



# DESIGNS FOR LEARNING

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# Between Sudoku rules and labyrinthine paths- A study on design for creative Sudoku learning

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*Sudoku is an intelligence game that has fascinated many people. In addition to offering entertainment, it also attracts players to solve more challenging Sudoku questions. Sudoku novices tend to fail to focus on understanding the operation rules because the grid, words, and numbers of Sudoku are too complicated. The main purpose of this study is to integrate the concept of illustrations of labyrinthine multipath into the interface design of rules teaching of Sudoku to complete the learning design of Sudoku games. The research subjects were a total of 73 elementary school third graders in Miaoli County in Taiwan. The study used a single group pre-test and formal test design to investigate the difference in students' learning effectiveness of Sudoku rules before and after they played Sudoku games.*

*This study used a self-developed ARCS learning motivation scale to analyze the effect of Sudoku game on students' learning motivation, and conducted in-depth interviews with three students with low learning achievement to observe their learning process and how their learning interest was aroused. The results showed that the Sudoku learning design with illustrations of labyrinthine multipath could help students understand Sudoku rules and enhance their learning interest in Sudoku.*

## INTRODUCTION

The concept of Sudoku originates from Latin Square, and was invented by Swiss mathematician Leonhard Euler in the 18th century. A Latin square is an  $n \times n$  array filled with  $n$  different symbols, each occurring exactly once in each row and exactly once in each column. Therefore, it is also called the Puzzle Game of Number Place. It was developed in the United States in the

1970s and then introduced into Japan where it gradually became popular and was formally named “Sudoku” (Delahaye, 2006). The rules of the world popular Sudoku game are simple and versatile. It does not require complicated mathematical calculations and only requires logical reasoning ability to play Sudoku. In addition to offering leisure and entertainment, Sudoku is also an intelligence game enabling players to use their brain to solve problems and train their logical thinking. It is suitable for general public to train their intelligence and logical thinking (Norte & Lobo, 2008). Grossi (2007) indicated that British Teachers magazine suggested the introduction of Sudoku into class, indicating that besides offering entertainment, Sudoku can help improve players reasoning and logical ability and be used as the teaching material for training students’ intelligence.

The researcher has played Sudoku for many years, and tried to help elementary school students understand Sudoku and enjoy the fun of it. The popular online Sudoku Forum showed that, after understanding Sudoku rules, novices usually exhibit two responses. Sudoku novices who can easily understand and use Sudoku rules usually are fascinated by the fun of numerical reasoning and can even further challenge more difficult problems and develop individual Sudoku problem-solving skills. On the contrary, those who cannot grasp Sudoku rules, and may easily feel confused tend to regard themselves as foolish people before or during the playing process. They may even suggest that they are lacking in problem-solving ability or complain that they are lacking in the ability to understand. Therefore, they are not interested in Sudoku games and are unwilling to further try to solve other Sudoku problems (Enjoy Sudoku, 2012). The learning content of current Sudoku websites usually introduces Sudoku problem-solving skills, and uses various images and texts to explain Sudoku problem-solving process. Animations or challenging games are less frequently used to present problem-solving rules and the concept of use. To Sudoku novices (especially elementary school students), such a method may simplify the explanation on Sudoku game rules and even help them understand the application of various problem-solving skills, instruct novices in accepting Sudoku games, and further make them become willing to challenge more complicated Sudoku problems.

Labyrinth – the term first appeared in ancient Greek mythology. It describes the place where the demigod hero fought against the half-man

half-cow monster. The hero follows the rope leading to the correct path of labyrinth to walk out of it after winning the victory (Kerenyi, 1976). At present, labyrinth becomes the elements triggering the development of many interesting themes. For example, mythology, fictions, and fairy tales usually take place in labyrinth (Minghella, 1997). Moreover, labyrinth is usually the background of digital games. For example, the background of Pac Man game of Arcade Game originating from the 1980s is labyrinth. The Pac-man similar to a 3/4 circle controlled by players has to eat the food on the paths in the twisted labyrinth and concurrently avoid the attack from foes (Wistrom, 2010) to complete the game. Labyrinth is characterized by the intuitive nature. In addition to single entrance and exit, the bifurcation leads to various confusing and twisted path patterns (Doob, 1990; Pokora, 2008). In order to increase the excitement of game, missions such as eliminating targets, dodging enemies, and looking for specific treasures, are additionally included into a labyrinth. On the paths of a labyrinth where players may easily get lost, players' challenging motivation can be strengthened and the excitement of game can be increased as well.

