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TrueBiters: An Educational Game to Improve the Understanding of Logic

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in de Ingenieurswetenschappen: Computerwetenschappen

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June 2016

Abstract

Education plays an important role in a country's progress. A lot of research has recently been conducted on improving the education process through educational games, which could be used to overcome challenges or obstacles in understanding difficult/serious topics or course materials for particular subjects. However, there are still a lot of open issues when it comes to the design of educational games. First of all there is still lacking evidence that games can indeed improve learning. Secondly, in current research there is a plea for adapting educational games to the characteristics of the learners. The work done in this thesis is a contribution to the justification of these claims. More in particular, we have investigated whether it was possible to design an educational game that could improve the learning of logic, and secondly whether it was possible to have better results by adjusting the design of game to the profile of the player/learners.

Therefore, a digital game, called TrueBiters game has been developed for the Android system in order to help students practicing the use of the truth tables to compute the truth-value of logical expressions in proposition logic. The game is played with two players. Each player starts with a list of bits and has to reduce the list of bits to the value of the rightmost bit by using the logical operators that he has available in his card deck. Step by step, the players will each build a pyramid of bits. The winner will be the player who first finishes his pyramid of bits with the last bit being equal to the rightmost bit from the initial bit list. In a player turn, the player can reduce two adjacent bits using a correct logical operator, which are represented on cards. On the cards the output value for the logical operator is shown, but not the required input values. He can also use a NOT card to swap the values of two corresponding bits in the initial list of bits. This action may invalidate all operators applied to these two bits and both players should correct them during the game. However, note that the other player in his own list may be able to cancel this action immediately by also using a NOT card.

The game is played with three Android devices; one to hold the board, and two to hold the card deck of each player. The devices communicate by means of Bluetooth. Cards are inspected by swiping the cards left and right and selected by sending it to the board by swiping it up. Positions on the board are selected by touch gestures. This interaction style was chosen to be able to investigate whether such an interaction style would be more appropriate for students with a kinesthetic intelligence (according to the Multiple Intelligence (MI) theory).

Two pilot experiments have been performed to evaluate the game. The aim of the first experiment was to evaluate whether the use of the TrueBiters game would result in an improvement of the players' knowledge about the logical operators for proposition logic; the aim of the second experiment was to evaluate whether players with high logical intelligence and high kinesthetic intelligence would have a better game play experience than others. The results of this pilot study were very promising. All but one students in the first experiment improved their score on the logic test, while the results of the second experiment showed that logical and kinesthetic participants had better game play-experience than the others.

Acknowledgments

First of all, I would like to express my deepest appreciation to my supervisor, Prof. Olga De Troyer, for her help and support during my master study. This master research would not be possible without her advice and encouragement.

I would like to thank Mr. Pejman Sajjadi for his advices and valuable discussions during my master research.

Furthermore, I would like to thank all of the participants/students for their time and for participating in the evaluation phase of the thesis.

Last but not the least, I would like to express my appreciation to my husband (Omar Hegazy) and my two sons (Abdalla and Abdel Rahman) for their love, patience, tolerance and encouragement.

Finally and Foremost, I would like to express my deepest gratitude and sincere appreciation towards my parents (Mohamed Ramadan and Karem El sayed), my sisters and my relatives for their support and encouragement.

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List of Acronyms

API	Application Programming Interface
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LMP	Link Manager Protocol
MCA	Musicube Arranger
NFC	Near Field Communication
RFCOMM	Radio Frequency Communication
RFID	Radio-frequency identification Device
SC	Spelling Cube
SDP	Service Discovery Protocol
TGD	Triadic game design
UID	User Interface Design
USB	Universal Series Bus
XML	Extensible Markup Language

List of Symbols

T	True
F	False

1 Introduction

1.1 Introduction

Education plays a vital role in the country's progress. Many researchers have highlighted the different factors that affect the efficiency of the education process. One of these factors is using the right technology to enhance the education environment with more facilities. Recently, technologies (i.e. laptops, smart phones, tablets, etc.) that were used for entertainment and for communications, have received significant attention for educational purposes. The rapid development of these technologies has also a significant effect on the possibility to improve the learning process. They provide the students with a good opportunity to understand and solve difficult problems.

Furthermore, a lot of research has recently been conducted on improving the education process through educational games, which could be used to overcome the challenges or obstacles in understanding difficult/serious topics or course materials of particular subjects. Abstract topics such as understanding logic are considered as difficult. In the particular case of logic, for instance the students struggle to remember and use the various truth tables to compute the truth-value of logical expression in proposition logic.

However, there are still a lot of open issues when it comes to the design of educational games. First of all, there is still lacking evidence that games can indeed improve learning. Secondly, in current research there is a plea for adapting educational games to the characteristics of the learners. The work done in this thesis is a contribution to the justification of these claims. More in particular, we have investigated whether it was possible to design an educational game that could improve the learning of logic, and more in particular for the use of the logical operators in proposition logic. Secondly, we wanted to investigate whether it was possible to have better results by adjusting the design of game to the profile of the player/learners.

In this thesis, a digital game, called TrueBiters game has been developed for the Android system in order to help the students practice the use of the truth tables to compute the truth-value of logical expressions in proposition logic. The game is played with two players. Each player starts with a list of bits and has to reduce the list of bits to the value of the rightmost bit by using the logical operators that he has available in his card deck. Step by step, the players will each build a pyramid of bits. The winner will be the player who first finishes his pyramid of bits with the last bit being equal to the rightmost bit from the initial bit list. In a player turn, the player can reduce two adjacent bits using a correct logical operator, which are represented on cards. On the cards the output value for the logical operator is shown, but not the required input values. He can also use a NOT card to swap the values of two corresponding bits in the initial list of bits. This action may invalidate all operators applied to these two bits and both players should correct them during the game. However, note that the other player in his own list may be able to cancel this action immediately by also using a NOT card.

