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# Applying Augmented Reality to Assisting Children in Solving Tangram Puzzle

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**Abstract:** This paper presents an augmented reality supported Tangram game system, named ARTangram. The ARTangram system allows children to use physical Tangram pieces to solve Tangram puzzles, detects children solving status by recognizing the locations of the pieces, and dynamically provides children with digital augmented outputs, including information, feedbacks, and prompts, to assist children in solving Tangram puzzles. The digital augmented information includes game progress, elapsed time, a shadow outline of the specific shape, and colored shapes to indicate correctly-placed pieces. The prompts include text information to inform of the piece to place, audio hints to imply the correct location of the piece, and visual shape hints upon the correct location of the piece. An evaluation was conducted to ask 20 kindergarten children to use Tangram puzzles to form a house shape with the assistance of the ARTangram system. The results reveal that children might encounter difficulties in solving Tangram puzzle and the ARTangram system helped children correctly place pieces when they encountered difficulties.

**Keywords:** Augmented reality, Tangram puzzle, computer generated prompts

## 1. Introduction

Tangram is a puzzle game which challenges players to put together seven geometric pieces to form a specific shape with a given outline. Players need to observe and compare the shape of pieces and given outline and then place each piece in the correct location. During placing each piece, players move the piece and rotate the piece to a specific angle. Tangram is proved to enhance children ability in geometry, either with concrete physical or with computer based manipulatives (Olkun, 2003; Olkun, Altun and Smith, 2005). However, concrete physical manipulative or tangible interface is more natural and familiar than virtual interface for young children (Marshall, 2007; Xie, Antle, and Motamedi, 2008) while computer based manipulative or virtual interface can be connected with interactive, immediate, and adaptive feedbacks (Burns and Hamm, 2011). Augmented reality is a technology, which can combine physical manipulative with digital information or feedback (Azuma, 1995; Kipper and Rampolla, 2013; Milgram, Takemura, Utsumi and Kishino, 1994). Schneider, Jermann, Zufferey and Dillenbourg, (2011) suggested that "*the coupling of tangible user interface with augmented reality allows for a very close mapping between tangible input and digital output…*" Price and Yvonne (2004) claimed that interacting with a physical world with augmented digital information can facilitate children active learning. Most adaptive learning systems offer virtual interfaces for students to interact and learn, detect student learning status by analyzing student inputs from keyboard and mouse, and adaptively provide digital feedbacks. This paper presents an augmented reality supported Tangram game system, named ARTangram, for exploring the feasibility of utilizing augmented reality to implement an adaptive learning system, which enables and detects physical manipulatives and adaptively provides digital feedbacks. The ARTangram system allows children to use physical Tangram pieces to solve Tangram puzzles. Augmented reality was applied in the ARTangram system to detect the locations of the pieces, to analyze children solving status, and to dynamically provide children with augmented digital outputs, including information, feedbacks, and prompts, to assist children in solving Tangram puzzles.

## 2. ARTangram System: Augmented Reality supported Tangram

### *2.1 Environment*

The ARTangram is an augmented reality supported Tangram game system. The environment of the ARTangram system includes a computer with a camera and a screen, seven physical Tangram pieces, and a plate (Figure 1). The plate has a physical given outline, such as house shape, for players to place pieces to form. The camera is fixed above the plate to capture a video for the system to recognize the locations of pieces. Each Tangram piece has a unique marker for identifying the piece and the plate has two markers as references for calculating the locations of pieces (Figure 2). Each Tangram piece also has marked a number and players are requested to place pieces in the number order from number 1 to number 7. This request aims to reduce the variability of children Tangram puzzle solving status and the complexity of developing adaptive system feedbacks. The ARTangram system is installed in the computer. The ARTangram system analyzes the video captured from the camera, recognizes the markers to detect the locations of Tangram pieces, diagnoses the children Tangram puzzle solving status, and displays the captured video and adaptive digital augmented outputs in the screen to assist children in solving Tangram puzzles.

