The logic gate board game for promoting intrinsic motivation and understanding in the science museum

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Abstract. Mostly, in museums, logic gates were communicated by permanent exhibits. Our logic gate board game was created to be an alternative for communicating the content and developing children’s self-motivation. Three logic gates—AND, OR, and NOT—were embedded in the board game. The main goal was to encourage the children to create their own strategies to complete a mission by using conditions (gates). A fairy tale was used to engage the children to play the game. We investigated children’s understanding and intrinsic motivation after playing the board game. The participants were 21 primary children (grades 4–6) who participated in a one-day camp at the science museum. They were introduced the rules and the context of the game before playing the game. During the gameplay, their interactions were observed. They were assessed by completing the test and the survey consecutively. Then, a debriefing session was held at the end of the assessment. Some were interviewed to investigate both their understanding and motivation. The results of the survey and interview show the success in promoting the children’s intrinsic motivation particularly, the enjoyment, concentration, and interest. From the observation, it seems that the children were completely focused throughout the game. Besides, most students could develop their understanding of the logic gates through the board game. Supported by the interview result, the children mentioned the strategy they used to complete the mission which required their logical thinking. However, it seems that the children still could not apply knowledge gained from the board game to the real-life problem.

1. Introduction

A concept of logic gates is one of the mainstreams of computer science education. This concept is imperious for understanding of computer working process, hardware design [1], and computer architectures [2]. Based on the understanding of the logic gates, children will be sequentially learned how a computer works, how a microprocessor is designed and implemented, how a computer program is operated, and what to consider when thinking about an efficient computer code. Therefore, the widespread of the logic gates concept was realized the importance of learning for children. An informal learning system could contribute to this situation in aspects of concepts and motivation of learning [3].

Learning science in informal contexts, e.g. zoos, aquaria, and museums, were reported by National Research Council (NRC) (2009) [4] that could engage in large portions of visitors. The informal
education settings differ from formal ones in several important issues. The formal education settings often are concentrated on cognitive outcomes, such as heavy learning gains, retention, and knowledge construction while the informal education focuses on sparking inspiration, interest, light and wild content, and excitement. The informal setting actually serves as alternative essential venues for learning. Visitors are provided a chance to observe and engage different authentic science practices and explore duty of science-related careers. Hence, they know why they need to learn such a content even though they never realize how deep the content is. Museum exhibitions and activities are designed to accommodate varieties of visitors such as a single learner or groups of learners visited at the time, a wide range of ages, and a single or multiple entry visitors. Moreover, the activities in museums are designed to draw the learners’ attention actively which differ from direct instruction or practice-and-drill activities. These differences are a main guideline for designing the museum activities.

However, logic gates were mostly communicated by permanent exhibits in science museums [5]. Designing activity for a museum to motivate young visitors is a challenge for science educators. Thus, how we can communicate the logic gates to children are considered in this study.

Increasing academic evidences have proceeded that games are effective learning tools for over the past decade [6]. Board games for learning have many benefits for children. Social scientists have argued that the games provide an opportunity for children to get along with others [7]. Obviously, children enjoy playing the game. Some games can encourage children for cooperative playing. Otherwise, the children played against one another to establish a winner in the competitive game. Moreover, games can encourage children to consider the concept of rules and constraints, do actions under the rules, and make most benefits of the circumference. According to main categories of game-based learning, most games were designed for formal education settings such as schools [8]. Serious games in classroom were mainly focused in many previous researches. Those studies have been typically investigated game technologies for training [9] or increasing awareness of social, geopolitical, or economic issues [10]. To design games for the museum context which is free-formed learning, not only cognitive aspects are concerned but also children’s motivation and inspiration are more served. We aim to communicate correct science content more easily, attractively, and enjoyably.

Thus, we aim to develop a board game in the context of informal science education which takes parts in a science museum. This board game, called Logic-Design, presents a content of logic gates. Children’s understanding will be investigated during and after they play Logic-Design. Moreover, children’s motivation of logic gates will be examined. The research questions are:

R1) What are levels of children’s understanding of logic gates after playing Logic-Design?
R2) What are levels of children’s intrinsic motivation on learning logic gates?

![Figure 1. The Logic-Design board game setting.](image)

Logic gates are basic logical functions. They normally are used in digital circuits. Some simple circuits may have only a few logic gates, while complex ones such as microprocessors of computer, may have millions of them. There are seven different types of logic gates: AND, OR, NOT, XOR, NAND, NOR, and XNOR gates. A logic gate takes one or two input of binary values (1 or/and 0, or


ON or/and OFF), and returns the output of the single binary value. By combining thousands or millions of logic gates can perform highly complex operations.

In this study, three logic gates, i.e. AND, OR, and NOT gates, were introduced by Logic-Design (Figure 1). Logic-Design was developed to motivate the children to play and learn. A fairy tale “Little Red Riding Hood” was used for making a virtual story in this game. The little red riding hood travels in the woods to bring the foods to her grandmother. The fairy tale was adapted for incorporating in the game world to build the concept of logic gates. There are plenty of foods: honey jars and bananas (Input) she carried. However, her grandmother can have only ONE honey jar or ONE banana (the game’s goal). Thus, she needs to distribute or exchange some foods along the way to her grandmother’s house until one goal left (Output). In the woods, she can visit bear’s houses, monkey’s houses, and neighbor’s houses (Gates) to share or exchange her foods (Figure 2).

