

The Study of Enhancement of Students' Spatial Intelligence: Puzzle Fun APP Usability Test

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Abstract – Spatial intelligence is a person's initial ability and has a great impact on a student's learning. However, school education tends to focus on cultivation of language, logic, music, and nature intelligence and there is no specific discipline for a student's spatial intelligence. Gamification, the use of game element and game-design technique in non-game contexts, is a very popular way to acquire knowledge. Unlike traditional toys (e.g. LEGO, tangram), games on digital devices such as computers, mobiles and iPad can provide a brand new learning experience. This study conducted an usability testing for an application called Puzzle Fun. The application is designed as a game that helps to enhance students' spatial intelligence and the concept of Boolean operators, which is an important base for subjects such as graphics, technology, programming and design. We recruited 10 participants (4rd through 6th grade students) in this usability testing and found that the button design of this game is not friendly enough for those children that they failed to link the specific functions of buttons. They also reported other difficulties such as they were unable to control the graph scale button accurately, and failed to expect the levels of difficulty.

Keywords – Game-based Learning, App Game, Spatial Intelligence, Usability.

I. INTRODUCTION

A. Definition of Spatial Intelligence

One of human initial abilities is spatial intelligence referring that people can specifically or abstractly use ideas such as shapes, characteristics and relationships mainly via spatial reasoning to operate objects, explore the world and communicate with one another [1]. Although there are a wide variety of opinions about the definition of spatial intelligence in academic circles, spatial intelligence is essentially about the measurement of psychological space that people use to solve visual problems or complete tasks; that is to say, it is the ability about personal estimation, predication and judgment for the relationships between graphs or objects [2] and the main purpose of engineering graphics is to train and enhance graphic communication skills for students [3-5].

A great number of studies have indicated that spatial intelligence can highly predict a person's academic achievements or professional performance. More jobs need spatial intelligence but not language abilities [6, 7]. This shows the importance of spatial intelligence to human survival. Also, a number of studies have shown that space visualization is indispensable to a student's performance on certain subjects, such as calculus [8], mathematics [9], engineering graphics, computer-aided design [10] and civil engineering structure design [11]. In addition, [12] pointed that abilities for space visualization and mental rotation

are especially important to professional technical areas such as engineering.

B. Limitation for Cultivation of Spatial Intelligence

Howard Gardner, a professor at the Harvard University in the U.S., propounded the theory of multiple intelligence in his book, *Frames of Mind*, published in 1983, which states that there are 7 kinds of human intelligence including linguistic intelligence, spatial intelligence, logical-mathematical intelligence, bodily-kinesthetic intelligence, musical intelligence, interpersonal intelligence, intrapersonal intelligence. Later he added the eighth intelligence, naturalist intelligence [13]. Teaching of spatial intelligence could be assisted by producing visualization reports and fine art collages, making models and drawing pictures [7, 14, 15].

A wide range of studies have shown that ability for spatial intelligence can be improved if well-arranged training is given [16], especially by means of engineering graphics teaching [17-19]. The study of engineering graphics teaching also pointed out that the ability for space visualization can indeed be improved if proper teaching methods and enough time are given [20-23]. In addition, students made significant progress on spatial intelligence after they operated specific physical models [17].

C. Cultivation of Spatial Intelligence by Game Based Learning

The above studies, whether conducted via physical objects or multimedia, were all for helping students to be able to quickly understand spatial ideas, such as abstract concepts or to enhance their spatial intelligence. However, they were all limited in classrooms and conducted during class time. It will be the trend in the future for such activities to be conducted by combining newly developing information technology to enhance students' learning willingness and their spatial intelligence [24-26]. Therefore, this study aims to invent an APP game for students to learn via electronic products such as smart phones and tablet personal computers so that their learning motivation and interest will be enhanced via touch-screen interfaces. This will facilitate them to have long-term ongoing learning as they can keep record of every learning result. Moreover, they will be able to learn all the time via tools at hand instead of just learning on campus.

