Developing Transmedia Puzzle Play to Facilitate Spatial Skills of Preschoolers

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Abstract
This proposed project aims to develop a research-driven interactive product that facilitates spatial skills of preschoolers. Here, we present the preliminary qualitative results of a user study with the paper prototype of *Fungram*, merging physical tangram pieces on the screen within a narrative context. A pilot study was conducted with eight children between the ages of 25 and 48 months, who were presented tangible tangram pieces along with two sets of papers with and without narrative context. Our preliminary qualitative data indicates that narrative context helps children's coherence of abstract figures and triggers rotation of geometric tangram pieces. This study provide insights about children's user needs and action strategies within the proposed use scenario with graspable puzzle pieces related to screen interaction at this age range. We suggest that transmedia play expand opportunities for children to employ their spatial skills in different settings.

Author Keywords
Spatial learning; spatial manipulatives; transmedia play; preschool children; child-centered design; physical-digital interaction.

ACM Classification Keywords
H.5.2 [User Interfaces]: User-centered design, Prototyping. K.3.1 [Computers and Education]: Computer-assisted instruction, Collaborative learning.

1. Introduction
A wide range of research indicates that digital applications promote children's engagement as a playful learning experience only if age-appropriate content and design strategies are implemented suitably [4,8]. We put particular emphasis on young children's spatial skills because recent studies show close relationship between spatial experiences with blocks, puzzles, and shapes at very early ages and longitudinal success in STEM (scientific, technical, engineering and mathematical) disciplines [11,12]. Studies show that young children benefit from e-books or apps more if they use them interacting with other media such as printed books [13], tangible toys or regular home artifacts, expanding learning experience with transmedia practices in a dynamic narrative [5]. Intermediality also supports constructivist learning goals that emphasize the active role of learner involving exploration and experimentation while making connections among information in specific context [3]. We suggest that transmedia activities interacted with or independent from digital affordances would encourage young children to make connections among various settings to engage their spatial skills.

Hereby, we base our design process on a set of findings on spatial learning, the impact of play and narrative on learning process, and how digital technology affordances can scaffold the content design. Children who play with more puzzles between 2 and 4 years of age have better spatial transformation abilities than their peers when they are 4.5-years-old [7]. The input given in the form of narrative provides effective context for teaching spatial content in block building activity [1, 2], and even helps younger children to comprehend more complex prepositions (i.e. under) better [9]. By means of transmedia, the interaction qualities of the narrative space are enriched as the possibility of playfulness of the content is augmented [3]. Thus, we seek ways to combine physical spatial puzzle play within narrative context utilized by digital technology.

We follow a child-centered design process of 5 steps; 1) discovery of cognitive research output suggesting possible ways of training spatial skills at early ages as an input for our content design; 2) interpretation of format design bringing tangible spatial manipulatives merge with touch-screen in a narrative context; 3) ideation of materials and tools that would provide opportunity for the generated idea and explore the possible needs of the target users through preliminary prototypes; 4) experimentation for building the interaction and information architecture required for the content design; 5) evolution of the output by tracking learning and implications. In this current study we present the first three phases, which is derived, in part, from transmedia format design and conducted a pilot study to reinterpret our idea generation.

We chose to use tangram due to various reasons: 1. it is an overlooked spatial puzzle especially for this target age group; 2. it consists of 5 geometrical shapes among 7 pieces (2 identical large, 1 middle, 2 identical small-sized right-angled triangles, 1 square, and 1 parallelogram) enable rotation action; 3. it is suitable to create several configurations of figures to be integrated within a narrative context; 4. flat shapes would allow

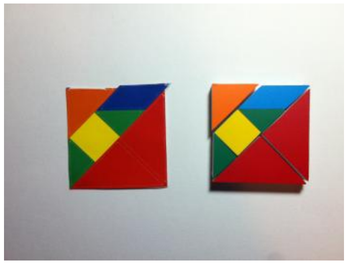


Figure 1. On the left the stickers used for making the figures on papers, on the right the tangible tangram set.

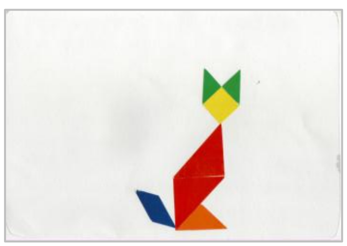


Figure 2. A sample of picture presented without a narrative context in the first set.

image processing for each pieces through either color or surface detection integrating OpenCV and mountain camera in the further experimentation phase of our design process.