Passini (1996) pointed out that whether players can clearly identify orientation and walking direction in a labyrinth is closely related to the Wayfinding Design. Elvins (1997) mentioned that the term – Wayfinding is defined as the ability how individuals use adequate approaches and make sure of designation to look for a certain path and reach a specific location. Wayfinding is also the process to look for solutions via continuous spatial orientation. The process includes the perception and cognition of the surrounding environment, strategies of transforming surrounding environmental information into path, actual on-site action plan, and the overall procedures to implement strategies at adequate locations (Arthur & Passini, 1992). Therefore, Wayfinding is the process of selection of direction and location and exploration of path. Wayfinding behavior is composed of four stages (Downs & Stea, 1973; Lawton, 1996): (1) To preliminarily understand the location of designation, to observe the relationship between destination and the surrounding environment, and to make a choice based on map and the comprehensive indices and existing environmental information; (2) To use Survey Orientation strategy after understanding the surrounding environment: to use the geographic information distribution map of location and landmark, including the concepts of distance, direction, and location,

to combine it with network system as the concept of two-dimensional space; Route Orientation: to use mobile path to connect location with the geographic information of landmark to form the concept of one-dimensional space; (3) To constantly monitor the path to the destination and make sure of the correctness of direction during the behavioral process and to integrate and assess information through information collection and update and construction of mental mapping; (4) To identify nearby location or to confirm the landmark in order to reach the destination correctly through inquiry or map guiding before/after moving to the correct path at the last stage of destination identification. Krieg-Bruckner et al. (1998) also indicated that Landmark knowledge and Route knowledge designs hidden in relevant indices and visual objects are factors affecting users' possession of Survey knowledge for wayfinding.

Learning motivation is the main cause for the good interaction between designers and learners (Prensky, 2001). Csikszentmihalyi (1975) suggested that a good motivation can lead learners into Flow stage, guide them into highly focused learning condition, and help them reach Immersion stage. The factors affecting the occurrence of immersion include skill and challenge. If skills are higher than challenges, learners will feel bored. On the contrary, if skills are lower than challenges, learners will feel anxious and their motivation will be significantly reduced. Csikszentmihalyi (1996) also suggested that in a game situation, the integration of incentives such as entertainment and fun, into game design can attract players to explore the same and guide them into accepting challenging assignments and obtain satisfaction and achievement during problem-solving process. Keller (1983, 1984 and 1987) proposed the four-dimension model of learning motivation – A (Attention), R (Relevance), C (Confidence), and S (Satisfaction), in order to take into account the methods to enhance learning motivation. For example, Attention-based design is to attract the attention and concentration of learners and to increase their interest. Relevance-based design is to increase learners' understanding of relevant learning content, and the teaching design has to conform to learners' objectives and connects them with their previous experiences to enhance their motivation. Confidence-based design is to increase learners' learning confidence. Learning motivation and effectiveness will be affected if the excessively difficult learning content makes learners feel afraid or the excessively simple one makes them

feel bored. Satisfaction-based design it to enable learners to obtain satisfaction in learning, to maintain their learning motivation, and to achieve objectives or obtain feedback during learning process.

The main purpose of this study is to combine the illustration of labyrinthine multipath with the wayfinding characteristic of labyrinth and to apply them to the learning design for understanding of Sudoku rules, in order to help elementary school students who are Sudoku novices learn to play Sudoku. This study used the illustrations of labyrinth as a visual tool to complete the interface design and learning content of Sudoku rules in order to help students understand Sudoku rules and problem-solving process through the clues of multipath. Elementary school third graders were mainly selected as subjects. This study used a single group pre-test and formal test design to investigate the difference in learning effectiveness of Sudoku rules before/after students play the Sudoku game with illustration of labyrinth. In addition, this study used a self-developed ARCS learning motivation scale to analyze students' learning motivation, and conducted in-depth interviews to observe their learning process and how their interest was aroused.