D. The Importance of Boolean Operators

Boolean operators are now common parts of database searching [27, 28]. Most databases use such operators, AND, OR and NOT. Also, they are widely used in Computer-Aided Design (CAD) and Computer Graphics (CG) [29, 30]. Various kinds of models can be composed by combining and calculating simple geometry

components. In addition, Boolean operation is an important base for subjects such as graphics, technology, programming and design [31-34]. In other words, the importance of such operation is unspeakable. Therefore, this study ponders how to make Boolean operators to be part of the game design through APP Game Project and game-based learning so that students can be familiar with Boolean operators in natural game situations.

II. GAME DEVELOPMENT PROCESS

A. Game Objective

Train players to know differences and usage of intersection, union and difference by means of this game, attract players by using lovely interfaces so that they will be interested in this game and then teach them methods of graphic composition.

B. Gameplay

There are options of difference, union and intersection above the interface, and geometrical figures, such as a circle, an oval and a triangle are below the interface. Touch an object on the screen with a finger and the object will appear in the center of the screen. Next, move the object to a designated area shown as dotted line and then let go of your finger. Lastly, choose the option of union, intersection or difference to achieve the designated objective after the object is completely moved.

- 1) Judgment: Use the object moved later to unify, intersect and differentiate the object moved earlier.
- 2) Game time: From 60 to 240 seconds (game time will be increased according to difficult levels of the game). Time for the game level of seaside is 60 seconds; jungle is 120 seconds; desert is 180 seconds and snow and city area are 240 seconds.
- 3) Operation method: Players need to collate the final picture at the top left-hand side to proceed Boolean operation for the object. There are objects below for players to choose; they can drag an object to the work area directly and then click intersection, difference and union to proceed Boolean operation after the object is placed well. Next, click "ok" to see if they successfully pass the level and decide if they want to take up the challenge again or proceed to next game level.

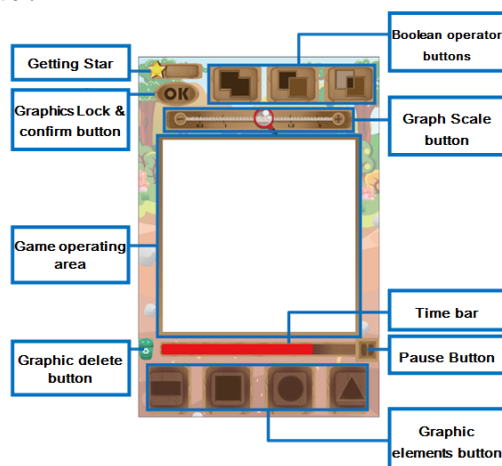


Fig. 1. Game operator interface

III. METHODOLOGY

This study was divided into two parts. For the first part, the six-stage usability testing planned by [35] was used as reference. We and test takers played the APP game together. During the process, test takers were invited to play the game and told us how they felt about operation of the game. Qualitative data of usability of individual tests was acquired from this part. For the second part, test takers were asked to help us fill out a simple questionnaire for collecting quantitative data of satisfaction so that we would understand the overall experience and satisfaction about their use of the game.

A. Participants

"Puzzle Fun", the APP game in this study, is an educational game developed for fourth to sixth graders of elementary schools and so we recruited a total of 10 test takers within this age group in the great Taipei area as our target group. 2 of them were sixth graders and 8 of them were fourth graders. Half of them were males and the other half were females. English letters such as A, B and C were used as codes for them mentioned in the following text. All of the students did not have medical history of mental illness and were users of mobile phones or tablet PCs.

B. Tasks Definition & Questionnaire

For the first part, this study listed a total of six tasks for test takers to perform. Before they undertook the test, a test administrator explained to them that this was a jigsaw puzzle game and was not an examination. The purpose of the test was to understand whether or not the design of this game was good and were there any problems of operating this game so it was ok even if they failed. Table 1 is the usability task table providing the explanation that what this task is designed for in terms of usability problems.