2. Related Work

There are a few products combining traditional toys that stimulate children's spatial skills such as lego, wooden bricks, tangram pieces on touch-screen. TICLE by Lori Scarlatos (1999) is one of the earliest tangible interfaces designed for children providing multimedia guidance. In this one, physical tangram pieces are used on a projected desktop, using spatiality and connectedness and the physical pieces were represented on a computer screen [10]. *Tangram for Osmo* by Tangible Play Inc. (2014) targets children older than 7 years old and this app enables tangible tangram puzzles match on-screen shapes, however not involve narrative. Recently launched *Magik Play* designed by Magikbee (2015) claims to merge traditional wooden toys with iPad, promoting motor skills, spatial reasoning, and collaboration via dynamic narrative, however not being reviewed yet. Still, none of the products target very young children (e.g. 2-year-olds), which is a critical age for spatial learning [7].

3. Method and Procedure

In line with these background research findings, we investigate 3 main research questions to understand children's action strategy in grasping tangram puzzles in order to interpret further step of interaction design: (1) Can young children recognize abstract tangram figures? (2) Even if they do not recognize the figure, to match the related pieces with the shapes would they follow color cues or shape cues as an action strategy? (3) Would encountering the abstract tangram figures in narrative context affect young children's rotation actions?

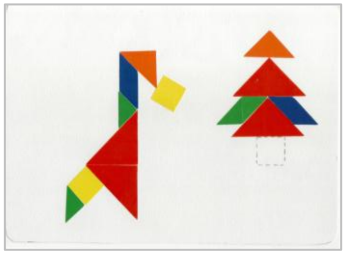
3.1 Participants

We tested 8 children (5 females) between the ages of 25 and 48 months old, with a mean age of 35 months. All children were native Turkish speakers without any developmental disorders. None of them had played tangram prior to this experiment. Each child was tested individually and each experiment took about 15 minutes. Audio-visual records were taken during the experiments. Shadowing method was used to observe and code the user experience process of children.

3.2 Preliminary Paper Prototype: Fungram

We tested the preliminary paper based prototype of the tool along with one set of tangible tangram consisting of seven pieces. The size of the papers used in the experiment (see Figure 2, Figure 3) were 9.7 inches (255 mm) the same size as iPad2 screen, each was put horizontally on the table when presented. The tangible tangram pieces were made of high density polystyrene, a low-cost material suitable for prototyping, which looks like a wooden toy (see Figure 1). The size of the longest side (hypotenuse) of the large triangle piece was 2.5 cm, all the edges of the pieces had a diameter of 10 mm. The figures on the papers were made with paper stickers in the same size and colors matching with the tangible tangram pieces.

We prepared two sets of tasks: the first consisted of only figures without any narrative context (see Figure 2), whereas the second set consisted of figures displayed within a narrative context (see Figure 3). In both sets, the pictures were put in an order in which the figures ranged from easier to harder to recognize.



The giraffe is very hungry. He accidentally ate the body of the tree under the leaves. Can you help him to put the body of the tree back under the leaves?

Figure 3. A sample picture presented with narrative context in the second set.

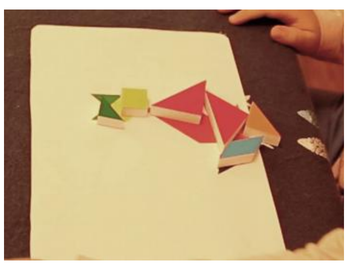


Figure 4. 35-month-old girl follows color cue without fully employing rotation strategy in the first task.

In the first set of papers (see Figure 2), children were asked to identify a tangram figure on the paper (i.e., cat, sailing boat) and then they were asked to put the matching tangible tangram pieces on the corresponding shapes. In the second set of papers (see Figure 3), the figures were introduced to the children by the experimenter within a narrative context and children were asked to solve a problem by finding the right matching shape on the missing piece, which was given in a visual cue of border lined blank. The narrative content provided to the child orally in Turkish by the experimenter. Each picture presented one at a time in order to avoid a possible distraction of attention of the child caused by the simultaneous presence of multiple pictures. This is also how a child would encounter the pictures on the screen in the final product.

4. Results

The preliminary results indicate that narrative input harnesses the intention of rotation as well as helping abstract figure recognition. In the first task of abstract figure recognition, pictures given without narrative context and children were asked what they see on the picture. Gender differences occurred rather than age differences. Regardless of age, none of the females could recognize or identify the figures without narrative input in the first set. They were rather focused on the individual geometrical pieces by pointing them separately. In contrast, all male participants could identify the displayed figure in different ways although not necessarily giving the expected answer. 46-month-old boy identified cat figure as a house made of colored stones, whereas 37-month-old boy thought it was a rabbit. Notably, although 26-month-old boy was the youngest participant, he was the only one who identified the cat figure as a cat. Since, as being abstract figures, we were open to any identification from the child. In the case of not receiving a response or identification, we asked the participants "do you think it looks like a cat, or sailing boat?" then girls could recognize the object and affirmed by pointing the ears, the head, the sails and body parts.