## DESIGN OF SUDOKU GAME WITH ILLUSTRATIONS OF LABYRINTH

### LABYRINTHINE DESIGN

The function of the design concept of illustrations of labyrinth is to guide students to determine correct paths and to give them clues to the number to be filled into Sudoku grids. In the end, it will explain in detail the reason to fill in such number to increase students' understanding of the concept of Sudoku rules. In a Sudoku game, each number occurs exactly once in each row and exactly once in each column of the grids. The bifurcation of labyrinth multipath was integrated into Sudoku to reveal the common mistakes to be made when numbers are filled in corresponding grids in order to help learners progressively understand Sudoku rules. There are many patterns of Grids layout of Sudoku game. In general, the most basic one is a  $9 \times 9$  Sudoku grid layout. Students who are Sudoku novices usually start to experience Sudoku through  $4 \times 4$  or  $6 \times 6$  grid layout. However, the change in Sudoku grid layout is associated with the bifurcation of labyrinth multipath. If a  $9 \times 9$  grid is used, the bifurcation of labyrinth multipath will be

more complicated. As a result, this study used  $4 \times 4$  grid layout as the basic Sudoku problem.

#### DEFINITION OF SUDOKU PROBLEM-SOLVING ORDER

In terms of labyrinth image design, cute animals that students are familiar with were used as Avatars to arouse students' interest in labyrinth. When students started to solve the labyrinth, they could choose the representative animal at the entrance grid. The Wayfinding and problem-solving process of labyrinth were established based on Sudoku rules and the existing problem-solving order of  $4 \times 4$  Sudoku grid layout. Taking the Sudoku problem in Figure 1 as an example, (D, 2) grid was the entrance, and the answer could be obtained based on the rule that a number cannot occur repeatedly. The answer of (C, 1) could also be obtained based on the rule that a number cannot occur repeatedly. Consequently, the problem-solving order was as follows: (D, 2)->(C, 1)->(B, 2)->(B, 1)->(A, 1)->(C, 3)->(D, 4)->(D, 3)->(A, 3)->(A, 4). During the problem-solving process, the students were constantly instructed in the concept of Sudoku rules.

	A	B	C	D
1	5	4	2	2
2	3	3	1	1
3	9	4	6	8
4	10	3	4	7

Figure 1:  
Definition of Sudoku Problem-solving Order  
(source: compiled by this study)

#### DESIGN OF BIFURCATION OF LABYRINTH MULTIPATH

According to the problem-solving order of Figure 1, there were 10 problem-solving procedures totally. Because students could answer the last grid

without being provided with any clue, there were 9 forking paths totally corresponding to the problem-solving order. Figure 2 (a) was the corresponding labyrinth where the Sudoku problem-solving order and its corresponding labyrinth forking paths were designed and the target destination was sought by an animal: during the process of existing the labyrinth, the information on potential options of numbers might appear at the fork in the path for each problem-solving procedure. Moreover, bifurcation effect would be developed in response to the quantity of paths. For a correct path, the clue of a correct number would be given. For a wrong path, on the contrary, the clue of a wrong number would be given. Figure 2(b) was the design result of the forking paths corresponding to the problem-solving order. At the entrance of D2, the clue of a correct number “4” was placed on the path leading to the left. On the contrary, the clue of a wrong number “3” was placed on the path leading to a dead end.

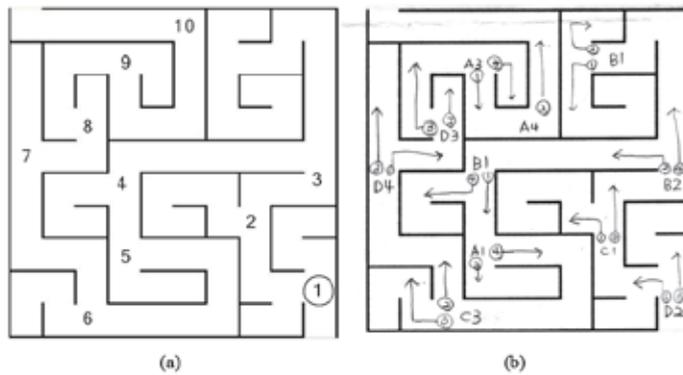


Figure 2:  
Design concept of forking paths of labyrinth: integrated with Sudoku  
problem-solving order (source: compiled by this study)