The game is played with three Android devices; one to hold the board, and two to hold the card deck of each player. Cards are inspected by swiping the cards left and right and selected by sending it to the board by swiping it up. Positions on the board are selected by touch gestures. This interaction style was chosen to be able to investigate whether such an interaction style would be more appropriate for students with a kinesthetic intelligence (according to the Multiple Intelligence (MI) theory (Gardner, 2011).

This educational game is using a Bluetooth Network to achieve the required communication between the smart devices (i.e. smart phones and tablets). To start this game, the Bluetooth network is firstly established to connect the devices.

1.2 Research Objectives

The main objective of this thesis was to investigate whether it was possible to design an educational game that could improve the students' knowledge of the logical operators in proposition logic. Secondly, we wanted to investigate whether it was possible to have better results by adjusting the design of game to the profile of the player/learner, more in particular to the learner's intelligences according to the Multiple Intelligence Theory. Thus, the research question that we want to answer is:

To answer these two research objectives, we first had to design an educational game that could potentially improve the students' knowledge of the logical operators in proposition logic and was theoretically adapted to a particular set of intelligence dimensions. This resulted in the TrueBiters game,

Next, we were able to answer the research question "Can the TueBiters game improve the learning outcome of its players and result into a better gameplay experience for the audiences for which the game was intended with respect to their multiple intelligences profile?"

The research objective has been attained by means of research methodology based on Design Science, which will be illustrated in the following sections.

1.3 Research Methodology

In this thesis, we use a research methodology that is based on Design Science as shown in Figure 1 (Vaishnavi & Kuechler, 2004) . The process consists of four main phases; the main goal of the first phase is to become aware of the problem by studying and analyzing the most important aspects of the problem. Once the problem has been defined, a temporary design should be provided in the suggestion phase. According to the proposal and the tentative design, the solution is implemented in the development phase. Moreover, the output product (i.e. solution) then is evaluated to highlight the positive and negative points. It should be noted that the last three phases are accomplished iteratively. In the following subsections, we explain how the different phases have been performed.

- **Awareness of the problem**

To be aware of the different aspects of the problem, the state of the art analysis about available education games and their effect on the improvement of education has been discussed. Then the importance of the serious game has been demonstrated. The difficulty of learning abstract topics such as logic has been highlighted by analyzing the number of the students who have a problem in understanding logic and failed in "*Logica en formele systemen*" course. Furthermore, learning styles have been explained in more detail.

- **Suggestion**

TrueBiters game has been proposed in order to offer a solution to the aforementioned problem. The proposed game was intended as a serious game; therefore, the proposed game was designed with respect to the Triadic Game Design (TGD) (Harteveld, 2011). In order to achieve the balance between the three worlds of TGD (reality, meaning and play), it was important to be familiar with relevant implementation software. Therefore, we investigated Anime studio pro7 and android studio programs as these software programs could be used to realize a high quality game.

- **Development**

In this phase, the TrueBiters game has been implemented based on a Bluetooth network between android devices. Two smart phones act as clients while one tablet acts as a server. The game software has been developed using android studio. The server should open a server socket to listen to the incoming requests from the clients. Once the player sends a request to the server, the server can accept or reject this request. The connection between the server and the clients is established successfully when both devices have a Bluetooth socket on the same RFCOMM channel. Additionally, the data can be transmitted between the devices through input and output streams. The graphics used in the game screens have been designed using Anime Studio Pro 7; However XML files have been used to organize the structure of the user design interfaces elements. Each element has been identified by a unique id, which used in building the pyramid tiles based on the player answer.

- **Evaluation**

In order to investigate the research question, two experiments have been conducted. The aim of the first experiment was to evaluate the first hypothesis: "The use of the TrueBiters game will result in an improvement of the learning outcome of its players". During this experiment, four students played the game against each other in a kind of tournament. It should be pointed that the participants were students who failed the logic course of the 1st Bachelor Computer Science. The aim of the second experiment was to evaluate our second hypothesis: "Players with high logical intelligence and high kinesthetic intelligence will have a better game play experience than others." Moreover, the proposed game has been evaluated based on the work of Sajjadi (Sajjadi, n.d.), which provides a mapping between MI dimensions and game mechanics.

