PuzzleTale:
A Tangible Puzzle Game for Interactive Storytelling

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ABSTRACT
We describe the design and development of PuzzleTale, an interactive storytelling system that makes use of tangible puzzle pieces on the surface of an interactive table. In the PuzzleTale system, assembling the tangible puzzle piece can affect the digital characters and create a flexible story context. Different assembled patterns represent the diverse ways that users explore and compose the story.

The PuzzleTale system creates a dynamic causal relationship between the process of interactive storytelling and the outcome of a story. There are two variables which continuously affect the story context including the amount and the sequence of digital characters that the reader plays. The system engages the reader participating in the development of the story through playing tangible puzzle pieces with digital characters as a decision making tool, thus providing individualized storytelling experiences.

Categories and Subject Descriptors
H.5.1. [Information Interfaces and Presentation]: Multimedia Information Systems---*Animations*; H.5.2. [Information Interfaces and Presentation]: User Interfaces---*Input devices and strategies, Interaction styles*; H.5.3. [Information Interfaces and Presentation]: Group and Organization Interfaces---*Collaborative computing.*

General Terms
Design, Human Factors

Keywords
Interactive storytelling, tangible interface, puzzle piece, interaction design.

1. INTRODUCTION
Physical puzzles are powerful tools for training logic and organization. During the process of solving puzzles, users not only manipulate physical objects to build spatial relations, but also develop cognitive skills for applying virtual information. In other words, puzzle games provide a channel to understand virtual information embedded in physical objects. Through tactile interaction, a strong relationship between the physical and virtual worlds can be built.

The jigsaw puzzle is one type of physical puzzle that engages us in the construction or discovery of an image. As such, solving jigsaw puzzles involves both a process (the assembly of pieces) and an outcome (the completion of a visual image). When we tell stories, we engage in another kind of activity that also involves both process and outcome. The storytelling process creates a causal chain of events that generally lead to some conclusion. In doing this, storytelling organizes characters, events and settings into a narrative structure. In thinking about puzzle solving and storytelling in terms of process and outcome, we became interested in exploring how tangible puzzles could be used as an interface for interactive storytelling. What would happen if each puzzle piece became a piece of the story? How might a digital story unfold as the puzzle pieces are assembled? And how would the process of assembly affect the outcome of the story?

We explore these questions through the design and development of PuzzleTale, an interactive storytelling system that makes use of tangible puzzle pieces on the surface of an interactive table. By projecting digital content onto the pieces of the tangible puzzle as they are assembled, we have turned puzzle solving into a storytelling activity. At the same time, our puzzle interface can be assembled in many different ways, and has thus enabled an interactive story structure that encompasses multiple different story paths and conclusions.

2. BACKGROUND AND RELATED WORK
With the rise of personal computing in the late 20th century, artists and researchers began to explore computational approaches for creating interactive story experiences, building on the non-linear structures and experimental storytelling forms that had emerged in older media. The framework of interactive storytelling is different from the conventional linear story. A linear story follows a track from start to finish in the most powerful and expeditious manner possible. In contrast, interactive storytelling focuses on providing diverse dramatic possibilities, perspectives or outcomes. The approaches to this have varied across different works. For example, Chris Crawford defines interactive storytelling as "a form of interactive entertainment in which the player plays the role of the protagonist in a dramatically rich

environment." [2] Early attempts to understand interactive storytelling may be traced back to the 1970s, with Roger Schank's research in artificial intelligence and cognitive psychology [13]. Schank stated that memory takes the form of meaningful stories and that problem solving progresses by using different cases or examples stored in memory. During the 1990s, a number of research projects on interactive storytelling began to appear, such as the Oz Project [8] led by Dr. Joseph Bates at Carnegie-Mellon University, the Improv Project [11] led by Ken Perlin at New York University, and the Virtual Theater group at Stanford, led by Dr. Barbara Hayes-Roth [4]. The first published interactive storytelling software that was widely recognized as "the real thing" was Façade, created by Michael Mateas and Andrew Stern, released in 2003 [9]. Incorporating elements of both video gaming and drama, Façade took advantage of voice acting and a 3-D environment, as well as natural language processing and other advanced artificial intelligence routines, to provide a robust interactive storytelling experience.