For the second part, there were 9 questions on the "Questionnaire Scale for Children's Use Attitudes to Puzzle Fun APP". Questions on the first part of the questionnaire mainly focused on use attitudes and those on the second part of the questionnaire asked users about their use status of mobile games. The questionnaire was produced based on the 4 point Likert scale.

Table 1. Mapping Table for Tasks and Purposes of Usability Testing

Task	Purpose
Task 1 This is the first time that you play this game. You click the icon of Puzzle Fun to enter the game and select the first level.	Understand whether or not users can enter the first level of the game smoothly; whether they will select a wrong level or cannot find a way to enter the game.
Task 2 The game has started. Although you are not clear about rules of this game, you want to finish this level. (Please tell me how you play this game until you complete this level.)	Understand whether or not users can complete a level smoothly without novice guideline or teaching. This includes whether or not button design on the game interface can show its notion or function accurately.

Task	Purpose
Task 3 After completion of the first level, you want to keep playing this game until the end of all levels of Mamo Forest.	Understand whether or not there are repeated questions at different levels or can the game be played smoothly when another level is selected.
Task 4 When you play the game, you suddenly find that you select a wrong geometric figure. You don't want the figure on the screen and want to re-select a new one.	Understand whether or not the game has error tolerance and users can make corrections or remedies smoothly when there is an error.
Task 5 When you play the game, you select two geometric figures for interaction and then find the result is not what you want and so you want to change these two figures to become difference.	Understand whether or not the game has error tolerance and users can make corrections or remedies smoothly when there is an error.
Task 6 You are in this level for so long that you don't know how to complete it so you want to have a hint.	Understand if users can get help in the game when they have pain points playing the game and if the help offered in the game really helps users.

C. Usability Testing

Usability testing is a way of usability evaluation that were more easily used under the internet environment. Usability testing is one of evaluation methods of user guidance. The way of doing it is a test administrator asks a test taker to complete tasks and observe and record the test taker at the same time for the purpose of optimization of the existing product. Task analysis is used to understand users' target when they use a product and tasks required for users to achieve targets through observation and interviews and that priority is based on importance. There are six stages of usability testing as follows:

- 1) Testing Plan for Development: Plan for testing method, purpose, content, users and time arrangement.
- 2) Selection and Recruitment of Test takers: Set up competency level and background of test takers who can represent target users and conduct recruitment accordingly.
- 3) Preparation of Testing Materials: Prepare for instruction words to test takers and data collection tools; think about organization and framework of testing.
- 4) Test Performing: The basic usability testing is performed using the one-on-one way. A test taker and a test administrator are in the same room. The test administrator can operate the system and raise questions and undertake task operation using the overall functions of the product upon testing.
- 5) Explanation to Test Taker: The test administrator needs to make inquiries at the test takers during the testing process and recall the test taker's performance in the testing and ask the test takers to explain reasons for their behaviors and thoughts.
- 6) Findings and Suggestions of Testing Results: Preliminary conclusion after testing completion can be

used as a basis for direct review and design optimization, and analysis for the second sage is an extensive analysis covering more other analyses and findings.

IV. USABILITY ANALYSIS

At the stage of usability testing, test takers were invited to perform tasks for this study. Usability problems, pain points reported by each test taker and phenomena observed by study personnel during the process were consolidated for qualitative data, and usability problems of each facet of "Puzzle Fun" APP game were summed up. There were tasks of six stages for this usability testing, namely entering to a game level, completing level one, completing all levels of the first part, cancelling geometric figures, undoing actions and seeking hints. See Table 2 for completion status of each stage. For Task 1: entering to a game level and Task 4: cancelling geometric figures, almost every test taker could complete them smoothly. For the rest of the tasks, hints and guidance needed to be given to test takers for completion of the tasks after they tried many times but still failed.