2. Method
We added the Logic-Design board game in the schedule of Digital City one-day camp organized by Information Technology Museum, Thailand (ITM). Twenty-one primary children including seven children in Grade 4, nine in Grade 5, and five in Grade 6 voluntarily participated in playing the board game. They were twelve boys and nine girls, were divided into groups of four to five. These participants were introduced to the rules and the context of the game before they played the game. Next, the children spent time for playing the board game. During the game play, the children’s interaction with friends and the game were observed. The children were assessed by completing a knowledge test and an intrinsic motivation survey consecutively. Then, a debriefing session was held at the end. Some voluntary children were interviewed to investigate their understanding and motivation. To examine the children’s understanding, the data was collected by the knowledge test, the behavior observation, and the interview. The intrinsic motivation survey, the behavior observation, and the interview were utilized to gather the children’s intrinsic motivation.

Knowledge test: The test was classified into three objectives: Remember conditions: children were asked to explain the abilities of each condition in their own words. The question was “Please write messages or draw pictures that can express the characteristics of each condition that you noticed in playing the Logic-Design board game. Use conditions: with the context of the game, the children were given the numbers of honey jars and bananas as inputs and a target output (either one honey jar or one banana). Then, they were asked to use the houses (conditions) to distribute or exchange foods. An example of the question is “If Grandma needs only one banana. But Little Red Riding Hood has two bananas and three honey jars. Thus, how does the Little Red Riding Hood have to design her travel in order to give some food and
leave only a banana as Grandma needs? *Apply conditions in another context:* the children were asked to apply these conditions to another context. The question is “Suppose the promotions of a store. If you want only one coupon back in order to accumulate points in exchange for souvenirs, what kind of conditions do you need to buy in this store? And, which conditions was being used in the promotions of this store?”

### Table 1. Levels of understanding

| Levels of understanding                          | Three main objectives            | Description                                                                 |
|-------------------------------------------------|----------------------------------|----------------------------------------------------------------------------|
| Level 5 – Complete understanding (20 scores)     | Remember conditions              | • Explain the ability of conditions correctly in *every* part.              |
|                                                  | Use conditions                   | • Solve problem by using the conditions correctly in *every* part.         |
|                                                  | Apply conditions in another context | • Apply the conditions correctly in *every* part.                          |
| Level 4 – Almost complete understanding (16–19 scores) | Remember conditions            | • Explain the ability of conditions correctly *four* out of five parts.    |
|                                                  | Use conditions                   | • Solve problem by using the conditions correctly *four* out of five parts.|
|                                                  | Apply conditions in another context | • Apply the conditions correctly at least *four* out of five parts.       |
| Level 3 – Partial understanding (11–15 scores)   | Remember conditions             | • Explain the ability of conditions correctly *three* out of five parts.  |
|                                                  | Use conditions                   | • Solve problem by using the conditions correctly *three* out of five parts.|
|                                                  | Apply conditions in another context | • Apply the conditions correctly *three* out of five parts.               |
| Level 2 – Emergent understanding (6–10 scores)   | Remember conditions             | • Explain the ability of conditions correctly *two* out of five parts.     |
|                                                  | Use conditions                   | • Solve problem by using the conditions correctly *two* out of five parts.|
|                                                  | Apply conditions in another context | • Apply the conditions correctly *two* out of five parts.                |
| Level 1 – Little understanding (1–5 scores)      | Remember conditions             | • Explain the ability of conditions correctly *one* out of five parts.     |
|                                                  | Use conditions                   | • Solve problem by using the conditions correctly *one* out of five parts.|
|                                                  | Apply conditions in another context | • Apply the conditions correctly *one* out of five parts.                |
| Level 0 – No understanding (no score)            | Remember conditions             | • Give *no answer* or identify that they *could not answer.*               |
|                                                  | Use conditions                   |                                                                           |
|                                                  | Apply conditions in another context |                                                                           |

Three experts in computer science education were asked to review the index of the Item Objective Congruence (IOC) [11] of the test. The IOC index of the test is 0.833 which indicates that this test is valid. Additionally, the Cronbach’s alpha as an estimate of the reliability of the test is 0.686 which indicates that this test is also reliable. To examine the children’s understanding, their responses were marked by mapping with the levels of understanding on a rubric [12] (Table 1).

Intrinsic motivation survey: the survey in Thai version also was administered after completing the test. This survey posed 18 items (details in section 4) which covered perceived learning, concentration, enjoyment, interest, immersion, challenges, and skills [13]. IOC of the survey is 0.713 which indicates this test is valid while the Cronbach’s alpha is 0.706 which indicates that this survey is reliable.
Behaviors observation checklist: during the implementation process, video recording was employed to record the children’s behaviors and leaning activities. The behavior observation checklist was used by a co-researcher in each group. The checklist consists of 16 main behaviors of children’s expression (e.g. asking questions, thinking about something) and feeling (e.g. exited, laughing, upset).

