

Development of a Boolean Logic Game for Visual, Auditory and Kinesthetic Learning Styles

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Abstract— This research aims to develop a top-down game to provide a comfortable learning environment for students with various learning styles. We use the visual, auditory and kinesthetic (VAK) learning style model. Top-down game development meets learning content needs within a Personalized Learning Environment (PLE). PLE is a system that is able to adapt students' characteristics in learning so that they can learn optimally. In this case, we chose Boolean algebra material presented to students taking Discrete Mathematics and Computer Architecture courses. The development of this learning environment uses the 4D method from Thiagarajan up to the third stage (Define, Design, Develop). The Define stage produces an instructional design consisting of Boolean algebra symbol material, Boolean algebra operations, and logic gate operations. The Design stage produces nine mini game designs representing three materials and each available for three learning styles. The nine game designs have been declared in accordance with the objectives of instructional design based on material expert validation. The Develop stage produces a digital game, media experts state that the game meets the parameters of digital game validity.

Index Terms—Learning Style, Top-Down Game, Four-D Method

I. INTRODUCTION

The development of e-learning has experienced significant progress as a consequence of the rapid development of technology [1]. However, most e-learning is still developed with a uniform learning model and is not able to accommodate diverse learning objects [2]. An effort to overcome this problem is through the development of a Personalized Learning Environment (PLE) system. PLE can help teachers identify students' abilities and learning processes so that they can accommodate students' learning needs

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appropriately [3]. The development of PLE that is integrated with learning styles so far still uses the questionnaire method so that the identification process is slower [4]. Because of these problems, it is the reason for opening up research opportunities for integration between learning styles and PLE [4].

Learning style is the way students use the learning process and absorb information [5]. Every student has a different learning style [4]. In this development research, we chose the Visual, Auditory and Kinesthetic learning style model from Neil D. Fleming [6]. An integrated learning media with the ability to capture learning styles can optimize the learning flow [4]. For teachers, personalized learning based on student learning styles can help them in customizing instructional and learning materials [4].

PLE development requires learning content that suits the characteristics of each student's learning style. Many journals have revealed the added value of using games in conveying learning contexts and carrying out educational scenarios [8]. Games with the Role-Playing Game (RPG) genre are effective in improving student performance [9]. In the PLE that we will develop, we need a game model that makes it easier for students to see the game broadly to make it easier for them to explore in the game. We found that the characteristics of games like that are found in the top-down model [7].

The development of this media requires a series of comprehensive steps, but we can still view each stage partially. The method we need is also user-oriented and prioritizes evaluation at each stage. We can find these requirements in the 4D method consisting of Define, Design, Develop, and Disseminate from Thiagarajan [10]. We can see the effectiveness of the 4D method in developing teaching materials or learning tools in training based on predetermined instructions [10]. In this research we limit development achievements to the third stage, namely Define, Design and Develop (3D).

II. METHOD

The type of research used in this development is research and development (R&D) with the 4D method model from Thiagarajan [10]. This method was chosen because it was considered able to present a simple development model with 4 main steps [11]. Based on the research objectives, we applied the Thiagarajan model to

the Develop stage and obtained validation from media and material experts. Figure 1 depicts the model.

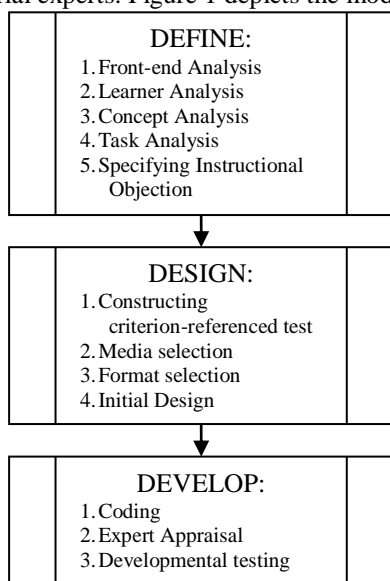


Figure 1. The Thiagarajan's model up to Develop Stage

In Figure 1, there are additional steps in the 4D method, namely the coding step at the Develop stage. This step was added because the media being developed was a game. The following is an explanation of the steps in Figure 1.