Table 2. Task Completion Status of Each Stage

Task	Code for Test Taker and Completion Status										Total		
	A	B	C	D	E	F	G	H	I	J	○ No.	▲ No.	X No.
Task 1	○	○	○	○	○	○	○	○	○	○	10		
Task 2	▲	○	▲	▲	○	○	○	○	▲	▲	5	5	
Task 3	○	○	X	X	○	X	○	○	X	X	5		5
Task 4	○	○	○	○	○	▲	○	○	○	○	9	1	
Task 5	○	▲	▲	○	○	▲	○	○	○	○	7	3	
Task 6	○	○	▲	○	▲	▲	○	○	○	▲	6	4	

(○ = completion, ▲ = completion after hints, X = incomplection)

During the process of tasks performing, test takers were guided to tell study personnel reasons for them to select buttons and difficulties and confusion they were encountering then. Also, study personnel recorded phenomena observed and raised questions to acquire further information during the same process.

The following problems are usability problems with a higher repetition rate put forward by the test takers and then consolidated for this study (The 11 usability problems are shown as U1 to U11.).

U1. After completion of geometric figures, test takers thought they have done it and did not know to use the function of union – They stopped after completion of figures and told the task administrator: "I've done it." (A) or asked: "and then?" (B)

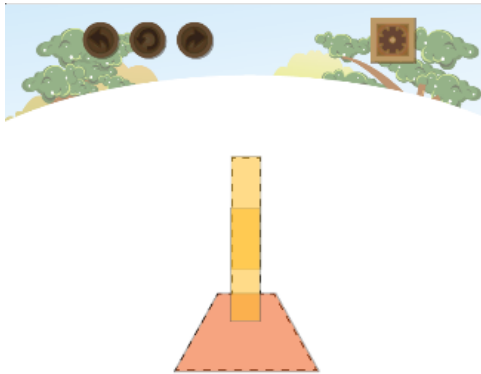


Fig. 2. Diagram for Usability Problems 1

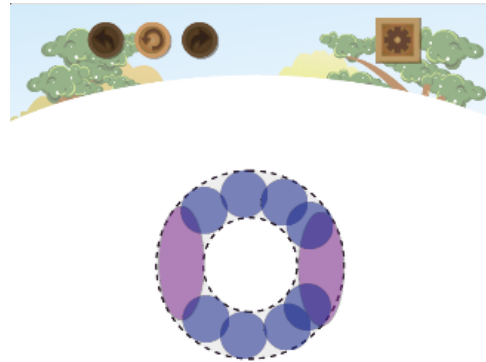


Fig. 4. Diagram for Usability Problems 3

U2. Test takers did not understand meanings of buttons, Next, Again and Menu – They wanted to enter the next level but they clicked the button of Again. They were asked if they did not understand meanings of the three buttons; their answer was yes (A, E, F).

U4. Without receiving an explanation, test takers did not know there was a hint function – Although they had been stuck on a certain level for a long time during the process of the game, they did not try to use the hint function (A, E, F, I, J). They were asked what they would do if they were unable to pass the level. Their answers were that they would ask their parents or just gave up the game (J).

U5. Without receiving an explanation, test takers did not know there were the second and third hints – Although they did not understand after reading the first hint, they did not try to use the button of hint again and they did not know there were more hints until the test administrator told them (A, E, F, I, J, G).