Furthermore, combining interactive storytelling with the tangible user interface (TUI) [5] is a powerful way to supply the storytelling process with affordances and intuition. Many tangible storytelling systems have focused on children's storytelling, since physical props (figurines, blocks, etc.) are an important part of the fantasy and story-based play activities that children engage in. A number of projects in this area have used digital technologies to link children's stories to physical toys. For example, StoryMat [12] offered a child-driven play space by recording and recalling children's own narrating voices and the movements their toys made on a large embroidered cotton mat. On StoryMat, a child could easily take over a story to add an alternative ending. The TellTale system used a modular toy to support children's oral storytelling. Children could record and reconfigure their own stories by re-arranging the physical segments of the toy [1]. In Picture This [14], a camera and gesture sensors were embedded in children’s toys for video composition. It functioned as a video and storytelling performance system in that children could craft videos with and about character toys as the system analyzed their gestures and play patterns. Children's favorite props alternated between characters and cameramen in a film. As they played with the toys to act out a story, they conducted film assembly. The similar method appears in the CENTORO [6] system. Children could make a robot play their story in the real world augmented with mobile projected graphical images.

There are some projects which are not just for children but for all ages. It means those projects may contain more complex information or manipulation skills during the interaction process. The users need more cognitive abilities to organize the complex story information. The Triangles system [3] was a physical/digital construction kit which allowed users to use two hands to grasp and manipulate complex digital information. It provided a physical embodiment of digital information topography. Unlike the previous examples, the individual tiles had a simple geometric form which did not inherit the semantics of everyday physical objects. The Tangible Viewpoints [15] presented a multimedia storytelling system that coupled a tangible interface with a multiple viewpoint approach to interactive narratives. The narrative structure used in Tangible Viewpoints supported character-driven stories. That was, different characters with distinct personalities and unique points-of-view were used as the primary basis for creating the narrative. The characters in those two projects are more abstract in shape but carry diverse information. Therefore, through delicate manipulation and deployment, the users can conduct the development of the story in abundant ways.

Through these projects, we discovered that tangible objects such as toys or physical objects that become part of a story are important to the cognition of the story plot. Tangible objects can thus help users build the connection between the real world and the story world. By manipulating tangible objects, users could immediately engage in storytelling or role-playing, and didn’t need too much preliminary training or learning. In addition, the tangible objects also played an important role in detecting and recording users’ intentions during the storytelling process. The development of the narrative could change dynamically based on the diverse methods, positions, and orders in which the children manipulated the tangible story objects. Therefore, the storytelling process through tangible objects suggested that the inter-relationship between individual digital contents could be used to develop multiple story contexts.

3. THE PUZZLETALE SYSTEM

3.1 Multiple-Track Storytelling Approach

We propose an easier approach for creating novel interactive storytelling with dynamic story contexts called multiple-track storytelling. In our story, there is one leading character and several supporting characters distributed on the tabletop. We define the story scenes that will be formed when the leading character meets the supporting characters. For example, in Fig 1, there are three supporting characters (A, B, C) and one leading character (LC), but the relationship between them is not fixed. The leading character can choose to meet the supporting characters in different sequences such as ABC or BCA. The meeting sequence will affect characters’ relationships and thereby change the story ending. In addition, the amount of supporting characters that the leading character meets is variable as well. For example, meeting AB without C would cause a different ending. In other words, the story reader can arrange the relationship between characters in different sequences and amounts during the interactive storytelling process. We call this flexible story structure multiple-track storytelling (Figure 1).