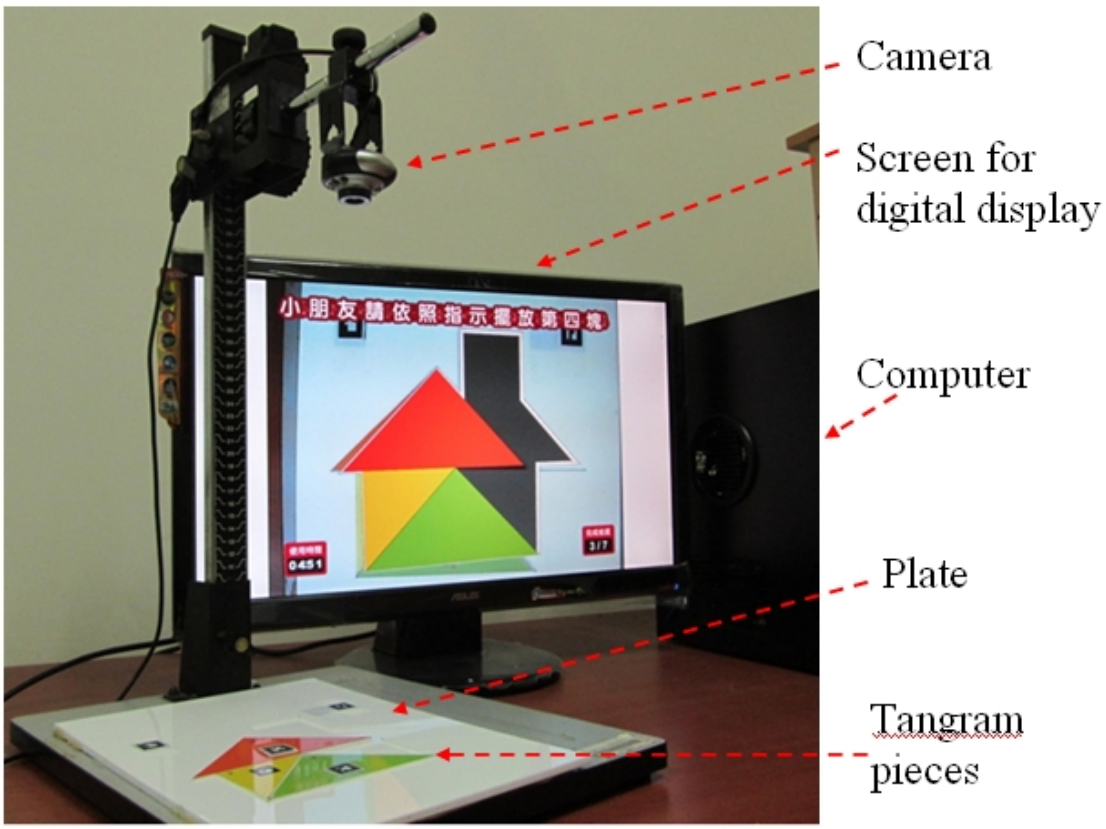


Figure 1. Environment of the ARTangram system.

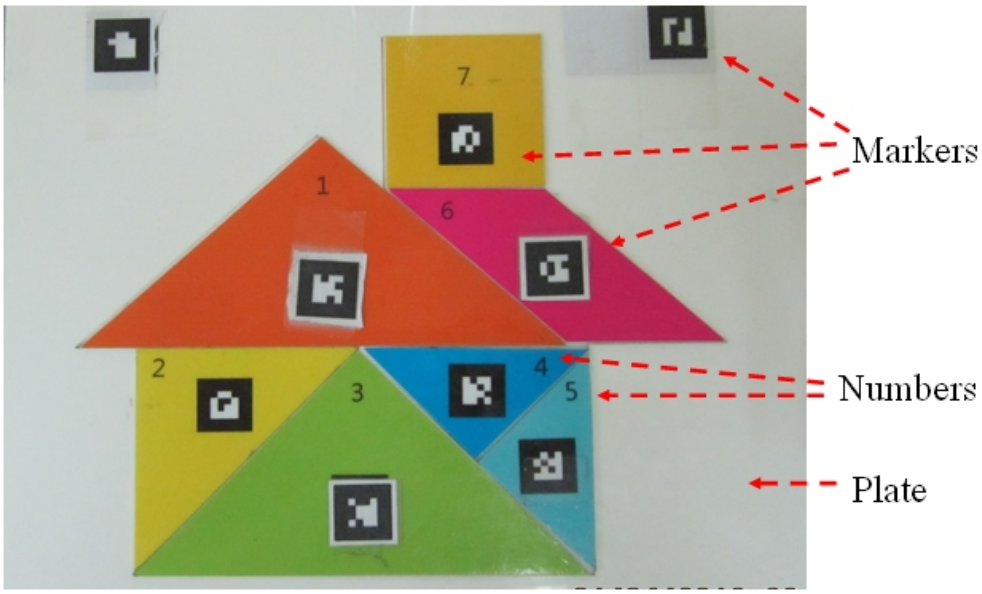


Figure 2. House shape by Tangram pieces

### *2.2 Digital Augmented Outputs*

Besides displaying the camera-captured video in the screen, the ARTangram system dynamically displays digital augmented outputs upon the video, including augmented information, feedbacks, and prompts.

