipulation and is spatial in nature. The experimental design was a three-by-two, fully counterbalanced cross with interface style and puzzle themes. In order to eliminate the order effect, each pair was asked to play with only one puzzle on only one of the three interface styles.

To facilitate a valid comparison, we used the same two puzzles implemented in each interface style. In our initial design, we held many of the physical characteristics of the puzzle constant across all three implementations, including; puzzle style, piece shapes, image style, piece size, number of pieces, and availability of underlying image.

The key differences among the three implementations were related to modality of feedback, social and physical interaction. The traditional puzzle lacked digital auditory or visual feedback. However, children received haptic and visual feedback for correct connections. A real sized poster of the puzzle was used as the underlying image for non-interactive visual feedback. The GUI puzzle implementation involved indirect manipulation by a single user (via the mouse or touchpad). The degree of freedom of movement of puzzle pieces were limited to two dimensions (rotation in 2D is possible). The puzzle size was limited by display size and portability requirements of the study set up. The TUI puzzle shared the style of direct physical interaction in three dimensions and the possibility of face-to-face social collaboration with the traditional puzzle. The TUI puzzle was implemented to include the same modalities of feedback (auditory and visual) and available operations as the GUI puzzle (e.g., turn underlying image on/off, puzzle reset). This study design enabled the investigation to focus on the features of TUIs, which were often cited as enjoyable and engaging: face-to-face social interaction (PUI, TUI), direct physical manipulation (PUI, TUI) and integrated feedback (GUI, TUI) with the PUI acting as a control.

The Puzzles

All puzzle implementations used one of two different content themes, each with the same modern style of cartoon illustration. One theme was a whimsical illustration of an imaginary castle with bats, ghosts, witches, knights and a princess. The other theme was an illustration of the legendary pirate Barbarossa and his ship, the Black Pearl. Both themes are inclusive of gender and are currently popular in children's media as can be seen in the success of Harry Potter and the Pirates of the Caribbean books and movies.

Traditional (Physical) User Interface

The two traditional or physical user interface (PUI) style cardboard jigsaw puzzles chosen for the experiment were designed and manufactured by DJECO, a European game publisher. Each puzzle consisted of 54 pieces (6 x 9). The dimensions of the completed puzzle were 42 x 45 centimeters. Both puzzles were recommended for children older than 5 years. In a pilot test, we determined that two six year olds could complete this size puzzle in fifteen minutes. Each puzzle came with a poster of the image, which we used as the underlay for the puzzle.

Graphical User Interface

The two graphical user interface (GUI) style puzzles were created using commercially available jigsaw puzzle creation software, "Jigs@w Puzzle 2", developed by TIBO software. Each puzzle was run on a laptop with Intel Core 2 Duo Processor, a 15.4" (39.1cm) wide-screen WXGA display, and equipped with a Microsoft wired optical mouse. The game interface occupies the full screen of the computer (see Figure 1). The puzzle pieces could be manipulated by using drag-and-drop manipulation, and each could be rotated by simultaneously right-clicking the mouse. Users could either show or hide a real size reference picture in the background. When pieces are correctly connected, they are connected permanently. Visual and audio feedback was provided by the software for correct matches. We found through the pilot study that the size of puzzle piece displayed on the laptop screen was smaller than the physical piece, and it affected participants' average completion time. We adjusted the total number of GUI puzzle pieces to be 42 pieces (6 x 7) to address this problem and ensure that the three implementations were of comparable difficulty.

Figure 1. GUI (left) and TUI (right) puzzles.

Tangible User Interface

The two TUI style puzzles were implemented on two identical, extensible tabletop prototypes designed specifically for this study (Figure 1). The puzzle pieces were two new versions of the traditional version. Input actions on puzzle pieces were captured using an infrared web camera embedded under the table. The ReacTIVision engine was used for fiducial marker recognition [13]. However, instead of marking each individual puzzle piece with a unique fiducial pattern, the markers were distributed along the edges of intersecting pieces. No one puzzle piece had an entire pattern. The system recognized user triggered events, which were when a correct connection between two or more pieces was made with the physical pieces. In response to these input events, a logic program, implemented with the Processing programming language, was used to control visual and audio feedback similar to the GUI feedback. The final prototype was a tangible interface to the physical jigsaw puzzle that embodied the properties and functions of both the PUI and GUI.