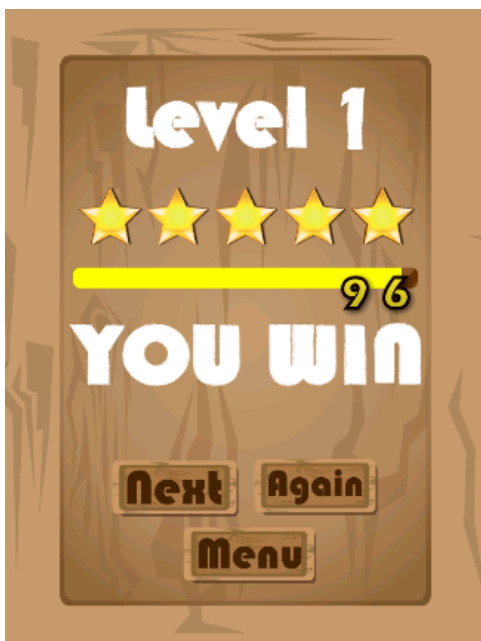


Fig. 3. Diagram for Usability Problems 2

U3. Even though completion results of geometric figures were not exactly the same as answers, test takers still passed the level – They used a circle or an oval to compose various kinds of figures and then used the function of union. Although their results were different from answers, they all passed (A,B,C,E,G).



Fig. 5. Diagram for Usability Problems 4&5

U6. It can sometimes be unsuccessful dragging a geometric figure into the trash can – The trash can has to

be clicked to open and then be dumped a figure. Test takers kept dragging their figures back and forth but were unable to dump them or they clicked to open the trash can but the way of dragging still made them unsuccessful (D, E, G,H). Also, some test takers asked: “Unable to be thrown away?” (J) or “This seems not to be thrown away.” (A)

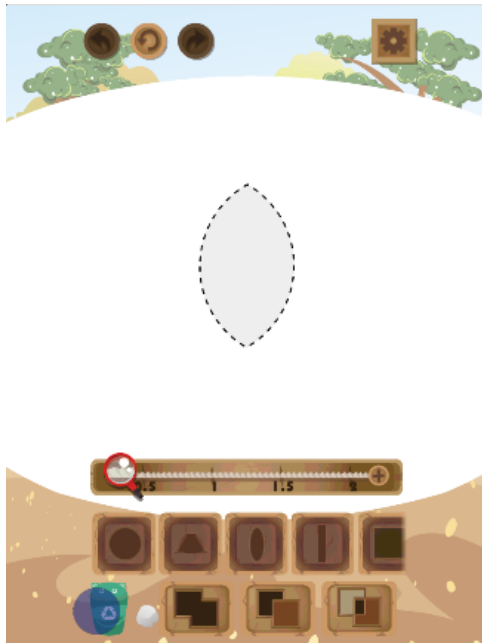


Fig. 6. Diagram for Usability Problems 6

U7. Except for the last geometric figure placed, no other figures could be moved – A test taker used to click several figures at a time, but could only move the last figure clicked; she threw away other figures unable to be moved to the trash can one by one. She was asked why she wanted to click so many figures at a time and her answer was “That way I will be less tired.” But she then said, “Just pretend that I didn’t say it.” (C) Also, another test taker asked: “Why can figures be moved?”

U8. Test takers wanted to move green part (Boolean operation proceeded) but were unable to do so – They kept moving in the green part with their fingers. The test administrator asked if they wanted to move it; they said yes and the administrator then asked them that did they think that could be moved? Test takers answered: “It seems not.” (B, D, J). Also, a test taker said loudly, “It can’t be moved.” when moving in the green part. (H)

U9. Test takers were waiting after completing a level. They did not know they needed to click the screen to enter the selection screen – They took no actions after passing the level and were asked if they were waiting for something. They said, “Well, they thought the next screen will be automatically popped up itself.” (E) or “I didn’t know a click is necessary.” (B).



Fig. 7. Diagram for Usability Problems 9

U10. Users did not know why the button did not work – After overlapping seven geometric figures, a test taker selected the button of difference but it did not work (C); another test taker just selected one figure but kept clicking the button of Boolean operation. When the test taker was asked reason for behavior, the answer was “Just click to see what will happen, but it doesn’t work.” (E)

U11 Test takers did not understand or misunderstood the buttons of union, interaction and difference – After the test, they were asked if they understood meanings of these three buttons. One answered no (J); the other thought the button of union means “completion” (E)

V. CHILDREN’S USE ATTITUDES TO PUZZLE FUN APP

Quantitative data collected through the “Questionnaire Scale for Children’s Use Attitudes to Puzzle Fun APP”, the second part of this study, was compiled as Table 3.