#### *2.2.1 Information and Feedbacks*

The ARTangram system provides players with digital augmented information and feedbacks, including progress, time, a shadow outline, and colored shapes on correctly-placed pieces (Figure 3). The progress indicates the number of pieces which the player has already correctly placed. The time is the elapsed time from the start of the game. The shadow outline displays the given outline, which is the same as the physical outline on the plate, for the player to form. When the ARTangram system detects that the player places a piece in the correct location, the system displays a colored shape upon the piece to verify it and play an audio feedback, such as "Good job!" If the given shape is formed, the system will display a congratulation text message and end the game. Otherwise, the system will prompt the player to place the next piece both in text and audio messages, such as "Please place the second piece!" If the player cannot solve the puzzle in 60 seconds, the system will display an encouragement text message, such as "Go!" (Figure 4).

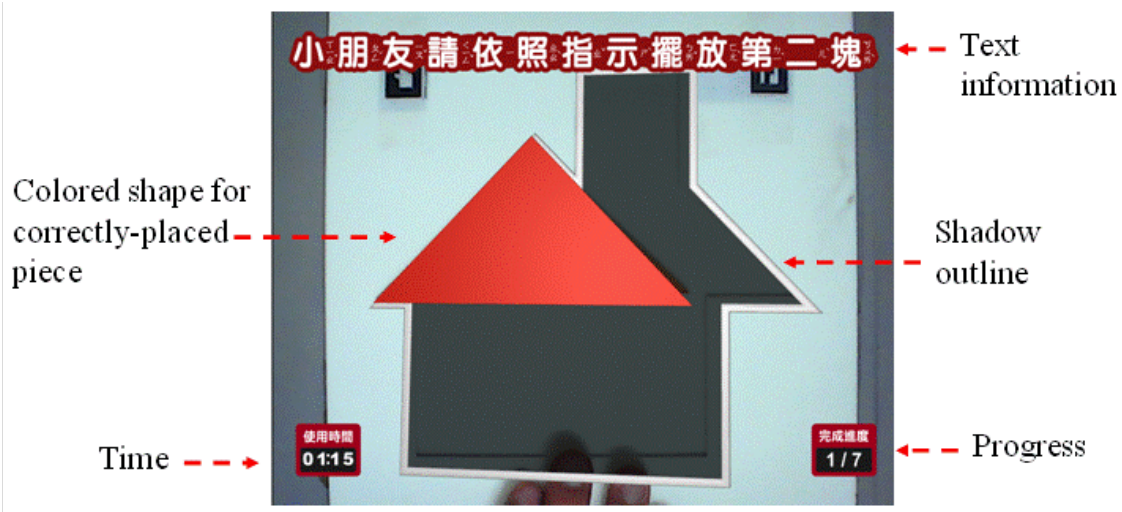


Figure 3. Digital augmented information of the ARTangram system

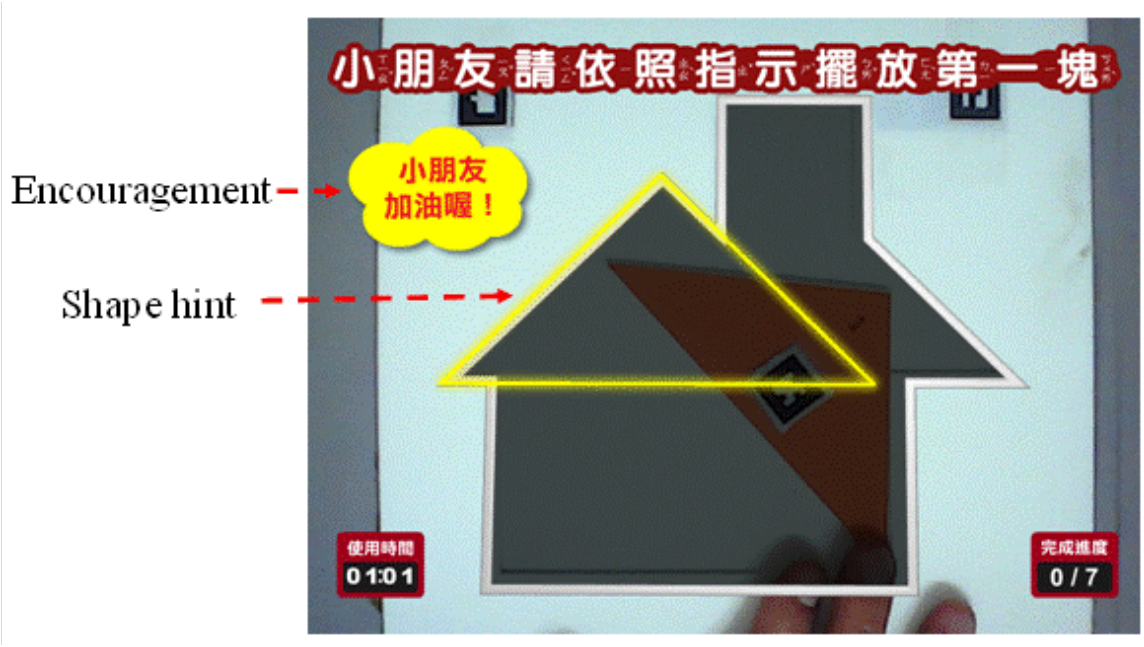


Figure 4. Visual shape hint for the third and fourth prompts of the ARTangram system

### *2.2.2 Prompts*

When solving Tangram puzzles, children might encounter difficulties. The ARTangram system provides 4 levels of prompts to assist children in solving Tangram puzzles. The first level prompt informs children of the piece to place both in audio and text messages, such as “Please place the third piece!” If a child can not correctly place the piece during 30 seconds, the system will offer the second level prompt to hint the location of the piece in an audio message, such as “You might consider the upper location!” If the child still cannot correctly place the piece after more 30 seconds, the system will provide the third level prompt to display a visual shape hint upon the correct location of the piece for 5 seconds (Figure 4). After more 30 seconds, the system will offer the fourth level prompt to display the visual shape hint until the child correctly places the piece. The difference between the third level prompt and the fourth level prompt is the display time of the visual shape hint.