Measures
This study design facilitated the collection of several forms of quantitative and qualitative data. A pre-questionnaire was used to collect participants' demographic information, computer experience level, interest in jigsaw puzzles and preference on image themes. We recorded the total duration of a pair's puzzle play, the duration from start to finish of their first completion of the puzzle and the duration of subsequent plays if applicable. We recorded observational notes related to task time. For example, we recorded if one member of a pair quit before the other. We also counted the number of times pairs began and the number of times they completed the puzzle in the allotted 15 minutes. We took observational notes and video taped all sessions for later analysis. A post-questionnaire, based on a modified version of four subscales of the Intrinsic Motivation Inventory (IMI) [25], was given to the participants after each session. We used a rating scale based on the Smileyometer, which has been validated for collecting children's subjective ratings [21]. The scale uses a pictorial representation of five different smiley faces. We concluded the sessions with two additional open-ended questions related to participants' preferences during their experience with the puzzle.

Setting
The study took place at Science World at the Telus World of Science, Vancouver, Canada, during a three-week period. Science World is an interactive science museum where children and adults explore scientific concepts through a variety of hands-on activities. We set up our study in a partially enclosed lab space, which was relatively isolated and allowed for environmental control during the study. The lab was setup differently on different days depending on the three different experimental conditions. A child's size table (comparable to the TUI table) was used as a space for children to fill out questionnaires, and to set up the GUI and PUI style puzzles.

Participants
We recruited 132 children from the regular visitor population using posters in various locations and from ongoing Science World summer camp participants. The participants were recruited without any discrimination other than satisfying the age constraint (7-9 years old) and being fluent in English. Participants were arbitrarily grouped into pairs depending on recruiting sequence. Pairs were assigned to one of the three different interface styles without any preference. Children were recruited to do a "Puzzle Study" and did not know about the different interface styles before volunteering.

Procedure
The duration of each session for a single pair was 30 minutes. The participants were asked to begin with a pre-questionnaire, which was verbally administered to mitigate for variation in reading skills and ensure adequate comprehension of questions. Pairs of children were then shown the puzzle implementation and asked to solve a jigsaw puzzle together. Each pair was told they would have 15 minutes to play with the puzzle. They were told that they could stop playing the puzzle at any time and instead move to an area with benches, pillows and a collection of popular children's books (alternative activity). After 15 minutes, the children were asked to complete a post-questionnaire, which was also verbally administered. The session ended with a closing interview in which the children were asked about their impression of the puzzle and what they liked or disliked about it.

RESULTS
In our study, data was collected in a number of ways. We based the majority of our results on a statistical analysis of questionnaire responses (enjoyment), the time logs and counts of play time(s) (engagement). A thematic qualitative analysis of our observational notes and audio records were used to contextualize the quantitative findings.

Participant Profile
We recruited 132 children (69 boys and 63 girls). Pairings were 23 pairs of boy and boy groups, 20 pairs of girl and girl groups and 23 pairs of boy and girl groups. Most of children were fluent in English. Ninety percent of all participants had played jigsaw puzzle before, and all participants knew how to solve jigsaw puzzles. Sixty-four percent the children indicated they really liked to play jigsaw puzzles, 24% indicated that they somewhat liked to play them, and the other 12% indicated that they did not like to play jigsaw puzzles. All participants had used personal computers, and 92% of the children considered themselves to be good mouse users. Eighty-one percent of the children used a computer a few times a week at their home or school, and 64% indicated that they used the computer everyday. None of the children had solved the puzzles used in the study.

Quantitative Results
Enjoyment

For the four subscales of IMI questionnaire, "not at all true" was coded as one and "very true" was coded as five. Pair-based averages were used since responses are dependent. Descriptive statistics by interface style are shown in Table 1. The relationship between interface style and children's average responses on the four subscales of IMI were analyzed using Kruskal-Wallis tests since the response data was not normally distributed. No significant differences were found. Although the difference is not significant, the sum scores on the *Perceived Competence* subscale shows a slight trend (Figure 2). *Perceived Competence* scores were highest for the PUI condition and lowest for the TUI condition. Similarly, scores for *Perceived Choice* were highest for the PUI condition and lowest for the TUI condition. Inversely, scores for *Pressure and Tension* were lowest for the PUI condition and highest for the TUI condition.