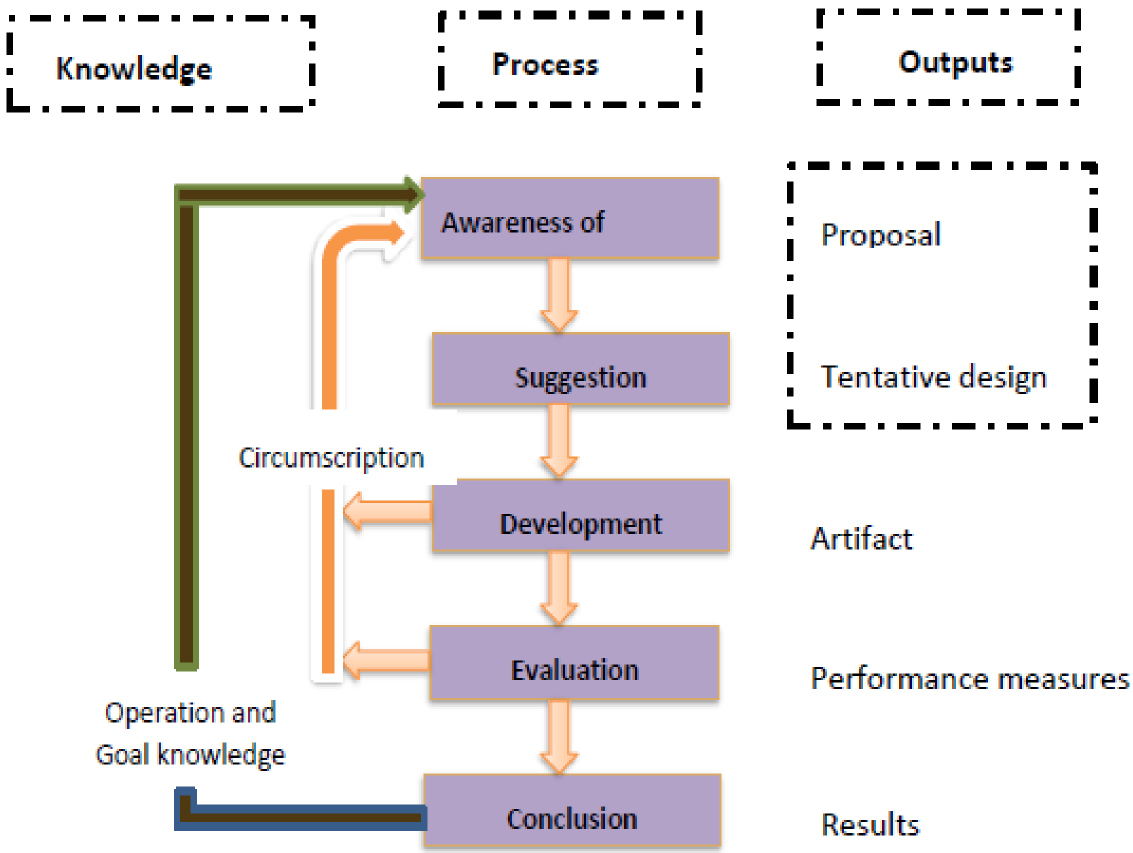

Figure 1: Design Science Research Process Model, edited from (Vaishnavi & Kuechler, 2004)

1.4 Thesis Layout

This section presents the layout of this thesis; it consists of seven chapters. Chapter 1 presents a general introduction. It discusses the main objective of the thesis work and the different phases of the research methodology used. Chapter 2 explains the different factors that have a significant impact on the learning process and presents the different learning styles. Chapter 3 provides a state of the art of education tools and games. Chapter 4 gives the overall design of TrueBiters game. It also explains the Bluetooth network technology, the different layers of the Bluetooth protocols stack, TrueBiters game architecture and the user interfaces. Chapter 5 explains the overall implementation of the TrueBiters game. This chapter presents the general requirements that should be available before establishing and implementing the proposed game, **the** organization of the user interface and the TrueBiters game implementation. Chapter 6 presents the experiments done using the TrueBiters game and the results. Finally, Chapter 7 presents the conclusion and the future work.

2 Learning Styles

2.1 Introduction

The efficiency of the learning process can be influenced by numerous factors. Many scientific researches have highlighted different factors in order to provide effective solutions to enhance the learning process. Some of these factors are described as follows (Mondal, 2015). **Environmental factor** includes the surrounding circumstances under which learning process is performed such as textbooks, equipment, school buildings and classrooms. **Physical factor** involves the learner's health, which has a significant impact on his learning. If the learner does not feel well, he cannot be able to concentrate on the tasks that are supposed to do. L**earner's aptitudes and attitudes factor** is to clarify the effect of the learner's interest on the efficiency of the learning process. The learners absorb the information easily if they are interested in what they learn. **Teacher's personality factor** has a significant impact on the effectiveness of the learning process. Whereas good teacher who can understand the differences between the students and can employ the suitable method to teach them. The difference between individuals is considered an important factor, where each one processes the information in different way due to the brain dominance. Based on the hemisphere dominance, the suitable learning style can be applied to improve the effectiveness of the dedicated learning process.

2.2 Brain Dominance

The human brain naturally consists of two hemispheres where the communication between them is performed through a thick band of nerve fibers called corpus callosum as shown in Figure 2. Brain dominance describes the way in which the brain processes the information. Each hemisphere processes information differently. For everyone, one of these hemispheres can be the dominant one and has a considerable impact on the learner skills. Therefore, the learners can be classified into two categories: right brain and left-brain learners (Capone (n.d), n.d.), (Kolb, 2005). Table 1 describes the differences between the right and left brained learners.