(a) Explanation on grid coordinates  
 (b) Cute animals corresponding to path choices



(c) Forking paths of labyrinth corresponding to Sudoku grid layout  
 (d) Explanation on concept of specific answer (number) in the grid

Figure 3:

Interactive design of labyrinth (source: compiled by this study)  
 see <http://can.elt.nhcue.edu.tw/LabyrinthineSudoku/index.html>

#### LABYRINTH INTERACTIVE INTERFACE DESIGN

After the forking paths of labyrinth were designed, design of labyrinth interactive interface was initiated. Before the commencement of instruction of Sudoku, the students were instructed to understand the concept of grid coordinates (Figure 3a) in advance and assisted in understanding the grid location of Sudoku grid layout. Moreover, cute animals were provided to instruct students to choose paths (Figure 3b). After students chosen a certain path, the animal would stop at the intersection where potential numbers

would appear. If students chose the wrong number, the animal would be led to a dead end and students would be provided with a negative feedback. On the contrary, if they chose the correct number, a detailed explanation on why the number was filled in the grid would be given and reasoning process of the number would be displayed to instruct students to understand Sudoku rules (Figure 3c, d).

#### EXPERIMENTAL DESIGN

A total of 73 elementary school third graders in Miaoli County in Taiwan were selected as the research subjects. This study used a single group pre-test and formal test experimental design and a self-developed test to investigate students' difference in learning effectiveness of Sudoku rules before/after they played the Sudoku game. As shown in Figure 4, the experimental design included the pre-test and formal test. During the pre-test, the basic introduction of Sudoku rules was given in the lecture. After the lecture was over, a test was performed to find out a total of 50 students who failed to successfully understand Sudoku rules in order to perform the formal test. During the formal test, students were instructed to play the Sudoku game with illustrations of labyrinthine multipath. The teaching lasted for 120 minutes. After the lecture was over, a formal test was performed to compare it with the pre-test result in order to analyze whether students' level of understanding of Sudoku rules was changed. In addition, the self-developed ARCS learning motivation scale was used to analyze the effect of Sudoku game on students' learning motivation. This study also conducted in-depth interviews with three students with low learning achievement of Sudoku rules (i.e. those whose learning achievement of the pre-test was lower than that of the formal test) to observe their learning process and how their interest was aroused as the investigation of qualitative data. The test on Sudoku rules used in the pre-test and formal test was designed based on the Sudoku rule that a number can occur exactly once in each row and exactly once in each column of the grids. A total of 10 items were designed as the analysis tool to test learning effectiveness. A t test analysis was performed in the end to compare the difference in learning effectiveness of Sudoku rules.