Interface style		Interest Enjoyment	Perceived Competence	Perceived Choice	Pressure Tension (R)
PUI	Mean	4.25	4.5	4.25	1.88
	N	22	22	22	22
	SD	0.75	0.45	0.68	0.54
GUI	Mean	4.26	4.20	3.89	1.98
	N	21	21	21	21
	SD	0.96	0.91	1.01	0.81
TUI	Mean	4.32	4.13	3.87	2.28
	N	23	23	23	23
	SD	0.53	0.62	0.85	0.69

Table 1. Descriptive statistics for the IMI subscales.

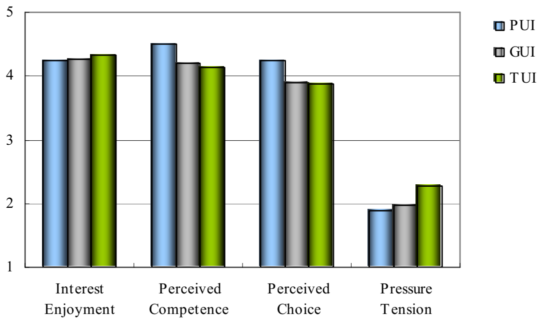

Figure 2 Means for the IMI subscales.

Aggregation across interface styles on the sum scored Interest and Enjoyment subscale showed that 48 of the 66 pairs (73%) found the puzzle highly interesting and enjoyable (pair mean >= 4.0) independent of interface style.

Engagement

Engagement was operationalized using five measures: total play time; time for first completion; time for second completion; number of starts; and number of completions. Descriptive statistics for play time and play count data are shown in Table 2. The time-log data revealed that on average total play time was longest for the GUI condition (13:20) and one minute less for the TUI and PUI conditions. However, 48% of the GUI players did not complete the puzzle even once within the total time of 15 minutes. Two of these GUI pairs quit before the 15 minute limit. Seventeen percent of the TUI players and 5% of the PUI players did not finish the puzzle within the 15 minute time limit. None of these pairs quit before the end time.

The relationship between the interface style and the time data was analyzed using Kruskal-Wallis tests since the data was not normally distributed. Results for first completion time showed a significant main effect at the $p<0.005$ level ($\chi^2(2)=11.50$; $p=0.003$). Figure 3 shows the relative amount of time pairs spent on the first and second play across interfaces. Post hoc analysis using the Mann-Whitney U test indicated that the average time spent on first puzzle completion was significantly shorter for the PUI condition than the GUI condition ($p<0.005$ level). The time for the TUI condition was also shorter than for the GUI conditions ($p<0.05$ level). Results for the time to subsequent play also showed a significant main effect at the $p<0.05$ level ($\chi^2(2)=7.60$; $p=0.022$).

Interface style		Total Play Time	Time to 1st Completion	Time to 2nd Completion	# of Starts	# of Complet.
PUI	Mean	12:24	0:10:32	6.13	1.36	1
	N	22	22	1	22	22
	SD	2.54	2.42	N/A	0.49	0.31
GUI	Mean	13:17	0:13:12	N/A	1.05	0.52
	N	21	21	0	21	21
	SD	2.24	2.21	N/A	0.22	0.51
TUI	Mean	12:22	0:11:31	6.35	1.13	0.91
	N	23	23	2	23	23
	SD	2.34	3.04	0.14	0.34	0.52

Table 2. Descriptive statistics for engagement data.

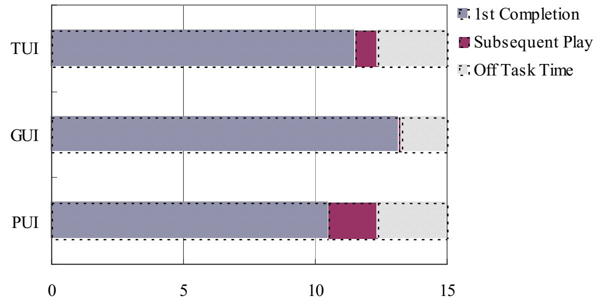

Figure 3. Play times for three interfaces.

The relationship between the interface style and the number of time pairs started over (i.e., repeat plays) was also analyzed using a Kruskal-Wallis test. The number of repeat plays was significantly different across the three interfaces at the $p<0.05$ level ($\chi^2(2)=7.72$; $p=0.021$). Mann-Whitney U tests indicated that repeat plays were significantly higher for PUI than GUI ($p<0.05$ level). The number of repeat plays on TUI was also higher than that on GUI but not significantly so.