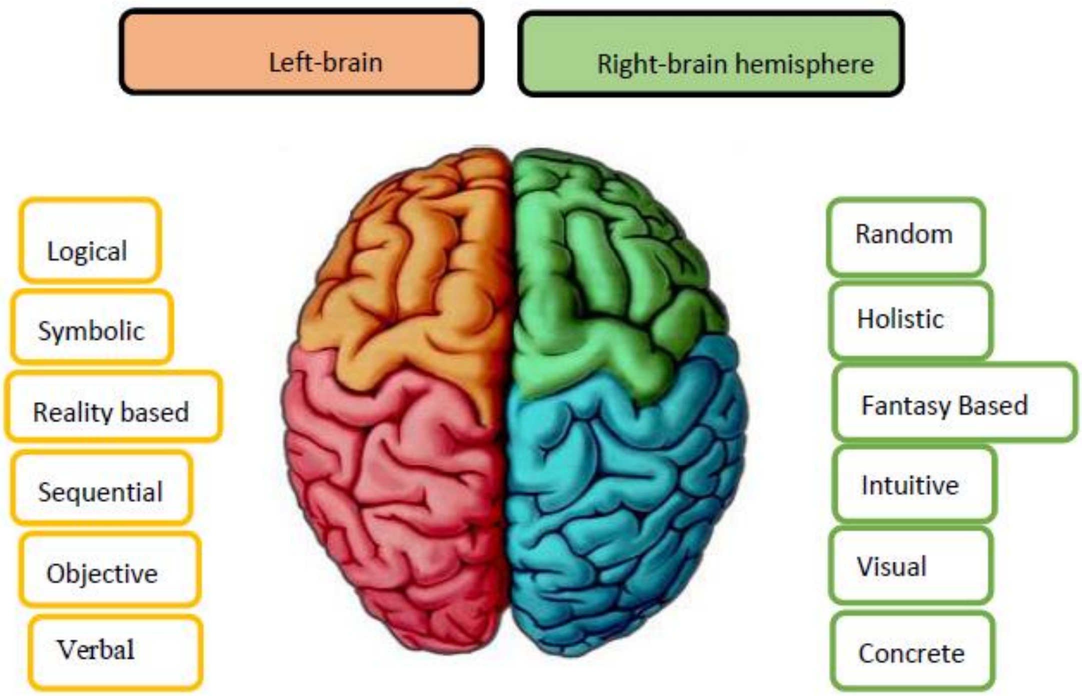

Figure 2: Brain left and right hemispheres

Table 1: Comparison between left and right brained learners

Left Brained Learners	Right Brained Learners
Logical The learners treat the information in a logical way by treating the information part by part.	**Intuitive** The learners are characterized as intuitive thinkers, where they often solve the problems based on their feelings.
Symbolic The learners deal with symbols and words easily, which allows them to memorize math formulas and words flexibly. Therefore, they can succeed in linguistic and mathematical work.	**Holistic** The learners firstly work with the whole picture then with the pieces.
Reality based The learners process the information based on reality where the learners look for the rules and instructions in order to follow them to achieve the success of their learning.	**Fantasy Based** The right brain learners are classified as creative people. Their learning style is based on fantasy and imagination. Subsequently, The learners tend to learn music, singing and dancing easily.

Sequential The learners prefer to complete their tasks in a sequential order.	**Random** The right-brain learner's mind is characterized by the fast movement of thoughts. While the learners were trying to finish a task, they may be interrupted by another thought.
Objective The learners absorb information through thinking and observation. They do not rely on their personal feeling and emotions.	**Visual** The right-brain learners have good visual ability. They often prefer to use visual images where they can remember visual information better than text. They usually enjoy drawing, writing, art, maps and music.
Verbal The learners choose their words accurately, which provide them with good language capabilities. Therefore, they have a good opportunity to be good speakers.	**Concrete** The learners prefer to work with concert things so they absorb information through sensing, doing, acting and feeling.

2.3 Learning Styles Definition

Many researchers have tried to clarify the learning style, but they could not reach to a common definition. Bennt (1996) has defined the learning style as the preferable method of the student to learn (Bennett, 1979). However, according to Mumford and Honey (1992) learning style has been defined as the learner's behavior and attitude, which defines the favorite mode of learning (Honey et.al, 2006). James and Blank (1993) has clarified it as a complex way and conditions used to allow the learners to process, to store and to recall what they are endeavoring to learn(James W. B. and Blank W. E., 1993).

2.4 Learning style Theories

According to the differences between individuals in perceiving and processing information, various learning style models have been proposed. The main purpose of these models is to provide the learners with simple modes to understand their favorite methods to learn. Multiple intelligence (MI) and VARK modes are the most common learning style models, which will be detailed in the following sections.

2.4.1 Multiple Intelligence (MI) Theory

During the last decades, there are numerous types of intelligence tests have been performed in order to measure the human intelligence. However, most of them measure only the logic and language like Traditional IQ and intelligence tests. Garden, 2011 has developed a new theory that classifies intelligence into eight types as shown in Figure 3 (Gardner, 2011)(Silveira, 2007),(Edutopia (n.d), 2009).

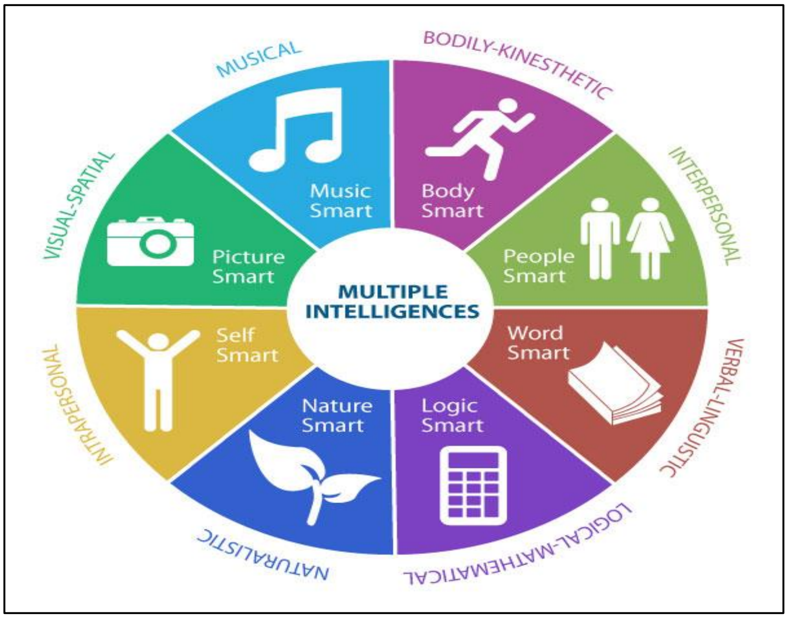

Figure 3: Multiple Intelligence (MI) Theory (Silveira, 2007), (Edutopia (n.d), 2009)

2.4.1.1 Bodily- Kinesthetic Intelligence

The Kinesthetic learners learn best through their muscle memory instead of visual or verbal memory. They remember things best by physically doing them rather than using traditional learning methods (i.e. reading and writing). They became quickly bored with the conventional education. Furthermore, they usually prefer to participate in the activities that require working with hands such as drawing, building things, painting or others that involve movement such as dancing and acting. The characteristics of Kinesthetic learners are mainly:

- often moving their hands and tend to use gestures during taking.
- enjoying doing the activities that involve moving and physical actions.
- unlike reading and writing
- conveying their feeling by doing physical action such as dancing, hugging.
- Facing an obstruction in sitting for a long period.(he has a difficulty in sitting for a long period of time)
- preferring to use flash memory cards to memorize.
- Enjoying using manipulatives.
- tending to shake their legs during studying.
- often drawing pictures while listening to the lecture.
- often like sports such as swimming, running, sailing and dancing
- Having a difficulty in spelling words correctly.