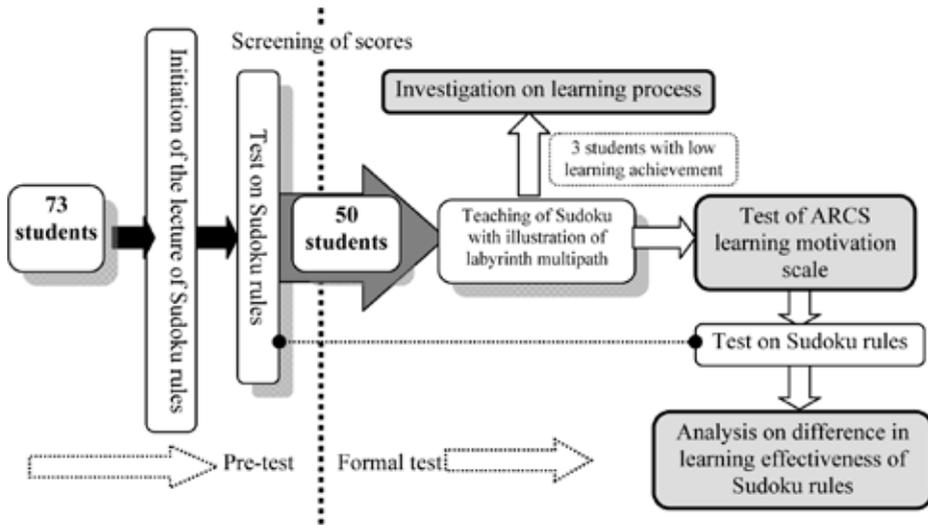


Figure 4:  
Study procedures

This study designed the learning motivation scale as the teaching material of illustrations of labyrinth based on the ARCS motivation model proposed by Keller (1983, 1984, and 1987), and performed assessment from four motivation dimensions, Attention, Relevance, Confidence, and Satisfaction. The relationship between various dimensions and the test on learning motivation for teaching material with corresponding illustrations of labyrinth was shown in Table 1. Cronbach's alpha ( ) coefficient was used to analyze the reliability of questionnaire test result. The overall reliability value was 0.873, suggesting that the reliability of scale was acceptable.

Motivation factors	Learning motivation for teaching material with illustrations of labyrinth (Corresponding items)	Cronbach's alpha( $\alpha$ )
<b>Attention</b> (6 items totally)	It can arouse students' curiosity about Sudoku. (A-2, A-3)	<b>0.633</b>
	It enables students to focus on Sudoku game. (A-1, A-4, A-5, A-6)	
<b>Relevance</b> (7 items totally)	It enables students to understand Sudoku rules through the game process. (R-1, R-5, R-6)	<b>0.636</b>
	It enables students to understand the connection between labyrinth paths and Sudoku game. (R-2, R-3, R-4, R-7)	
<b>Confidence</b> (5 items totally)	Students' confidence in success can be established once the game is completed. (C-2, C-3)	<b>0.759</b>
	The fun of labyrinthine Sudoku game enables students to develop a positive expectation towards Sudoku. (C-1, C-4, C-5)	
<b>Satisfaction</b> (6 items totally)	Students obtain satisfaction because they have learnt knowledge from the game. (S-1, S-2, S-6)	<b>0.679</b>
	Students obtain satisfaction because they complete assignments in the labyrinthine Sudoku (S-3, S-4, S-5)	
24 items totally		<b>0.873</b>

Table 1:  
Relationship between ARCS motivation factors and labyrinth Sudoku  
(source: compiled by this study)

## RESULTS

### ANALYSIS ON THE DIFFERENCE IN LEARNING EFFECTIVENESS OF SUDOKU RULES

This study provided a lecture on Sudoku for 73 elementary third graders. The results of the pre-test on the level of understanding of Sudoku showed that the answers of 23 students (31.5%) totally to the 10 questions were completely correct. Consequently, this study performed the formal test on the rest of them (50 students), and used the teaching material of Sudoku game with illustrations of labyrinth to instruct them in Sudoku rules. As shown in Table 2, the t test analysis was performed on the test scores of the pre-test ( ) and formal test ( ). The null hypothesis was as follows:., As shown in Table 3 and Table 4, on average, the number of questions with correct answers in the formal test was larger than that in the pre-test by 1.82 questions. In addition,  $t=-6.9631$ ,  $p\text{-value}=0.000<0.05$ . As a result,  $H_0$  was rejected while  $H_a$  was accepted. In other words, there was a significant difference between the pre-test and formal test scores of the understanding of Sudoku rules, suggesting that students' learning effectiveness significantly improved after the implementation of teaching of Sudoku game with illustrations of labyrinth.

Number of questions with correct answers	Pre-test			Formal test		
	Total number of students	Percentage	Handling method	Number of questions with correct answers	Total number of students	Percentage
10	23	31.5 %	Not being enrolled in the formal test	10	28	56.0%
9	14	19.2 %	Being enrolled in the formal test: Learning of Sudoku with illustrations of labyrinthine multipath	9	10	20.0%
8	16	21.9 %		8	5	10.0%
7	6	8.2 %		7	4	8.0%
6	4	5.5 %		6	2	4.0%
5	6	8.2 %		5	1	2.0%
4	3	4.1 %		--	--	--
2	1	1.4 %		--	--	--
	73	100%		50	100%	

(source: compiled by this study)

Table 2:  
Distribution of number of questions with correct answers of students in the pre-test and formal test

	Mean	Number	Standard deviation	Standard error of the mean
Pre-test	7.28	50	1.74	.24585
Formal test	9.10	50	1.30	.18350