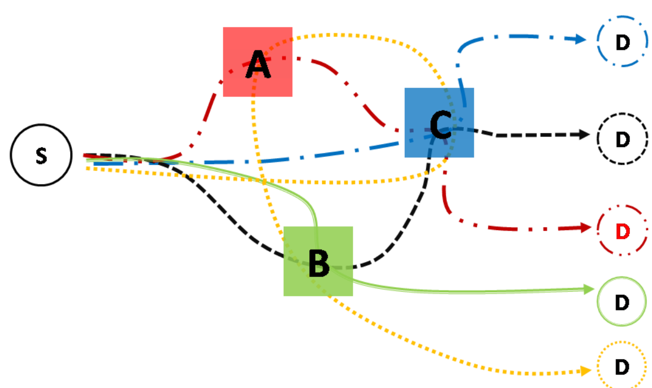

Figure 1. Multiple-track storytelling.

An interesting novelty of this interactive storytelling method is that the story components are fixed but the story context is flexible. We just use the concept of permutation to “re-arrange” the story characters, and this simple action makes diverse story endings possible. Furthermore, depending on the number of scenes, the number of story endings is predictable. The story designer can pre-make the story endings which correspond to all possibilities of story readers’ interactions. For example, if we define three supporting characters (A, B, C) in a story, we can calculate that the number of possible endings is sixteen (Figure 2).

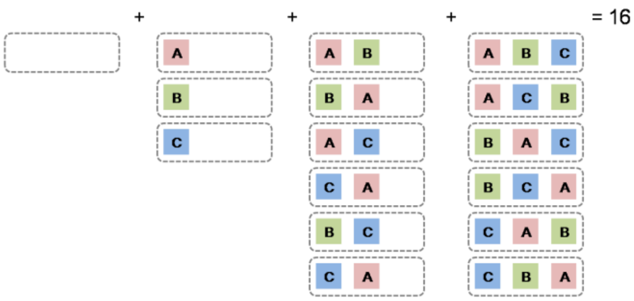

Figure 2. Sixteen endings based on three supporting characters.

According to the approach of multiple-track storytelling, the story context becomes a dynamic causality and results in multiple corresponding outcomes. The story readers re-arrange characters’ relationships to compose particular stories in terms of their personal preferences or expectations. The interactive storytelling process becomes a decision making process. Every choice from readers leads to the different story ending that we provide, and the causality is dynamic and continuous until the interaction process really comes to the end. The multiple-track storytelling approach thus provides a different convention for experiencing stories. Readers are involved in the story making process and have the power to affect the story ending.

In addition, the critical key of achieving multiple-track storytelling is the manipulation of the digital characters. In the story, the characters are virtual/digital and not directly linked to our physical senses. Yet in order to navigate the multiple-track story, the readers need to have a direct physical handle on the characters in order to compose their relationships. The PuzzleTale system provides a tangible jigsaw puzzle inspired interface to embody the digital characters in the physical world. We attach the digital characters to tangible pieces so that readers can manipulate them with their tactile sense. The tangible objects are a part of the story and provide an ideal channel for readers to link their cognition with storytelling process. We introduce how the PuzzleTale system works in the next section.

3.2 Physical Design

The PuzzleTale system allows users to interact with story characters via tangible puzzle pieces and compose a causal story ending on the table. The PuzzleTale system includes three layers: the digital content, the tangible interface, and the image recognition (Figure 3). The top and bottom layers are used to support the interaction occurring on the middle layer. The bottom layer detects the movement of tangible puzzle pieces and reports it to the top layer, which projects instant graphical images both on the puzzle pieces’ and table’s surface according to the movement report.