- imitating movement easily.
- selecting builder, dancer, firefighter, actor or athlete as favorite jobs.

2.4.1.2 Logical-Mathematical Intelligence

Learners with logical-mathematical intelligence have a strong capability of performing mathematical calculation flexibly. They are classified as abstract thinkers and they often enjoy scientific reasoning and experiments. They excel at different careers, such as engineers, computer programmers, scientists and bankers.

2.4.1.3 Verbal Linguistic intelligence

The individual with verbal linguistic intelligence has a good ability to manipulate and remember words. He excels in telling stories, reading and writing. Therefore, he learns multiple foreign languages flexibly. The verbal linguistic learner's skills give the opportunity to work in various careers such as politician, journalist, actor, teacher, broadcaster, etc.

2.4.1.4 Visual/Spatial Intelligence

This intelligence is described by the ability of visualizing and remembering images and objects. People with visual-spatial intelligence tends to use diagrams and charts to easily understand the dedicated concepts. They enjoy geometry, photographs, drawing, painting, reading and writing. According to their skills, they can work in the following careers such as engineer, Photographer, graphic designer, fashion designer, etc.

2.4.1.5 Auditory-Musical Intelligence

People with Musical intelligence have a good capability of discerning sounds and the relationship between sound and feeling. This fabulous ability provides the learners with a good opportunity to perform and produce a musical piece. They succeed in different jobs such as musical producer, musical performer, singers and acoustic engineers.

2.4.1.6 Interpersonal Intelligence

The learners with interpersonal intelligence have a good ability to interact and cooperate with others. This provides them with a good capability to work well as a part of a group. They can assess the intentions and emotions of people around them and are able to see the situation from different perspectives. They excel at different careers that required the aforementioned ability, such as psychologist philosopher, counselor, salesperson and politician.

2.4.1.7 Intrapersonal Intelligence

People with intrapersonal intelligence are characterized by the capability of understanding themselves. They often determine exactly their abilities and limitations; therefore, they can avoid making mistakes. They usually prefer to work alone so they are classified as introverted. This kind of learners should be accommodated and not force to work as a part of a group.

2.4.1.8 Naturalistic Intelligence

Naturalistic intelligence is a new intelligence, which has been added into the intelligence evaluation list few years ago by Howard Gardner, 2011(Gardner, 2011) (Edutopia (n.d), 2009). The learners with naturalistic intelligence learn best through observing the surrounding and environment. They have a good capability to recognize and analyze the living beings around them such as animals and plants. They often enjoy camping, hiking and they are interested in some subjects such as biology and zoology. However, they do not prefer to learn topics that have no connections to nature. The suitable careers for such people with strong Naturalistic intelligence are biologist, conservationist and environmental scientist.

2.4.2 VARK Model

Neil Fleming (2006 & 2014) has suggested VARK model as illustrated in Figure 4, which is considered one of the most commonly used learning style models (Fleming & Baume, 2006),(Vark (n.d.), 2014). The acronym VARK stands for visual, auditory, reading & writing and Kinesthetic where the learners have been classified into four categories. According to this model, the learner learns best by performing different techniques (Kolb, 2005), (Marcy, 2001).

Figure 4: VARK model

2.4.2.1 Visual

Visual learners learn best through seeing and observation. They are usually interested in using graphs, diagrams, pictures, charts and PowerPoint presentations to express their ideas. The learners have good imagination skills, which allow them to visualize and organize concepts and facts.

2.4.2.2 Auditory

Aural learners learn best through hearing and they tend to have a good ability to remember things. Listening, speaking, music storytelling, discussions and verbal instructions work well for aural learners.

2.4.2.3 Reading & Writing

Read/write learners prefer to take in information displayed as words. Learning materials that are primarily text-based are strongly preferred by these learners. Written instructions, manuals reports, power point presentations, writing lists and essays words are working well with read/write learners. They learn best by taking notes and reading the text, but they prefer to read aloud. They enjoy reading and writing in all kinds of forms. They prefer information to be placed in writing.

2.4.2.4 Kinesthetic

Kinesthetic learners process information best through manipulating, touching and doing things. They are often interested in participating in activities and games. They tend to employ all their senses when participating in learning.

3 Related Work: State of the Art Analysis of Educational Tools

3.1 Introduction

In this chapter, we are reviewing educational tools that are exploiting in one way or another the kinesthetic intelligence of the players. We looked in particular for games with some kind of tangible interface or interaction modality.

3.2 Smart Blocks

In (Girouard et al., 2007), Smart Blocks have been proposed to facilitate the learning by using inexpensive components based on RFID technology. This system is designed for children to learn the volume and surface area of 3D shapes. Each block contains 6 holes as shown in Figure 5. The dedicated blocks are connected to each other through connectors that fit into the cubes' holes as illustrated in Figure 6. Each connector comprises a unique RFID tag. Then, the formed shape is scanned by RFID reader that defines the presence of the blocks. The surface area calculation is based on the shape that is performed and on the presence of the blocks on the workspace. There are two learning modes of the application: 1) Exploration Mode, and 2) Question Mode (Girouard et al., 2007).

In the exploration mode, the children can connect the blocks together in order to form a 3D shape and then the volume and the surface area of the dedicated shape will be determined. Whereas, the question mode allows the students to test themselves by using question cards (Girouard et al., 2007).