1. Define

This stage is carried out in order to obtain the instructional needs of a class [10]. In this case, this stage is carried out to obtain the requirements of the PLE system. In this define stage there are several steps that must be fulfilled. Following are the steps according to Thiagarajan [10].

Table 1 Description of Each Define Stage

No.	Define Stage	Description
1	Front-end Analysis	This is a step to obtain and determine the needs of a class in general based on applicable instruction [10].
2	Learner Analysis	This is a step to determine the characteristics of students who will receive learning games [10].
3	Task Analysis	This is a step to determine the main tasks that must be carried out by students to obtain minimum competency [10]. In the context of game development, students must complete missions in the game to find out the teacher's

learning style.

4	Concept Analysis	This is a step to determine the basic concepts that will be taught to students for the learning content in the game.
5	Instructional Object Specifications	This is the step of writing learning objectives and expected behavioral changes after learning. Usually structured with operational verbs.

2. Design

After getting the instructions that have been created at the Define stage, the next step is to design the game that will be developed. At the design stage, there are steps that must be fulfilled. Table 2 shows the design steps according to Thiagarajan [10].

Table 2 Description of Each Step in the Design Stage

No.	Design Stage	Description
1	Constructing Criteria from Tests	This is a step to build assessment criteria and indicators of students' success in understanding the concepts being taught. After determining the indicators, the next process is creating a mission that must be carried out by students in the game they are playing.
2	Media selection	This is a step in determining the learning media that will be used to facilitate the learning process.
3	Format selection	This is a step in determining the format of a system to be developed. In this development context, the format is in the form of game specifications and how the game works.
4	Initial design	This is a design step for the game to be developed. This design is based on instructions, criteria, indicators, media and formats that have been determined in the previous process. The results of this design are in the form of character designs, game flow

designs, available mini-game designs, game mechanisms, and so on.

3. Develop

This stage is the stage of developing a previously created design into a finished product [10]. We carry out the Develop stage until we obtain expert validation. Expert Appraisal is a validation stage from various experts involved to assess the feasibility of the product being developed [10]. In this development, the experts involved in validation are material experts and media experts. This validation is carried out by experts trying out the game that has been created and then filling out a questionnaire to assess the suitability of the game.

In each questionnaire created, the scores used in the questionnaire use a Likert scale. The Likert scale is usually used to measure attitudes, perceptions or opinions on a social event [14]. In this development, the scale used is five levels by eliminating the score 3 on the questionnaire. This was done to force respondents to choose one of the poles between agreeing and disagreeing.

After getting the expert validation results and student responses, the process is calculated. Each of these calculations uses an average formula as follows.

$$x = \frac{\sum x}{n} \quad (1)$$

With:

x = Average

$\sum x$ = Number of data

n = Lots of data

After getting the average results, then calculate the eligibility percentage using the following formula.

$$P = \frac{f}{N} \times 100\% \quad (2)$$

With:

P = Percentage

f = Score obtained

N = Maximum score

$$\bar{P} = \frac{\sum P}{n} \quad (3)$$

With:

\bar{P} = Average percentage

$\sum P$ = Total percentage

n = Number of assessors

Then, the percentage that has been obtained is converted into eligibility criteria using a rating scale.

III. RESULT

A. Define

The Define stage produces instructional specifications for learning. In the define stage there are steps that must be taken. The following are the steps for the define stage and the results.

1) Front-end Analysis

The material that will be presented in the game is Boolean algebra material which is the basis of computer science [15]. This material is taught in the Computational Mathematics and Computer Architecture courses.

2) Learner Analysis

Participating students need to master Boolean algebra material in order to complete the game. Because students have different learning styles, the game provides different learning environments depending on the learning style the students have. Each learning style has its own characteristics [16].

3) Task Analysis

Students complete assignments by completing games. This is a way to learn Boolean algebra in an interesting way. In the game, there are three stages, in each stage there is one mission. In the stage, students are asked to collect balls which represent Boolean logic symbols. In each stage, there are three different learning environments available and students are free to choose which learning environment they feel is most comfortable for completing the mission. Details of the material that will be included in each mini game are:

- Introduction to symbols in Boolean algebra.
- Logical operations in Boolean algebra in the form of statements.
- Logic operations in Boolean algebra in the form of logic gates.