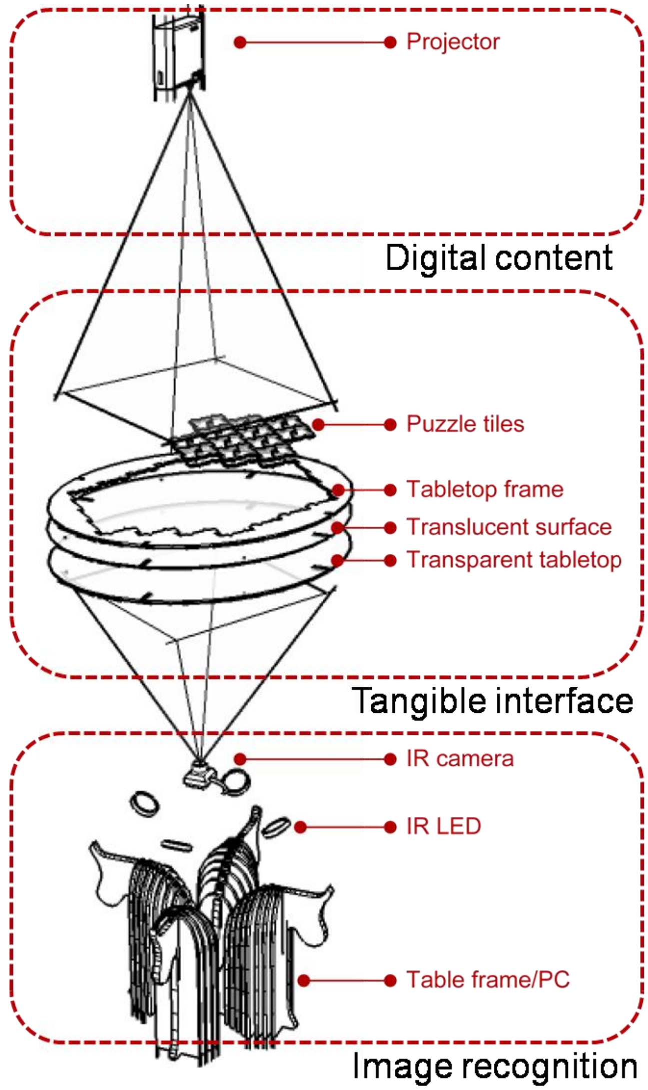

Figure 3. Three layers of the PuzzleTale system.

3.2.1 The tabletop interface

The middle layer including the tangible puzzle pieces and the table surface supports the interactive storytelling. The table surface is stacked with three oval-shaped sheets. The base sheet for carrying the weight of the other two sheets is hollow in the center to allow the IR camera to see through. The middle sheet is translucent and acts as a platform on which the tangible puzzle pieces can be placed and onto which are projected the digital contents of the story. In addition, according to its translucent characteristic, the visible light of the projections won’t go through this surface, and it thus acts as a filter to ensure the IR camera will detect only the fiducial markers that are attached to the base of the tangible puzzle pieces. The top sheet is made from plywood and is also hollow. It acts as a frame to constrain the tangible puzzle pieces which are assembled inside it.

3.2.2 Tangible puzzles pieces

We designed 28 identical dog-shaped puzzle pieces as the tangible objects. The shape of puzzle pieces provides a physical constraint which hints to the user how to assemble them in a particular direction. In addition, the inner frame of top table sheet is also cut with the shape of the assembled puzzle pieces. Therefore, the puzzle pieces can be arranged on the table surface according to their shape and to the constraint of the table frame (Figure 4). The consistent shape of puzzle pieces and table frame suggest to the user a reasonable and thoughtful way to deploy puzzle pieces one by one without stepping beyond the boundary or messing up the interactive process.

Figure 4. The dog-shaped puzzle pieces and the tabletop design.

Each tangible puzzle piece consists of three parts: the digital content, the physical board, and the fiducial tag (Figure 5). The digital content, such as an image or animation, is projected from the top projector onto the physical board. The digital content can move along with the movement of the physical board based on the tracking system under the table. There is a tag attached to the base of the physical board so that the system can track its position and movements.

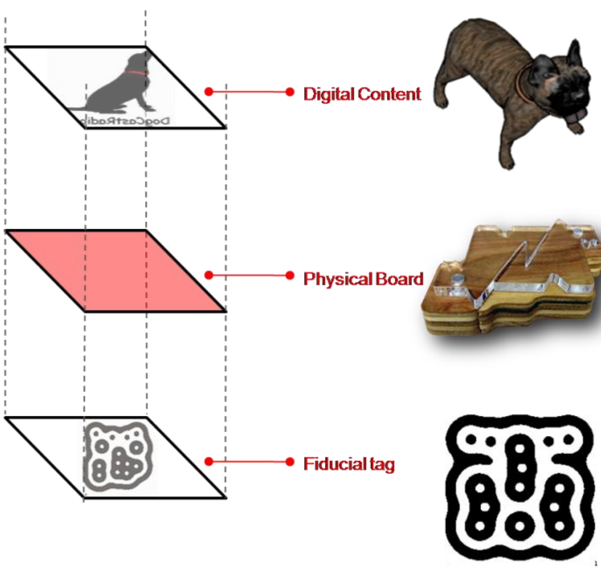

Figure 5. Each puzzle piece consists of three parts.