Figure 5: Smart Blocks (Girouard et al., 2007)

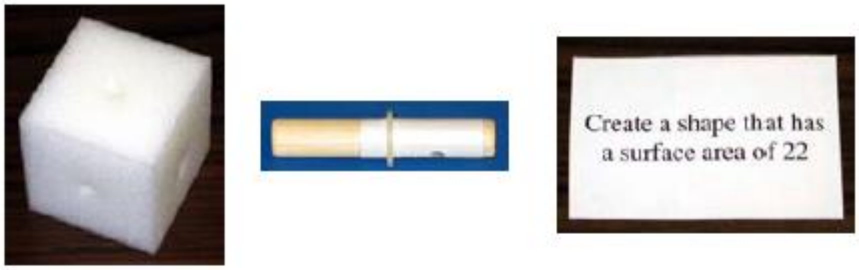

Figure 6: Cube, Connector, Question (Girouard et al., 2007)

3.3 Activity Pad

In (Pyykkönen, Riekki, Jurmu, & Sánchez Milara, 2013), Mikko et al. have designed an inexpensive education tool by NFC technologies. The authors integrated the tangible interaction and the affordance of paper as showed in Figure 7. As reported in (Pyykkönen et al., 2013), the system is implemented based on NFC technology, where the pad is consisted of 24 NFC readers. In addition, the NFC tags are attached to the tangible objects. During the first stage of the application, the teacher creates his proposed scenario and then the pad can be set into the interaction mode. The paper showed different scenarios of using activity pads. In Figure 8, one of these scenarios based on recognizing rocks is used to allow the user to explore and recognize different rocks types. First of all the teacher writes a small description of each stone and records the scenario. After that, the pad is set into interaction mode to allow the children to explore and place the correct rock in the right place. Then, the pad will give an immediate feedback on his answer using LEDs and sound.

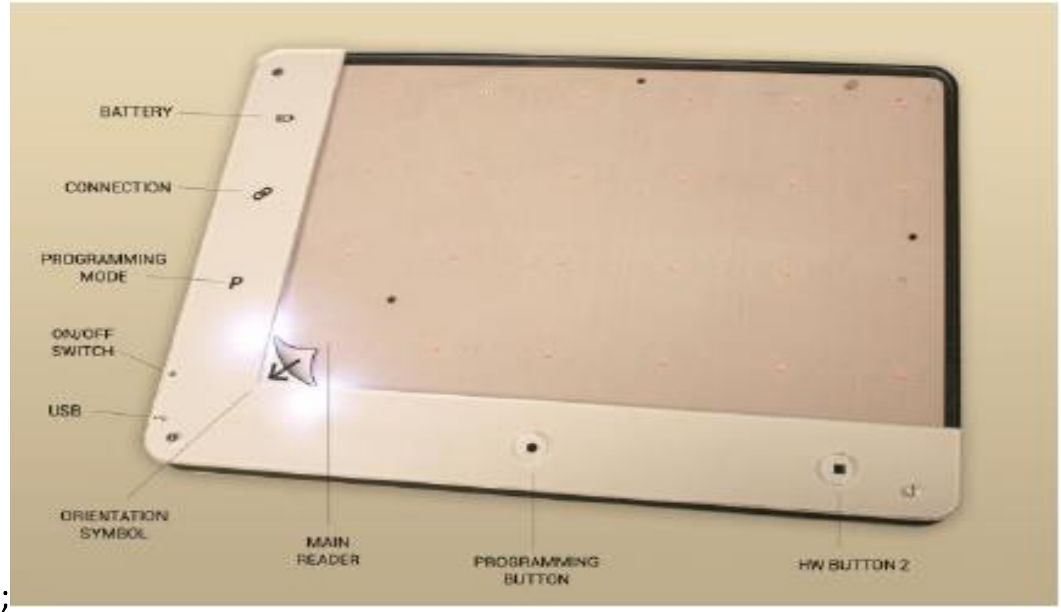

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Figure 7: Activity Pad (Pyykkönen et al., 2013)

Figure 8: The application for identifying rocks (Pyykkönen et al., 2013)

3.4 i-Cube

Goh et al. (2012) proposed i-Cube to enhance the learning process. The main design goals are: 1) supporting full 3-D spatial awareness and 2) designing flexible arrangement of the cubes (Goh, Kasun, Tan, & Shou, 2012).

The first goal is achieved by implementing i-Cube by means of a 3-axis Freescale MMA7260 accelerometer, which is responsible for sensing the orientation and motion of i-Cube.

In order to achieve the second goal, a flexible arrangement of the dedicated cubes, i-Cube is designed by the use of short-range inductive sensors, which provides a robust system. Moreover, the distance between the cubes is chosen to be 3 mm, which avoids the problems of using optical sensing that is used for a long distance. Furthermore, i-Cube is designed without LCD display. However, the visual feedback can be performed depending on the learning objectives by means of lighting a specific face to highlight an active concept or using various colors to indicate the concept groupings that have the same features. On the other hand, i-cube can be utilized in two different modes: 1) distributed computational mode or2) hybrid distributed mode (Goh et al., 2012).

In addition, Goh et al. (2012) discussed two applications of i-cube system. Firstly, the musicube arranger (MCA) which is mainly designed to allow the children to create a short repetitive musical sequences as shown in Figure 9. Secondly, Spelling Cube (SC) has been proposed to show that i-cube system could be useful for learning scenarios. It is mainly designed for preschool children for teaching the spelling of short English words (3-6 letters) as shown in Figure 10. Owing to the preschool educator's advice, visual display is integrated with the system, which is mainly used to give the instructions to the children and audio-visual feedback. Moreover, it can be used as interesting motivation for children by displaying some animated stories.