After students complete the mission, the game opens a portal to go to the next stage until the stage ends

4) Concept Analysis

Boolean algebra is a mathematical structure formed from logical rules [15]. Boolean algebra is used to design circuits with input variables 0 and 1 which produce output variables in the form of 0 and 1 as well [15]. Because it is formed from logical rules, Boolean algebra uses logical operations such as AND, OR, and NOT [17]. Boolean algebra is the basis of computer science because circuits in computer systems work using bases 0 and 1 [15]. Figure 2 shows us the compilation of truth tables from those logical operations.

NOT		AND			OR		
A	A'	A	B	A.B	A	B	A+B
0	1	0	0	0	0	0	0
1	0	0	1	0	0	1	1
		1	0	0	1	0	1
		1	1	1	1	1	1

Figure 2 Logical Operations in Boolean Algebra

Logic operations can also be described as electronic circuits that have basic elements called logic gates

[15]. Just like logic operations, logic gates also have basic operations; AND, OR, and NOT [15]. Figure 3 shows these logic gate.

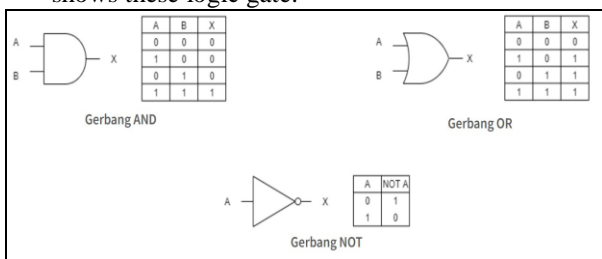


Figure 3 Logic Gates in Boolean Algebra

5) Instructional Object Specifications

After getting an overview of the material requirements for the game, here are the specifications for the instructional objects you want to achieve.

- a) Students can identify two statements in Boolean logic, namely true and false statements.
- b) Students can identify the operations that occur in two statements in Boolean logic.
- c) Students can use Boolean symbols to express two statements.

B. Design

At this stage, the instructional object specifications that have been created are used to design the game to be developed by adding elements of the Game Design Document from John Haste [18]. The game design results are as follows:

- 1) Constructing Criteria from Tests
Indicators to determine students' success in understanding Boolean algebra material.

Table 3 Tasks for students as players

No	Task
1.	In the first stage, students must collect two balls marked "TRUE". The task measures students' ability to identify true statements.
2.	In the second stage, students must collect two balls marked "FALSE". This task measures students' ability to identify false statements.
3.	In the third stage, students must collect several chakras marked "NOT", "AND", and "OR". This task assesses students' ability to use Boolean logic symbols to express the relationship between two statements.

2) Media Selection

The game runs on PC-Desktop platforms via browsers like Google Chrome, Microsoft Edge, Mozilla Firefox, etc.

3) Format Selection

The game is made in a top-down format. A top-down game is a game with a camera perspective from above and recording downwards [7]. This game format was chosen because it makes it easier for students to explore the game [7]. Students can access the game via the website link. This stage also determines the protocol for

using learning media [10] in the form of game scenarios.

4) Initial Design

The design stage produces scenario diagrams, mockups, and asset collections.

a) Scenario Diagram

We use the diagram in Figure 4 to visualize the scenarios in the game.