## 3. Preliminary Evaluation

An evaluation was conducted to evaluate whether the ARTangram system helps children solve Tangram puzzles or not and the attitude of children about the ARTangram system. The participants were 20 kindergarten children, including 9 boys and 11 girls. Children were instructed in the Tangram puzzle game and the usage of the ARTangram system. Children were asked to use Tangram pieces to form the house shape with the assistance of the ARTangram system. The student required prompts to place each piece in the correct location were recorded. The statistics of required prompts of each piece were listed in Table 1. All children successfully formed the house shape with the assistance of the ARTangram system. The average time of the children to solve the puzzle is 3 minutes and 22 seconds. In general, most children easily placed the first, third, fifth, sixth, and seventh pieces in the correct locations. One child needed the fourth prompt in placing the first piece and one child needed the third prompt in placing the third piece. Most children encountered difficulties in placing the second (80%) and the fourth (95%) pieces. Some children could not rotate pieces to the correct angle so that they could not find out where the piece should be placed. Some children placed pieces in the wrong location. For example, some children placed the fourth piece in the chimney of the house (the location of the seventh piece). About 25% children correctly placed the second and fourth pieces with the assistance of the second prompt, i.e. the audio hint of the correct location. Most children needed the visual shape hint to help them place the second (55%) and fourth pieces (70%). The results reveal that

children might encounter difficulties in solving Tangram puzzles and the ARTangram system helped children correctly place pieces when they encountered difficulties.