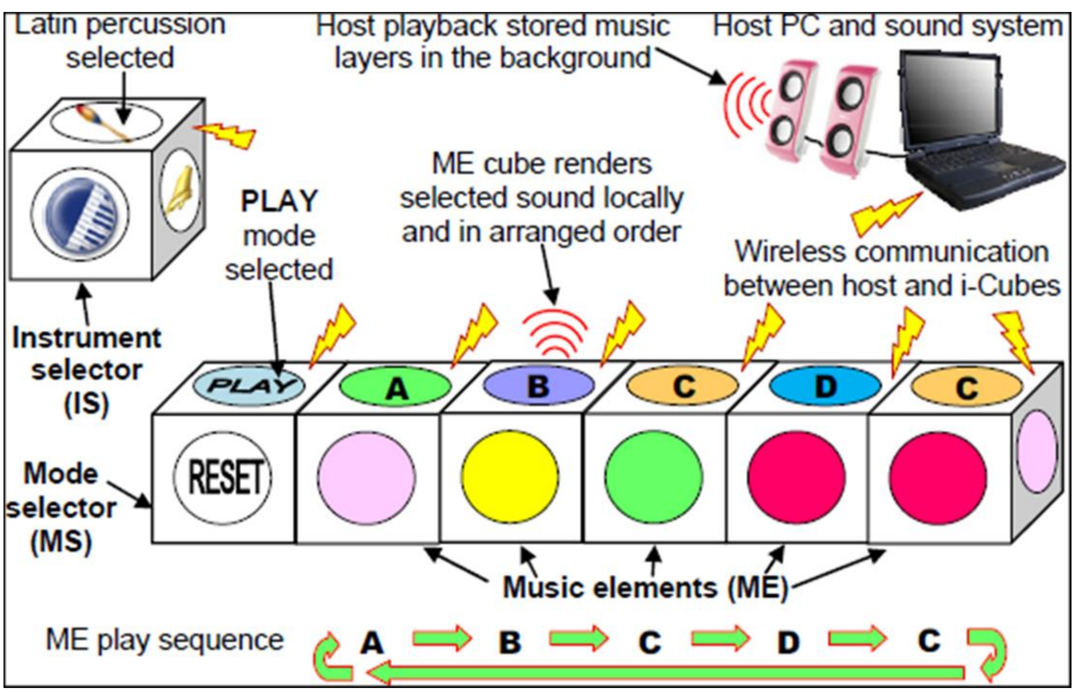

Figure 9: Musicube arranger (MCA) (Goh et al., 2012)

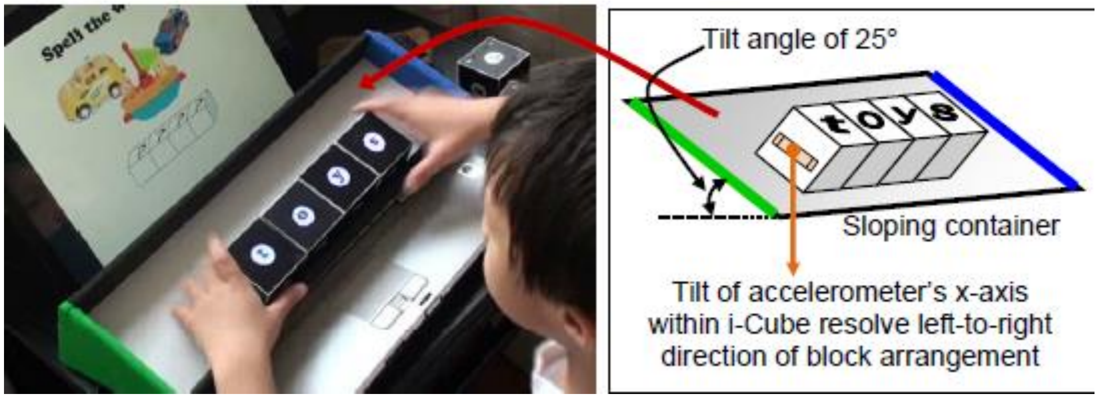

Figure 10: Spelling Cube (SC) (Goh et al., 2012)

3.5 Siftables

Siftables has been proposed by Merrill et al. (2007) as a new interesting platform that performs the main principles of wireless sensor-networks technologies integrated with the merits of GUI and TUI (Merrill, Kalanithi, & Maes, 2007). The implementation methodology is based on using a 3-axis accelerometer and transceivers (i.e. 4IrDA), which are responsible for sensing various actions such as motion, lifting, shaking and detecting the neighboring Siftable at a short distance that is chosen to be 1 cm as shown in Figure 11.

In addition, the use of LCD screen provides an immediate and enjoyable visual feedback to the user.

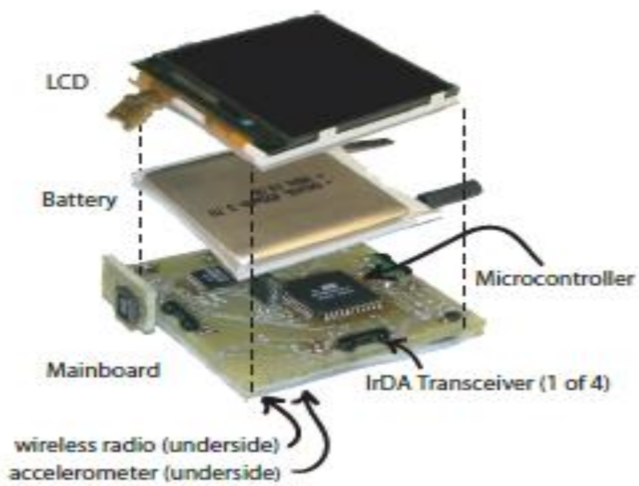

Figure 11: Main Components of a Siftable computing element (Merrill et al., 2007)

The aforementioned platform can be used in a wide range of applications. For example, the photo sorting is one of these applications, which has been discussed in (Merrill et al., 2007). First of all, the photographs are wirelessly transferred into the Siftables by a host computer. Then, the user can start the sorting process by pushing them in order to create various piles. The movement of Siftables can be sensed by using their accelerometers. Finally, the data between Siftables is transferred and shared by using radios as demonstrated in Figure 12.

Figure 12: Siftables (Merrill et al., 2007)

3.6 System Blocks

In order to enhance the learning process of abstract concepts, System Blocks have been proposed by Zuckerman et al. (2005) as a novel simulation tool (Zuckerman, Arida, & Resnick, 2005).