(source: compiled by this study)

Table 3:  
Results of number of questions with correct answers in the pre-test and formal test

	Pairwise difference					t	Degree of freedom	Significance (Two-tailed)
	Mean	SD	Standard error of the mean	95% confidence interval				
				Lower limit	Upper limit			
Pre-test- Formal test	-1.82	1.8482	0.261378	-2.345258	-1.294741	-6.9631	49	0.000

t=-6.9631, p-value=0.000<0.05 (source: compiled by this study)

Table 4:

The t test analysis on the number of questions with correct answer in the pre-test and formal test

#### ANALYSIS ON TEST OF ARCS LEARNING MOTIVATION

After the formal test was completed, this study used ARCS to investigate students' learning motivation, and performed descriptive statistical analysis. The test results and analysis of various factors were as follows:

#### ATTENTION FACTOR

The test results of Attention factor were shown in Table 5. The overall mean was 4.23. 77% of students agreed with the items, and 9% of them disagreed with items, suggesting that most of the students agreed with the effect of illustrations of labyrinth on attention factor. The results of items A-5 and A-6 showed that the avatar (animal) in Sudoku game with illustrations of labyrinth could guide students to solve problems. In general Sudoku game, players have to explore the game by themselves. The addition of labyrinthine elements made Sudoku game become more diversified and interesting and assisted students in concentrating on it.

Attention								
Items	Assessment results (%)	5	4	3	2	1	Mean	SD
A-2	There are many changes occurring during the game.	44%	38%	12%	2%	4%	4.16	0.9971
A-3	I develop the idea to challenge the game after the game is over.	58%	8%	22%	6%	6%	4.06	1.2683
A-4	I know that a "4 × 4" Sudoku game is to fill in the numbers 1~4 in the grids.	44%	22%	22%	4%	8%	3.9	1.2495
A-5	The functions offered in the game can help me focus on the change in Sudoku game.	70%	20%	4%	4%	2%	4.52	0.9089
A-6	I can focus on thinking about the numbers to be filled in the grids with the instruction of animal in the labyrinth.	76%	12%	10%	0%	2%	4.6	0.8330
Mean		58%	19%	14%	5%	4%	4.2267	

(source: compiled by this study)

Table 5:  
Assessment of learning motivation - "Attention"

#### RELEVANCE FACTOR

The test results of Attention factor were shown in Table 6. The overall mean was 4.34. 82% of students agreed with the items, and 4% of them disagreed with items, suggesting that most of the students agreed with the effect of illustrations of labyrinth on Relevance factor. The results of items R-6 and R-7 showed that the multipath clue provided by animal at intersection in Sudoku game enabled students to understand the connection between labyrinth and Sudoku. Students could understand Sudoku rules through the processing of giving the wrong answers. In addition, they could understand that the text feedback displayed when they gave the wrong answers was correlated with Sudoku rules.

Relevance								
Items		Assessment result (%)					Mean	SD
		5	4	3	2	1		
R-1	I can fully understand how to play a Sudoku game.	62%	22%	14%	2%	0%	4.44	0.8122
R-2	I can achieve my objective during the process of the game.	60%	12%	20%	4%	4%	4.20	1.1429
R-3	The content of the game is helpful to me.	52%	32%	8%	4%	4%	4.24	1.0412
R-4	I can associate the content of the lecture with the knowledge that I have learnt before.	48%	30%	16%	4%	2%	4.18	0.9833
R-5	The content of the game can help me understand the rules of Sudoku game.	58%	24%	16%	0%	2%	4.36	0.8981
R-6	I know that the rule of Sudoku game is that each number occurs exactly once in each row and exactly once in each column of the grids.	70%	14%	12%	0%	4%	4.46	0.9941
R-7	The clues provided by the animal in the labyrinth can help me find out the answer in the grids.	64%	22%	12%	2%	0%	4.48	0.7887
Mean		59%	23%	14%	2%	2%	4.34	

(source: compiled by this study)

Table 6:  
Assessment of learning motivation - “Relevance”

#### CONFIDENCE FACTOR

The test results of Confidence factor were shown in Table 7. The overall mean was 4.43. 83% of students agreed with the items, and 4% of them disagreed with items, suggesting that most of the students agreed with the effect of illustrations of labyrinth on Confidence factor. The results of items C-1, C-2 and C-3 showed that the design of game screen could attract students’ interest and eliminate their sense of unfamiliarity. With the instruction from cute animal images, students could complete the assignment of the game more easily. Most of the students could exhibit their confidence after they completed Sudoku game.