In putting the tangible tangram pieces on the matching shapes, the action strategy of children differed according to their age and individual skills rather than gender. As expected, older participants (48-month-old girl and 46-month-old boy) put the matching pieces on the shapes employing rotation complying with the orientation of the geometrical shapes. Younger children were more likely to follow the color cues and dropped the pieces on the relevant colors disregarding the alignment or orientation of the shapes (see Figure 4). The youngest children (28-month-old girl and 25-month-old boy) could not complete the whole task and lost their attention after putting four or five of the seven tangram pieces on the figure. However, 33-month-old girl, who was younger than five of the other children, showed an exceptional performance in this task. She could achieve to figure out not only rotating the shapes but also flipping the parallelogram piece in its symmetry axis when necessary. Even the oldest participants could not achieve to perform the flipping move in symmetrical axis of this piece.

In the second task (see Figure 2), children were shown pictures with multiple figures given in a narrative context. They were asked to solve a problem given in the narrative by finding the missing piece among the set of tangible tangram and put it on the border lined blank. In order to confirm if the child could recognize the figures in the narrative, the experimenter asked if

Figure 5. The youngest participant, 25-month-old boy matches the missing piece according to the narrative input. Although he puts the piece in vertical orientation, he pays more attention to rotation and alignment than he did in without narrative condition.

she could point to the pronounced figure related on the picture.

When given in narrative context all children could recognize even more complex tangram figures such as giraffe, kite, mountain, and turtle presented in the second task which we thought challenging and children might be unfamiliar with (especially when compared to the ones presented in the first task). Moreover, they performed relatively better in terms of putting the pieces on the relevant shapes, paying more attention to the geometrical cues such as alignment of the edges and rotational orientation of the shapes. This result also included our youngest participant 25-month-old boy (see Figure 5), who could complete 4 of the 6 pictures.

5. DISCUSSION AND FUTURE WORK

In this paper we presented an exploratory study with the preliminary paper prototyping of *Fungram,* a tool incorporates rotation of tangram puzzle activities into a game context guided by narrative. Our aim is to facilitate the spatial skills of children between the 25 and 48 months old. Since well-organized narration is suggested as a powerful scaffold for word-to-object mapping [1] and increasing engagement [9], the result presented here provides consistency with the previous research on spatial learning demonstrates that narrative input can help children to comprehend spatial relations which involve abstraction [1,9].

To our knowledge this study is unique in integrating and introducing tangram to very young children while benefiting the narrative cues. Among other spatial puzzles recommended for preschoolers such as lego blocks or wooden bricks, tangram pieces can be argued for being harder to play for young children. The difficulty depends on the fact that tangram allows highly abstract figures, offer limited geometrical shapes mostly in triangles, enable only horizontal use and not allow making the pieces join together. Thus, tangram can be regarded as requiring higher motor skills, spatial intelligence as well as more patience than a very young child might be expected to show. Although children participated in this study have not encountered tangram prior to this experiment, they did not need additional instruction to understand how to play with tangram pieces. Moreover, we observed that they enjoyed to build new figures apart from the tasks, and expanded their creative use.

We defined three visual cues to help children's matching and rotation strategy: color, size, and border lined blanks. We observed that although children tend to follow color cue in the first hand, it did not solely invite them to rotate. However, when color cue is replaced with border lined blank along with narrative input, younger children were more likely to rotate the shapes. Still, their rotation action involved two types of violations to be coded in the iterated user study: incomplete orientation of the angles, and careless alignment of the edges while matching two shapes. These action types would need to be considered in designing the screen interaction and content of feedback effect in order to define the optimum span to be tolerated in case the child runs off the borders of a shape in the digital version.

While tangram provides us insights about the action strategies of children, since it is based on 2D figures, it did not enable us to discover the manipulatives with their three dimensional relations. Therefore our future prototype will also include graspable spatial toys such as Fröbel Gifts, which enable 3D forms, figure configurations and wider range of spatial relations (e.g., overlapping, interlocking) between objects that also provide opportunity to promote using spatial language (e.g., prepositions). The data provided from young children's experiences with various spatial puzzles would branch out to numerous venues employing different rotation tasks.

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