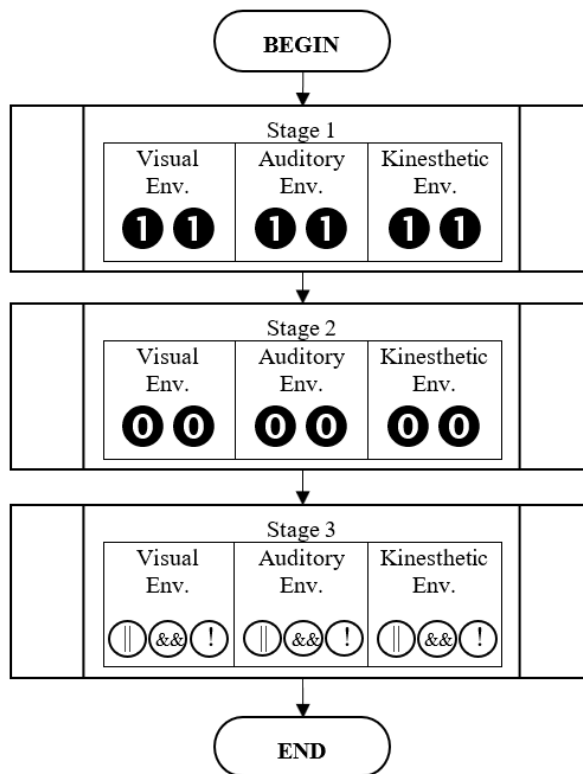
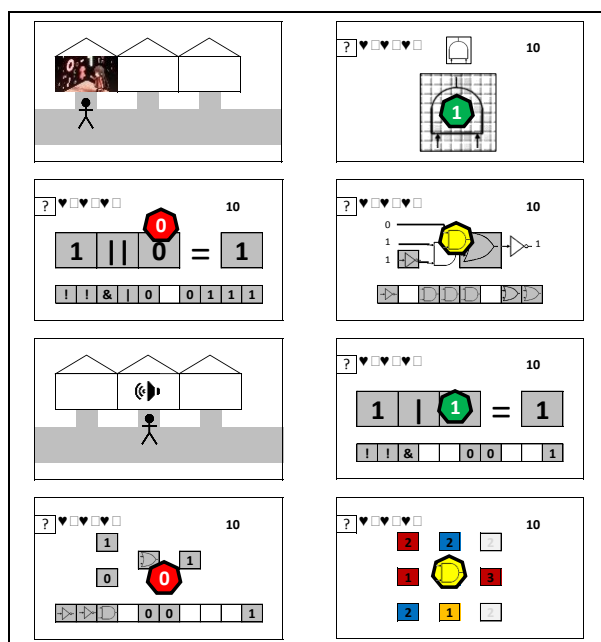


Figure 4 Scenario Diagram

b) Mockup

After creating a scenario diagram, the next step is to create a mockup as a framework for the game interface. Figure 5 shows the examples of the mockup that has been created.



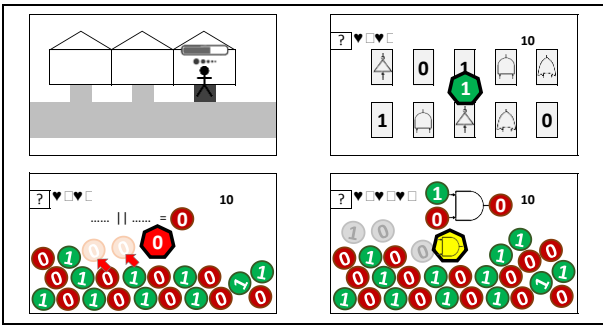


Figure 5 The examples of the game mockup

c) Asset collection

After the mockup is created, the next step is to look for the assets needed in the form of images, audio, game environment, etc. to support the game interface [19]. Figure 6 and Figure 7 shows the examples of the assets that have been collected.



Figure 6 Game's characters

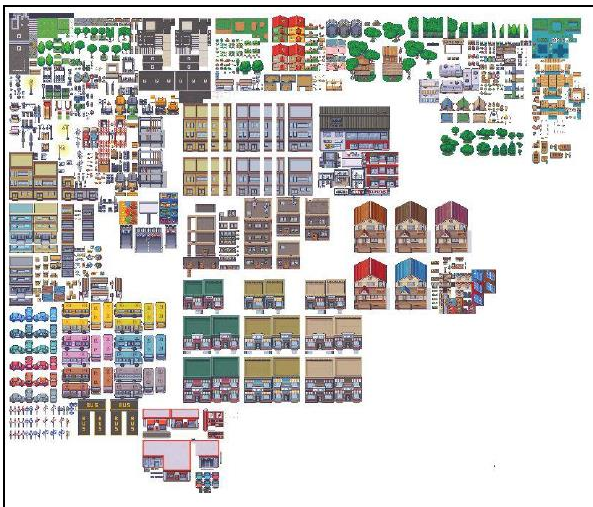


Figure 7 Game's environment from Artist LimeZu

C. Develop

After passing the design stage, the next steps are taken at the development stage.