We make use of the TUIO technology and fiducial tags developed by Martin Kaltenbrunner [7]. The fiducial tags attached to the base of each physical board are recognized and tracked by an IR camera under the table (Figure 6). Each fiducial tag has a different pattern to provide an individual ID. By tracking this pattern, the PuzzleTale system can record the instant position of each puzzle piece and synchronize the movement of the digital content projected on top.

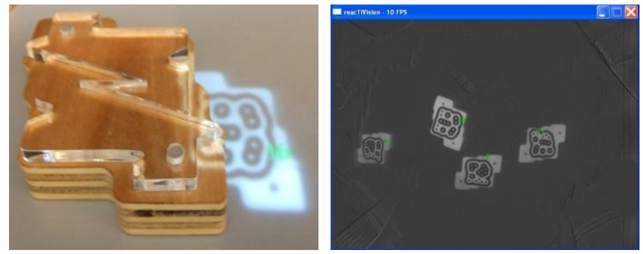

Figure 6. The IR camera identifies the fiducial tag.

3.2.3 Object tracking and data processing

During the interaction process, the PuzzleTale system records data related to the tangible puzzle pieces through image recognition of the IR camera's video stream. The fiducial tag attached under each puzzle piece provides the data of ID, instant position, and sequence. This collected data is used for composing the interactive story. As the tangible puzzles are assembled piece by piece, the sequence is documented. The same assembly pattern but different sequences are treated as different outcomes (Figure 7). Therefore, every step that the readers take will be tracked and continuously affect the story context until the end.

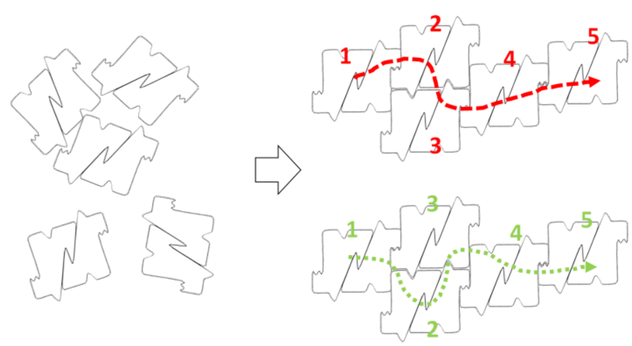

Figure 7. The same pattern but different sequences represent different outcomes.

3.3 Example Story Application

The PuzzleTale system was developed as a platform for experiencing interactive multiple-track storytelling. We designed a story with four characters to implement the concept of the flexible story structure. The four characters include one leading character-the male dog, and three supporting characters-the dog catcher, the female dog, and the old couple (Figure 8). In the beginning of the story, three digital supporting characters are randomly projected around the tabletop surface. The leading character is projected and attached on the initial tangible puzzle. Although all characters' positions are fixed in the beginning, the leading character's position is moveable through assembling other tangible puzzle pieces as jump boards.