Semi-structure Interview: some voluntary children in each grade were asked by two main questions: “what did you learn from this game?”, and “how do you feel when playing this game?” for evaluating their understanding and motivation.

3. Result and Discussion
3.1 Understanding of logic gates
From the students’ responses, we use the rubric to score their answers (Figure 3). The mean score of the first objective (remember conditions) was 13.90 out of total 20 scores (69.50%). The children were classified into little (1 child), emergent (5 children), partial (6 children), and almost complete (9 children) understanding levels. The average score of second objective (use conditions) is 8.76 out of total 20 scores (43.80%). The children were classified in little (8 children), emergent (6 children), partial (4 children), and almost complete (3 children) understanding levels. In a part of the average score of third objective (apply conditions in another context) is 6.43 out of total 20 scores (32.15%). The children were classified into no understanding (11 children), partial (9 children), and almost complete (1 child) understanding levels.

Figure 3. The number of children in each understanding level

Most children, especially in sixth and fourth grade, could develop their understanding of the logic gates through the Logic-Design board game. They could explain the keywords of conditions and identify the outputs of each logic gate. Moreover, they could write the routes by using the conditions of each logic gate in game context effectively in order to solve the problem in the test. Although there still were some drawbacks in applying to use the conditions of each logic gate in another context or their real-life activities.

During game playing, we observed most grade-six children frequently expressed the learning behaviors such as planning their own strategies to distribute and exchange foods, thinking about what condition cards they need to accomplish the game goal, and arranging their route with paths and condition cards beside the central board before their turn. We also saw those expressions from some grade-four children. One grade-four child seemed to have no plan to play. He played all the cards in
his hand without caring what the game goal is. Although some grade-six children could use all conditions correctly, it was not mentioned clearly by the interview. They mentioned to their strategies used in the game playing, including “I must think about any houses (means to the condition cards) before my turn to distribute some foods”, “I needed to think along playing what cards I will pick up”. These statements go in the line with the utterances of grade-four children who mentioned that “I always think what houses I should pick it up and where it should place until I won”.

Surprisingly, the grade-five children’s test scores contrast with their behavior and interview. Their learning behaviors go in the line with grade-six children even they showed slightly lower strategy planning than the grade-six children. In a part of interviewing, they did not mention about strategies they used, they just though that they wanted to be the winner of the game. Examples of their statements are “I tried to think how to be a first person who arrives at Granma’s house. So, I planned. But it always changes and I was not success because I did not have any cards that I want.”, and “I afraid my friends can arrive the grandma’s house before me. So, I decided to put a fox to block his route.”

However, it seems that the groups of grade-four children in this study presented higher performances than the groups of grade-five children from the test. By observing, the grade-five children seemed to lack attention to complete the test which effect their test scores They showed uncomfortable behaviors when they did the test contrasting with their behaviors when they play the game.

| Factors of intrinsic motivation | Negative Feedback | None Sure Feedback | Positive Feedback |
|--------------------------------|-------------------|-------------------|------------------|
| Perceived Learning             | 5                 | 5                 | 11               |
| Concentration                  | 6                 | 6                 | 11               |
| Enjoyment                      | 4                 | 6                 | 6                |
| Interest                       | 6                 | 6                 | 11               |
| Immersion                      | 9                 | 6                 | 11               |
| Challenge                      | 7                 | 6                 | 11               |
| Skill                          | 11                | 8                 | 11               |

### 3.2 Intrinsic motivation on learning logic gates

The results of the survey show the success in promoting the children’s intrinsic motivation. The frequency obtained from an intrinsic motivation survey were categorized into three types: negative neutral, and positive feedbacks. We founded the positive feedback gained highest frequency in all items. More than 50% of children had rated the positive feedback while less than 30% of children had responded the negative feedback (Table 2).

Particularly, the enjoyment factor gains the highest positive feedback (84.13%) while the skill factor was rated the least positive feedback (54.76%). In negative feedback, once again the skill feedback reaches the highest percentage (26.19%) and the enjoyment factor was the least one (6.35%).

From the observation, we also founded the children always expressed enthusiastic or requirement to play their own turn, laughing, smiles, fun, and excitement. Besides interviewing, they also mentioned that they enjoy and like to play the game. Examples of the utterances are “I feel very fun while played the game. Sometimes, I feel a little bit serious but still more fun”, “I like it. If I have a chance, I will play this game again because this time I played it not good.”

### 4. Conclusion

The results show the success of promoting the children’s intrinsic motivation on learning the concept of logic gates by using the Logic-Design board game for the children, especially on the enjoyment factor. Besides, in understanding aspect, learning the concept of logic gates through playing the Logic-
Design board game of the children can enhance their understanding in partial level. However, it still seems to be drawbacks for applying this concept to another context. For further study, we have planned to modify a few parts of the game, extend to a large sample size, and revise some research instruments for collecting data in both motivation and comprehension aspects.

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