1) Coding

We compiled the code at the develop stage using the Construct 2 game engine. The web page as the game base was uploaded to internet hosting. Figure 8, Figure 9, and Figure 10 show several screenshots of the game implementation results.

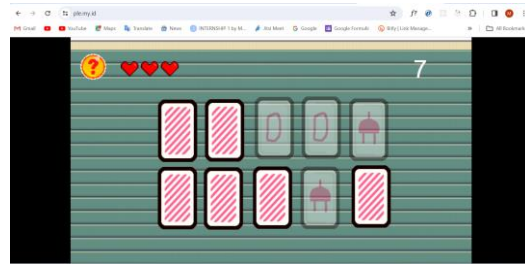


Figure 8 Mini Games Card Match

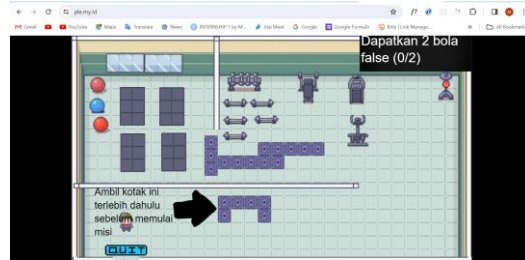


Figure 9 Virtual Room for Kinesthetic LS

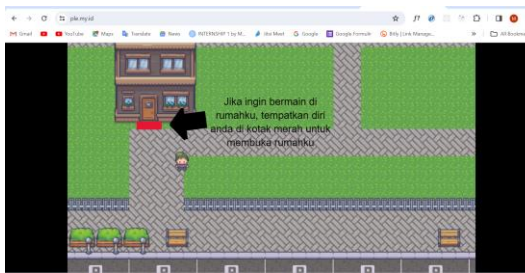


Figure 10 Stage 2 home environment

2) Expert Appraisal

This stage obtains validation results from experts. We involved three material experts and three media experts. Table 4 shows an overview of validation results from material experts.

Table 4 Material Expert Validation Results

Learning Aspects	Avg. Score	Max. Score	Percent-age	Eligibility
Objectives	4,67	10	47%	Quite E.
Material	30	40	75%	Eligible
Method	7,67	10	77%	Eligible
Resources	9	10	90%	High E.
Activity	20	25	80%	Eligible

From the five aspects of material expert assessment, we got an Average Score (\bar{X}) of 19 and an Average Feasibility Percentage (\bar{P}) of 74%. Based on the rating scale, the learning game was declared eligible, but the material expert added notes to add explicit learning objectives.

Then, Table 5 shows an overview of validation results from media experts

Table 5 Media Expert Validation Results

Media Aspects	Avg. Score	Max. Score	Percent-age	Eligibility
Software Eng.	29,67	35	85%	High Eligible
Learning Design	24,67	30	82%	High Eligible
Visual Comm.	38,33	50	77%	Eligible

From the three aspects of media expert assessment, we got an Average Score (\bar{X}) of 23 and an Average Feasibility Percentage (\bar{P}) of 81%. Based on the rating scale, the learning game was declared high eligible, but media experts added notes to add Boolean algebra explanations, change the AI audio to developer audio, fix overlapping sounds, and fix a bug about logic gates.

IV. CONCLUSION

Based on the development results, we conclude that the game has met all instructional learning needs based on the validation results of three material experts. There are notes regarding additional learning objectives. These notes can be met when the game is run at the Dissemination stage in class. Instructional objects are interpreted in nine top-down genre mini games. Each of the three mini-games introduces Boolean algebra symbols, Boolean algebra operations, and logic gate operations. Each material is created according to the characteristics of three different learning styles; Visual, Auditory, and Kinesthetics. The nine mini-games were declared very eligible by three media experts with minor technical notes; Boolean Algebra explanations, sound replacement, and bug fixes for overlapping sounds and logic gates.

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