Table 1: Required prompts for students to place piece in the correct location.

| | First prompt | Second prompt | Third prompt | Fourth prompt |
|---|---|---|---|---|
| First piece | 19 (95%) | 0 (0%) | 0 (0%) | 1 (5%) |
| Second piece | 4 (20%) | 5 (25%) | 7 (35%) | 4 (20%) |
| Third piece | 19 (95%) | 0 (0%) | 1 (5%) | 0 (0%) |
| Fourth piece | 1 (5%) | 5 (25%) | 7 (35%) | 7 (35%) |
| Fifth piece | 19 (95%) | 0 (0%) | 1 (5%) | 0 (0%) |
| Sixth piece | 20 (100%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Seventh piece | 20 (100%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Total | 102 (73%) | 10 (7%) | 16 (11%) | 12 (9%) |

After solving the Tangram, children were asked to fill a questionnaire to access their attitude about Tangram puzzles and the ARTangram game system. The questionnaire contains five questions. A researcher helped children understand the questions. Table 2 lists the results of the questionnaire. In general, children had positive attitude about Tangram and the ARTangram game system. The results of question #1 show that six children did not play Tangram puzzles before and other children liked Tangram. The results of question #2 reveal that all children liked the game. All children were satisfied with the piece-detention ability of the system (question #3) and considered that the system helped them solve Tangram puzzles (question #4). All children were satisfied with the game system in general (question #5).

Table 2: Questionnaire results.

| | Strongly agree | Agree | No opinion | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| #1: Did you like Tangram before? | 4 (20%) | 10 (50%) | 6 (30%) | 0 (0%) | 0 (0%) |
| #2: Do you like this game? | 12 (60%) | 8 (40%) | 0 (0%) | 0 (0%) | 0 (0%) |
| #3: Are you satisfied with the piece-detection ability of the system? | 14 (70%) | 6 (30%) | 0 (0%) | 0 (0%) | 0 (0%) |
| #4: Does the system help you solve Tangram? | 15 (75%) | 5 (25%) | 0 (0%) | 0 (0%) | 0 (0%) |
| #5: Are you satisfied with the game system in general? | 16 (80%) | 4 (20%) | 0 (0%) | 0 (0%) | 0 (0%) |

## 4. Conclusion and Discussion

This paper presents an augmented reality supported Tangram game system, named ARTangram. The ARTangram system enables children to solve Tangram puzzles through physical maniplatives. The physical maniplatives are more natural and easier for young children. The ARTangram system utilizes augmented reality to detect the locations of Tangram pieces, to analyze children Tangram puzzle solving status, and to dynamically provide digital augmented outputs, including information, feedbacks, and prompts, to assist children in solving Tangram puzzles. The ARTangram also demonstrates different forms of the digital augmented outputs: text, audio, and visual forms. The results of the evaluation show that the ARTangram system helped children correctly place pieces when they encountered difficulties. The ARTangram system reveals the feasibility and potentiality of applying augmented reality to implement an adaptive learning system, which combines physical maniplatives and digital augmented adaptive feedbacks to assist children in learning.

The ARTangram system is a prototype system for exploring the feasibility of applying augmented reality to adaptive learning systems. The ARTangram system was implemented with some simplifications and limitations for reducing the complexity of developing the system. The ARTangram system can be enhanced to be more flexible and adaptive by further implementation and artificial intelligence techniques. First, the ARTangram system only stores a puzzle solution of the house shape (Figure 2), but the location of the second piece can be exchanged with the location of the fourth and fifth pieces. The ARTangram system can be enhanced to store multiple possible solutions. Second, the ARTangram system requests players to place pieces in number order. The request is, in part, a kind of guide, but also restrains children from placing pieces in their orders. Allowing children to place pieces in their orders will increase the possible Tangram puzzle solving statuses and require containing more feedbacks and prompts in the system. Third, the ARTangram system provides prompts piece by piece. It provides immediate feedback when the children cannot correctly place a piece, but it deprives children of the opportunity to find out that the pieces were incorrectly placed by themselves. For example, some children placed the fourth piece in the chimney of the house, but it will result in no place for the seventh piece. If the system did not immediately provide prompts, children might find out the predicament when placing the seventh piece. Children might change the locations of pieces to successfully solve the puzzle, or might fail to recover the error. How to provide appropriate adaptive feedbacks for children requires further investigation. Fourth, the ARTangram system currently provides feedbacks and prompts based on the current Tangram puzzle solving status. Building student model and taking individual traits into account will make the system more adaptive.

The ARTangram system currently displays captured video and digital augmented outputs in a screen. Children move their sight to and fro between Tangram pieces and screen. Using head-mounted displays or augmented reality enabled glasses, such as Google Glass, as display equipment will solve this problem.

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