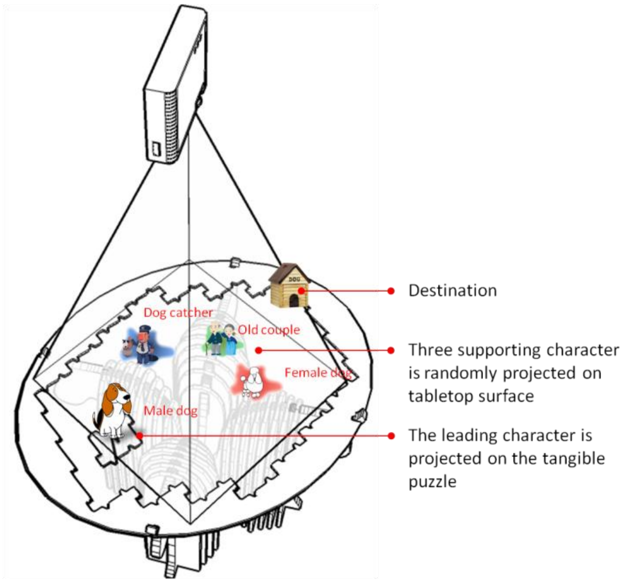

Figure 8. The position of the four characters at the beginning of the story interaction.

When the next tangible puzzle piece is assembleed with the original tangible puzzle piece in the right angle, the leading character will jump from the orginal one to the next one. Through iterative steps, the reader can guide the leading character to any position around the tabletop surface. During the interaction process, if the leading character encounters other supporting characters prjected on the surface, the story context will be dynamically changed.

There are two variables that affect the final story ending. The first variable is how many supporting characters the leading character meets. Choosing different amounts of supporting characters during the interaction process, even choosing none, will relate to the final story ending. The second variable is the sequence of choice. Different sequences will also affect the story context dynamically. Therefore, every decision that the reader makes will continuously change those two variables. Once the leading character reaches the destination, the story context is really fixed and the story ending is presented based on the final variable. The story ending that we pre-made displays on the table surface to show the reader the consequences and final outcome according to his/her decision making during the interaction process.

After one time interaction, the reader can easily reset the story and play it again with different choices in order to see another story ending. With three supporting characters, the permutation and combination of scenes adds up to 16 different story endings (Figure 9).

Figure 9. There are sixteen different story endings.

3.4 User Interaction

The PuzzleTale system uses tangible puzzle pieces as the interactive tools for the reader to play with our multiple-track storytelling system. The task in this interactive story is to lead the male dog home (destination). Every time the interactive story begins, three supporting characters are randomly placed around the pool. The leading character is projected on the left-down initial position waiting to be triggered. The target icon (destination) is projected on the right-up side to present the final goal. There are 28 tangible puzzle pieces including 1 white piece and 27 brown pieces. The reader needs to place the white puzzle piece on the initial position in order to trigger the story. The brown tangible puzzle pieces can then be used for track making. As the reader places the first brown tangible puzzle piece against the white one, it will attract the male dog to jump on it. The reader keeps assembling other tangible puzzle pieces in sequence to make a track. The male dog follows the track step by step to reach where the reader wants him to go. During the interaction process, the reader can decide whether the male dog meets other supporting characters.

Finally, the reader guides the male dog to reach the destination and the story ending will display on the whole tabletop. The story ending is derived from two variables including how many times the male dog encountered the other characters and in what sequence the male dog met them. If the reader wants to try again to see other possible endings, he/she needs to remove all tangible puzzle pieces from the pool first, and then put the white tangible puzzle piece into the resetting point which pops up along with the story ending image. After the reader resets the story, the story will go back to the initial status, and the reader can play it again following the same steps (Figure 10).

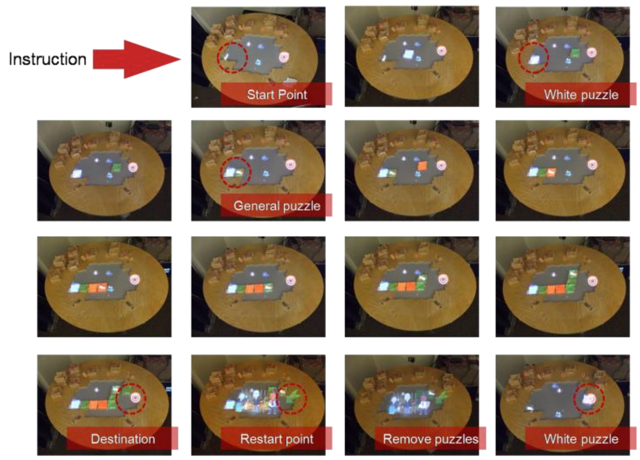

Figure 10. The PuzzleTale system interaction process.