Gender

Boys and girls interact differently with computer technology [12]. Since outcome measures may be dependent on gender pairings, we analyzed the relationship between gender pairings (boy-boy, girl-girl, girl-boy), interface style and IMI self reported measures. The results from the MANOVA tests on the *Interest and Enjoyment* and *Perceived Competence* subscales of the IMI indicated a significant interactional effect between gender pairings and interface style at the $p<0.001$ level as shown graphically in Figure 4.

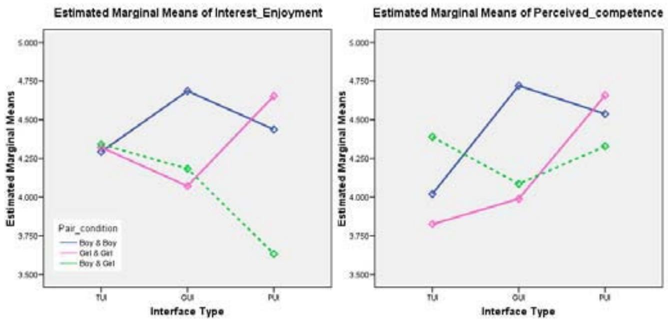

Figure 4. Estimated marginal means of Enjoyment (left) and Perceived Competence (right).

While all gender pairings' mean scores on the *Interest and Enjoyment* subscale were nearly the same for the TUI condition, the boy-boy pairs had significantly higher scores than the girl-girl and girl-boy pairs for the GUI condition. In addition, the girl-girl pair scores were significantly higher for the traditional PUI condition than for either of the computational conditions (GUI, TUI). For girl-girl pairs mean scores for *Perceived Competence* subscale were also higher for the PUI condition than for either of the GUI or TUI conditions. Mean scores for boy-boy pairs were highest for the GUI condition.

Qualitative Results

The qualitative analysis was based on thematic analysis of observational notes and digitized audio recordings of the two post-play open questions. Observations were grouped using four main themes, which were hypothesized to be important in children's tangible interaction: collaboration, physical manipulation, integrated representations (feedback) and spatial strategies [4].

Collaboration

We observed different collaboration strategies on the different interfaces. Over two-thirds of pairs solved TUI and PUI puzzles using parallel, independent play in which they seemed to be absorbed in their own activity but they still observed each other's actions and expressions and often copied them. For example, each child in the pair often concentrated on a different area of the puzzle. In some cases, their verbalizations revealed a conscious strategy to work cooperatively by dividing puzzles areas between them. "You do the top part and I'll do the bottom." Verbalization in parallel play also often concerned advising the other child where a piece should go. In some cases, children took a directive role where they gave verbal instructions to the other child. This often happened in a pair with an age difference (e.g., one child was 9 years old and the other was 7 years old).

We observed that pairs using the GUI system used a different collaboration strategy to solve puzzles (as expected). Despite the single mouse on the GUI puzzle, most pairs found a way to collaborate with each other. Over two thirds of the pairs took sequential turns during their play. This was common in pairs where one child took a dominant or directive role. In these cases, the other child often found other ways to collaborate, such as pointing at the screen or giving verbal suggestions to his/her partner.

We observed that two-third of the pairs worked primarily silently while solving their puzzles. Verbal communication between these pairs tended to concern their task progress. The other one-third demonstrated more verbalizations. These pairs often talked through the whole session. Many gave verbal instructions and pointing instructions (deictic gestures) to their partner during the play. Frequent verbal interactions included arguing about piece position, pointing out wrong pieces or searching for a certain piece and were observed among all the conditions.

Physical Manipulation

We observed that some children had difficulty rotating GUI based pieces. Rotation required a child to simultaneously hold down one mouse button while clicking the other. We observed that over half of the boys preferred using touch-pad rather than using mouse on the GUI system, effectively moving to a more direct style of interaction.

Observational analysis revealed that children were much more active in terms of body movement in both PUI and TUI conditions. For example, some children moved themselves around the table rather than moving the puzzle pieces. Some children made the puzzle in an upside-down direction (Figure 5). This form of perspective taking was not possible in the single access GUI condition.

Figure 5. Perspective taking (L); Image matching patches (R).