Table 3. Summary Table for Results of Questionnaire Scale for Children’s Use Attitudes to Puzzle Fun APP

No.	Question	Mean	SD
1	I think the functions of Puzzle Fun are easy to operate and use.	2.9	0.5676
2	I can play Puzzle Fun smoothly via the icon of the mobile game.	2.8	0.4216
3	Instructions of this mobile game are clear, easy to identify and able to tell me how to play the game.	2.8	0.9189
4	I like the way this mobile game displays its operation function screen; it helps to play the game.	3.2	0.7888
5	In different screens, I can understand different operation functions of this mobile game.	2.7	0.6749
6	I am highly interested in this mobile game.	3.4	0.5163
7	I will play this mobile game when a teacher or classmate recommends me it.	3.3	0.6749
8	The content of this mobile game surprises me and it is interesting.	3.5	0.5270
9	I know meanings of “Interaction”, “Union” and “Difference” of the three icons.	2.5	0.7071

(max= 4, N= 10)

The above questionnaire results have shown that questions related to users' positive emotional experience (users feel interested, surprised and want to play) at the time of using "Puzzle Fun" APP all scored more than 3 points whereas questions related to users' experience of smooth and easy operation, being able to understand functions almost all scored fewer than 3 points.

VI. CONCLUSIONS AND FUTURE WORK

The main purpose of developing educational APP games is to let children acquire knowledge by means of games. "Puzzle Fun" APP used in this study focuses on Boolean operation for geometric figures and so it is highly important whether or not users can understand the three concepts (union, intersection and difference) of Boolean operation. 11 usability problems with high frequency of occurrence have been found in the first part of the qualitative data in the study. Of the 11 problems, U1, U3 and U11 are the problems that may affect whether or not learning objectives can be achieved. This is the focus that cannot be ignored for the optimization. Hence, it is necessary to make design of the three button functions of Boolean operation easy to be connected to their concepts or provide novices with teaching guidance[36]. Otherwise, learning objectives cannot be achieved by means of the game. And for U2, U6 and U9, these are problems that game design is different from the language users used to or operating gestures are not the same, so users might not be able to play the game smoothly or may make mistakes during the game. Although they can keep playing the game, they may spend more time on repeated trial and error learning[37]. As for U7, U8 and U10, these are problems that no proper feedback is provided by the game, making users confused and do not know why there is no feedback for behaviors and what to do next. Study personnel also found that users felt like stopping to play the game when frustrated[38]. Lastly, for U4 and U5, although hints are not essential elements of the game, these two problems show the situation that game functions cannot be fully utilized, meaning that preset functions by developers are not effectively provided to users[39].

The second part of the quantitative data has indicated that "Puzzle Fun" APP may arouse users' considerable interest and make children want to play[40]. However, when it comes to use, they are less able to operate the game smoothly and understand each functions. And what is more important is that the concepts of Boolean operation are not fully learned and understood by children.

To sum up, other than the aforementioned 11 optimization key points this study has proposed, there are also five guidelines for future design and review that this study would like to put forward: Whether or not 1. the game can achieve learning objectives and effects and deliver knowledge successfully; 2. the game can be played smoothly and reduce effectively the time users need to spend on trials and errors; 3. when users play the game, there is sufficient feedback provided to reduce their frustration that they do not know what to do; 4. functions of the game set by the game developers can be fully

utilized and can achieve effects; 5. the game is interesting and arouses users' interest to play.

User experience design is a user-centered design approach that helps developers to design a product or service which conform to the users' needs. There are many developmental differences between children and adults, and it is not enough for us to capture the habits and needs of children only through imagination. By conducting usability testing, it provides a chance for developers to discover where the pain points are and what target users' needs through their experiences. This helps developers improving the user interface of applications and the interaction design (e.g. reward) to achieve the goal of educational use.

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