4. EVALUATION

We conducted both quantitative and qualitative evaluations of the PuzzleTale system. The two evaluations have different analytic goals. Through quantitative analysis, we collected statistical data to understand the usability of the PuzzleTale system. Through qualitative analysis, we tried to learn if the approach of combining a puzzle interface with an interactive story can provide a fun and engaging story experience.

We recruited 10 subjects from the student population at Georgia Tech. The subjects had diverse backgrounds, including 3 subjects from the Human-Computer Interaction program, 3 subjects from the School of Industrial and Systems Engineering, 3 subjects from the School of Electrical and Computer Engineering, and 1 subject from the Digital Media program.

Figure 11. One subject is interacting with the PuzzleTale system to guide the main actor home.

Before subjects started the interaction, we gave them some brief instructions about how the PuzzleTale system works. Then we asked subjects to practice some minor tasks to familiarize themselves with the PuzzleTale system. For example, we asked them to use the tangible puzzle pieces to lead the main actor, or to try to arrange some different tracks to meet the minor actors. After they finished the minor task, we gave them the main task. Each subject was given 28 tangible puzzle pieces, and asked to guide the main actor to arrive at the destination (Figure 11). During the process, the subjects could do anything they wanted to interact with the PuzzleTale system. For example, they could just play with the main actor or they could try to meet the other minor actors. In addition, the PuzzleTale system is resettable and subjects could play again and again until they were satisfied. After playing through the interactive story as many times as they liked, we asked the subjects to complete a questionnaire for both quantitative and qualitative data collection.

4.1 Quantitative Analysis

The goal of the quantitative analysis was to estimate the usability of PuzzleTale system. We use six criteria which are developed by NASA-TLX for the usability study. NASA-TLX [1] is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. These subscales include Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration. It can be used to assess workload in various human-machine environments. We set up five scales from low to high for each criterion and ask subjects to grade it. We designed the radar diagram with those six criteria to present the results (Figure 12).

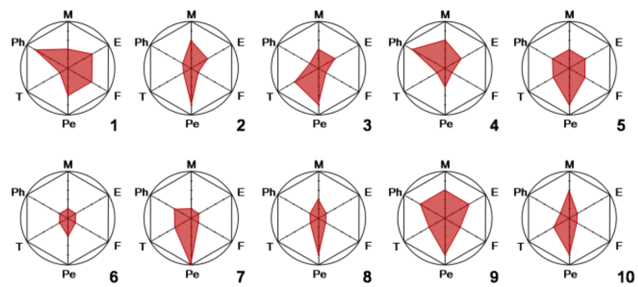

Figure 12. The quantitative analysis results with 10 subjects.

Through the 10 radar diagrams, we found that each subject had a quite diverse and individual experience of the usability of the PuzzleTale system. This may be a result of their different backgrounds and disciplines. However, comparing with the ideal model (Figure 13 Right), the average model of ten subjects (Figure 14 Left) is similar to it. It means that although subjects have individual differences in some criteria, the synthetic performance of the PuzzleTale system is still proximate to the ideal value. In other words, the usability of the PuzzleTale system has low Mental Demands, low Physical Demands, low Temporal Demands, high Own Performance, low Effort and low Frustration.

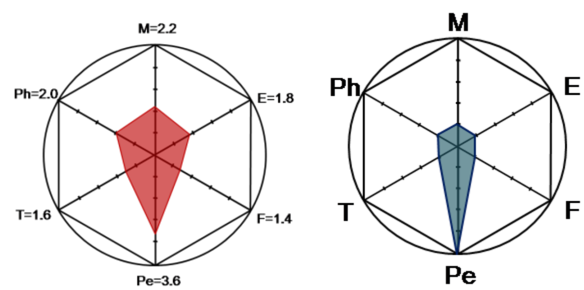

Figure 13. Left- Average model of 10 subjects, Right- Ideal model of NASA-TLX.