Integrated Representation: Reference Picture

In all three conditions we provided the option to build the puzzle on top of the displayed puzzle image. In the PUI and TUI conditions, this meant that the reference picture occupied an integrated input and output space (i.e., puzzle pieces lay on top of display). In the GUI condition the picture was displayed in the output space (i.e., the screen) separated from the input space (i.e., the mouse). Most pairs in all conditions built the puzzle on top of the image during the first attempt to solve the puzzle. Only two out of twelve pairs who completed the puzzle a second time chose to do so without the help of the reference picture. It was evident that children preferred image matching rather than color or shape matching (Figure 5). However, we saw no perceivable benefit to having the input and output spaces integrated in space.

Spatial Strategies

We assumed that most children would start building their puzzle from its corner or frame part. However, in an analysis of the chronology of play sessions we observed that children often began to play by randomly picking up a puzzle piece and matching it to the reference image. They continued to build from this first piece, creating a patch, which was later joined to other patches (Figure 5). We observed this strategy in about one third of the pairs in the PUI and TUI conditions. This was related to their parallel, independent play style of collaboration. We did not observe this in the GUI condition. In general, only 15% of pairs started to solve a puzzle by working from the edge or frame. Of these, most pairs included a child who had indicated that they often played puzzles at home.

Preference

Most participants commented that the puzzles were fun and enjoyable. They also liked the illustration style and the themes of the puzzles. Thematic analysis of the preference comments resulted in the identification of three other common themes: challenge versus task achievability; reference picture assistance; and help through collaboration.

Children commented that the puzzle was challenging but that they liked it because they could finish it within the allocated length of time. Some children commented that they were concerned about how much time they had already spent and how much time they still left for solving the puzzle in the progress of play. This finding is in line with guidelines proposed by Salen and Zimmerman [27], which state that an enjoyable game balances challenge against possibility of winning. It is possible that two thirds of the pairs rated all puzzles as enjoyable because the puzzles contained right balance between challenge and achievability regardless of interface style. Children also commented that they liked getting help during play from either the reference pictures or their partner (collaboration). This result was consistent with our observations on their collaborations and use of the reference picture.

Some children indicated that they did not like it when the picture underlying the puzzle was turned off (perhaps by their partner). A few children mentioned that they disliked feeling pressured due to the time limitation. This comment was more frequent from the pairs in the GUI condition. Some children complained that there were too many pieces in GUI puzzles (which had fewer pieces than the TUI or PUI puzzles).

DESIGN IMPLICATIONS

Based on the findings of this study we see several implications for design of tangibles for children. First, collaboration style was related to input design. The multiple access points afforded by a tabletop game (tangible and traditional) combined with enough space to move supported parallel independent play rather than sequential turn taking. Second, there does seem to be a benefit to physical manipulation of objects on a tabletop space. We observed evidence of moving the body to engage in perspective taking. Direct interaction with pieces was reported as easier and less frustrating for children than indirect interaction using a mouse or touchpad. Third, the value of integrated representations depended on the cognitive strategies being used in problem solving. For a jigsaw puzzle, children preferred a visual strategy (picture matching) to a spatial one (shape matching) and so the display of the reference picture was important. It is unclear if there was a benefit to having the picture integrated with the input space. Fourth, the gap between girls and boys comfort levels with computers was not automatically bridged by using tangibles based on familiar objects.

There are several limitations of the study. First, a more controlled comparison would involve a comparable display size for the GUI condition. The operationalization of engagement for children remains problematic. Task time may more accurately measure cognitive difficulty than engagement in problem solving games. Multiple measures are needed. While we suggest that dual-cursor technology should be included for control purposes, doing so might reduce ecological validity since dual mouse computer applications are rare. Future studies should involve other forms of games.

SUMMARY

Our comparison of physical, graphical and tangible user interfaces to a jigsaw puzzle game allowed us to elicit and reflect on fundamental differences related to children's enjoyment and engagement between three different interface styles. We found that children's self-reports of enjoyment were similar for all three interface styles. We found that children took longer and had more difficulty completing puzzles in the GUI condition. From our observations and interview responses we suggest that the GUI task took longer due to single user access and the difficulties imposed by using an indirect interaction mode constrained to a 2D space. Repeat play was used as an alternative indication of engagement. Significantly more pairs in the PUI and TUI conditions engaged in repeat play, starting the puzzle a second time. The interrelationship between task difficultly and task engagement is again highlighted in this result. We also found significant gender effects as well as evidence to support the benefit of tangible tabletop designs for collaborative problem solving activities. In summary, this study contributes knowledge as one of the first empirical studies comparing traditional (physical), graphical and tangible user interfaces to interactive play environments for school age children.

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