Confidence								
Items		Assessment results (%)					Mean	SD
		5	4	3	2	1		
C-1	With the instruction from the labyrinth, I am confident that I know how to play the game.	70%	22%	8%	0%	0%	4.62	0.6354
C-2	I am confident that I can achieve the objective of the game.	70%	16%	12%	2%	0%	4.54	0.7879
C-3	When I play the game, I am confident that I can successfully complete it.	64%	14%	18%	4%	0%	4.42	0.8827
C-4	I complete the game because I have made efforts.	58%	24%	12%	4%	2%	4.32	0.9781
C-5	I think that it is not difficult for me to complete the game.	58%	18%	16%	8%	0%	4.26	1.0063
Mean		64%	19%	13%	4%	0%	4.43	

(source: compiled by this study)

Table 7:  
Assessment of learning motivation - “Confidence”

#### SATISFACTION FACTOR

The test results of Confidence factor were shown in Table 8. The overall mean was 4.27. 79% of students agreed with the items, and 8% of them disagreed with items, suggesting that most of the students agreed with the effect of illustrations of labyrinth on Satisfaction factor. The results of items S-2 and S-4 showed that to most of the students, Sudoku game was a new attempt. Even though they did not fully understand it in the beginning, they could gradually become familiar with it and obtain satisfaction with the assistance from illustrations of labyrinth. In addition, they agreed that they have understood Sudoku rules and problem-solving skills.

Satisfaction								
Items		Assessment results (%)					Mean	SD
		5	4	3	2	1		
S-1	I can challenge Sudoku problems by myself after learning the Sudoku game with illustrations of labyrinth.	56%	24%	10%	4%	6%	4.2	1.1606
S-2	I can learn knowledge or skills from the game.	72%	14%	10%	2%	2%	4.52	0.9089
S-3	I feel satisfied when I fill in the correct numbers in the grids.	44%	32%	10%	10%	4%	4.02	1.1516
S-4	I feel satisfied when I successfully find out the answers.	56%	30%	12%	2%	0%	4.4	0.7825
S-5	I feel satisfied when an increasing number of answers in the grids that I fill in are correct.	52%	18%	22%	6%	2%	4.12	1.0812
S-6	I still can persist to the end even though I cannot achieve the objective of the game.	58%	22%	12%	6%	2%	4.28	1.0309
Mean		56%	23%	13%	5%	3%	4.27	

(source: compiled by this study)

Table 8:  
Assessment of learning motivation - “Satisfaction”

#### INVESTIGATION OF LEARNING PROCESS

After the formal test was completed, this study further probed into the learning process of three students with low learning achievement. The number of questions with correct answers from students in the pre-test and formal test was shown in Table 9, suggesting that the learning effectiveness of students with low learning achievement significantly improved after the formal test.

Code	Gender	Pre-test	Formal test
		Number of questions with correct answers /total number of questions	Number of questions with correct answers /total number of questions
S1	Male	2/10	6/10
S2	Female	4/10	10/10
S3	Male	4/10	9/10

(source: compiled by this study)

Table 9:  
Number of questions with correct answers from students in the pre-test and formal test

The in-depth interview process was filmed and recorded. In addition, the interview content was converted into transcripts for investigation and analysis. The results of the investigation on three students' learning process of Sudoku game with illustrations of labyrinthine multipath based on the transcript content were as follows.

STUDENTS WOULD BE EASILY ATTRACTED BY THE GAME SCREEN  
WITH ILLUSTRATIONS OF LABYRINTH

The on-site observation on students using illustrations of labyrinth found that students focused on the screen with illustrations of labyrinthine multipath. According to the oral inquiry, the students indicated that they found the game interesting, especially during the screen teaching of "explanation on coordinates" when students could learn the concept of Sudoku grid coordinates and associate it with Sudoku rules. Moreover, when students were requested to indicate specific coordinate location, they could also precisely indicate it.