4.2 Qualitative Analysis

Through the qualitative evaluation, we wanted to understand whether the PuzzleTale system provides a playful and engaging form of interactive storytelling for users, and to gather feedback about our approach of combining a puzzle interface with interactive stories.

4.2.1 Instant feedback during the interaction

Subjects wanted more feedback about the state of the PuzzleTale system. Some subjects complained that there was no response while the main actor was meeting with minor actors. The system didn't provide enough feedback to suggest whether the meeting events were triggered or not. In addition, subjects also suggested that even if the main actor didn't yet meet any minor actors, there still needed to be some sounds or animations to encourage users to keep going. It was clear that subjects cared about the working process of the PuzzleTale system and that we need to make the system state more clearly visible in order to support smoother interaction.

4.2.2 The tangible puzzle pieces become pieces of the story

In the PuzzleTale system, the tangible puzzle pieces were not only the tools for interaction, but also acted as pieces of the story. The digital content projected on the surface of each tangible puzzle piece was the portal into the story world and helped subjects to think how they could compose the story by arranging those story elements. For example, some subjects said that they enjoyed having the power to control the story script by guiding the main actor, and they found that arranging puzzle pieces was an intriguing way to do this. They liked the fact that they could explore the story freely and didn't need to follow a predefined script anymore. On the contrary, they could unfold the story as desired based on the arrangement of the tangible puzzles. Since the story pieces were embodied in a physical form as puzzle pieces, users felt a close and concrete connection to the storytelling process and to the actual structure of the story itself. For example, through successive interactions subjects gained a clearer understanding of how the script would progress and of the alternatives in the storytelling process because they were controlling the story elements. The tangible puzzle pieces became like avatars for the subjects, allowing them to participate in the story development.

4.2.3 The interactive decision making process makes the story more engaging and richer

We observed that most of the subjects played with the PuzzleTale system at least 3 times or more. Each time they played through the story, they tried a new way of arranging their tangible puzzle pieces. Subjects claimed that they wanted to meet the minor actors in different combinations and sequences to see if the story ending would be different. For example, at first time if the sequence involved meeting first the dog catcher and then the old couple, the next time they would try to meeting the same minor actors in reverse to see if the result would be different. In addition, subjects were also interested in exploring all possible story endings. They were attracted by the dynamic story endings that came up according to their different choices. This demonstrates that the novel storytelling method of the PuzzleTale system can enrich the puzzle and story interaction and can inspire users to explore the possible processes and outcomes.

Overall, the PuzzleTale system demonstrated a promising new direction for storytelling by using tangible puzzle pieces as an interface for exploring an interactive story. Most important, the physicality of the story seemed critical to all subjects. The tangible puzzle pieces combined with the digital contents gave users the sense of being involved in the story making process.

5. FUTURE WORK

After the qualitative evaluation, some of the comments received from users can be used to improve the system immediately. Most of the users suggested that the system needs to provide some feedback while the male dog is meeting one of the minor actors. It is a practical suggestion because instant feedback such as sound or animation would help to get the users' attention and provide them with better awareness of what they have done.

We also consider the extensibility of the story. In the current story, the number of story endings depends on the number of story scenes involving minor actors. We can extend the story to have more endings by increasing the number of minor actors. In this version, we implemented three minor actors and got 16 different story endings. In the future, we plan to add more minor actors to create a greater variety of choices and story endings. Furthermore, in considering how to improve the flexibility of the story structure, we plan to make the minor actors alternate and be replaceable. For example, at the beginning of the story, the user could select their favorite minor actors and drag them into the stage. The PuzzleTale system could then instantly calculate the possible story endings to match what the user's choice. In that way the interaction would occur not only during the process of story reading, but also in a prior phase of story editing.

In addition, a storytelling application between two or more tables could create the collaborative interaction among larger groups of users. Currently, the PuzzleTale system is designed for small groups of users at one table only. In the future, we would like to develop an online PuzzleTale system for multiple remote users. Through the online PuzzleTale system, remote users could co-edit a common story which could be played across remote tables; this way, they could share in and coordinate the interaction process to gain a collective experience.

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