ILLUSTRATIONS OF LABYRINTH COULD HELP STUDENTS  
REATTEMPT TO PLAY SUDOKU

The interviews found that after completing Sudoku game with illustration of labyrinth for the first time, most of the students were willing to try it again by themselves and accept the challenges from the game. According to the oral inquiry, the students all indicated that the lecture on Sudoku rules received during the pre-test could not help them fully understand Sudoku rules. However, they found the learning method of Sudoku with illustration of labyrinth interesting, especially when they could choose different animals to represent different labyrinth entrances.

THE ILLUSTRATIONS OF LABYRINTH COULD HELP  
EXPLAIN SUDOKU RULES

The observation found that, when students were learning the illustrations of labyrinth, they usually focused on the multipath screen of labyrinth, especially when they were unfamiliar with Sudoku rules. The path direction of labyrinth could easily assist students in solving Sudoku problems.

## DISCUSSION

This study used illustration of labyrinthine multipath to exhibit the concept of Sudoku rules to assist students in understanding the rules of Sudoku game. A self-developed test was used in the pre-test/formal test to understand students' level of understanding of Sudoku rules. This study used a T test to analyze the learning effectiveness of Sudoku rules with illustrations of labyrinth. The results showed that the number of questions with correct answered increased from 7.28 questions in the pre-test to 9.1 questions in the formal test (shown in Table 3). The learning effectiveness significantly improved. After the formal test, this study also used ARCS learning motivation scale to test students' performance, and probed into the learning process of three students with low learning achievement. The comprehensive analysis found that in the design with illustration of labyrinth, the use of cute animal avatars could easily guide students to focus on the observation of numbers in the grids. The clues of path direction and numbers provided by cute animals could help students think about problem-solving methods. The overall illustrations of labyrinthine multipath enabled students to become confident that they can complete the challenges of Sudoku games, to agree that they can understand the Sudoku rules during the game, and to exhibit positive learning motivation.

In the investigation of learning process after in-depth interview of three students, some findings could be summarized from interview transcripts. The students could precisely indicate specific coordinate location in the learning process. Therefore, this study suggested that the game screen with illustrations of labyrinthine multipath could assist students in focusing on the learning content. Furthermore, students also enjoyed assisting different cute animals in obtaining their favorite food after exiting the labyrinth. In addition, the students found the learning method of Sudoku with illustration of labyrinth interesting, especially when they could choose different animals to represent different labyrinth entrances. Detailed path instructions and rule explanations were provided during the Wayfinding process, which could assist students in successfully complete the assignments of the game and make them willing to reattempt to play the game. According to oral inquiry, students also suggested that the illustrations of labyrinth could help them easily understand the Sudoku rule: each number occurs exactly once in each row and exactly once in each column of the grids. Moreover,

compared with the lecture on Sudoku rules in the pre-test, such illustrations were interesting and could help them understand Sudoku rules more easily.

To associate the change in labyrinthine multipath with the problem-solving process of Sudoku, the multipath design of labyrinth is undoubtedly closely related with Sudoku rules and complexity of problem-solving. This study suggested that, after a Sudoku problem is chosen, it is preferable to define the problem-solving order first. The principle for drawing multipath is: the number of intersections of labyrinthine multipath = number of grids of (initial layout) - 1. The Sudoku problem-solving order should be integrated with the labyrinth where each problem-solving procedure corresponds to the intersections of labyrinthine multipath. Moreover, a correct number and a (potential) wrong number should be placed on the correct path and wrong path, respectively.

Illustrations of labyrinthine multipath can be regarded as a visualizing clue guiding learners to explore the change in other learning process during a game. The path design Sudoku game with illustrations of labyrinth was developed by designers. Future studies may use programs to develop more clue options of different multipath patterns and directions corresponding to the problem-solving process of learners at the intersections of labyrinth, which can increase the diversity of problem-solving process of Sudoku game. Moreover, Illustrations of labyrinth may also be applied to more complicated Sudoku grid layouts or the development other learning content, such as multiple digital narrative structure and learning of language grammar, and problem-solving process of games similar to Hanoi Tower in the future.

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