The implementation methodology is mainly based on four components, which are illustrated in detail by describing an example. Cookie store is an example of using system blocks, which has been evaluated by 5th grade students as demonstrated in Figure 13. The main purpose of cookie store is to allow the students to bake and sell cookies to school's students. Stock is considered as the most important component of the dedicated system, which represents the amount of cookies in the basket by the use of a vertical line of LEDs. Moreover, there are two types of flow block that is used to determine the cookie rate that can be controlled by its corresponding variable. The first type is Inflow block, which is used to increase the number of baking cookies in the stock by baking more. The second type is outflow block that is used to decrease the amount of cookies.

In order to verify the aforementioned simulation tool, an evaluation has been conducted by the authors (Zuckerman et al., 2005).

The evaluation is based on an exploratory study where the interviews were performed with the students from two different schools with the following results: Learnability of system Blocks is good where the students were capable of performing the simulation without following previous instructions. Moreover, the students were satisfied with the efficiency of system Blocks and it was helpful for the students to understand the net flow dynamic concept (Zuckerman et al., 2005).

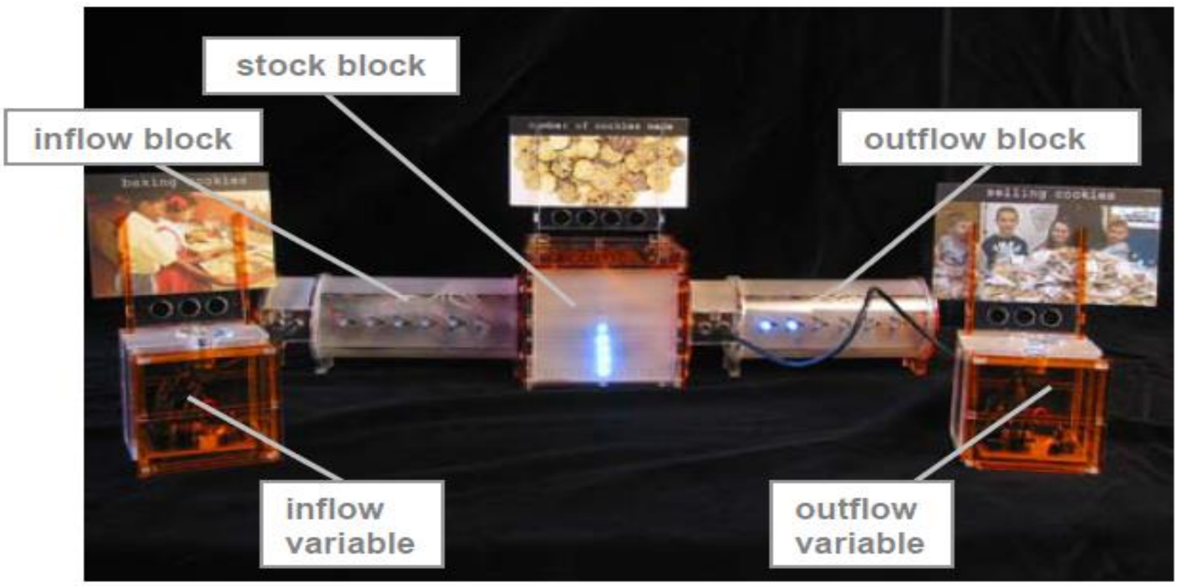

Figure 13: System Blocks simulating a "cookies store" Example (Zuckerman et al., 2005)

3.7 Chemicable Method

In (Agrawal, Luthra, Jain, Thariyan, & Sorathia, 2015), Mehul et al. proposed a Chemicable method as a tangible education tool for learning chemical bonding based on Reactvision, which provides a fast and robust tracking method as demonstrated in Figure 14. This system is designed for students of grade 8-10 (Agrawal et al., 2015), and it consists of a table, projector and fiducial markers attached onto the physical objects as shown in Figure 15.

Figure 14: Operation of ChemicAble tool (Agrawal et al., 2015)

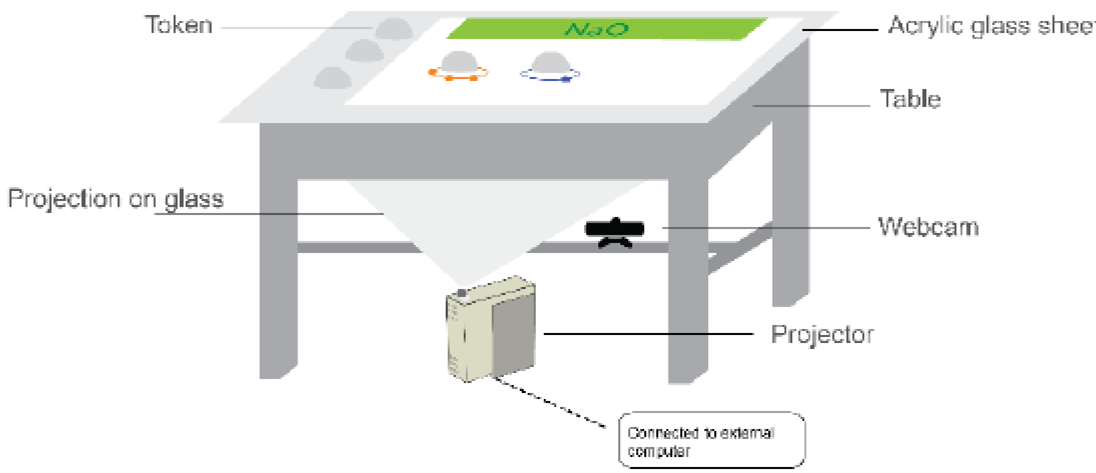

Figure 15: the system architecture of ChemicAble tool (Agrawal et al., 2015)

3.8 Tern Method

In (Horn & Jacob, 2007), Michael proposed another an inexpensive educational tool. The proposed tool is mainly used to allow the students to learn how to make computer programs in easy way using a tangible objects. This tool is defined as *Tern concept*. This concept consists of wooden blocks embedded with circular symbols on top of them called SpotCode as illustrated in Figure 16. In order to allow the children to form a computer program, they connect the blocks offline. After that, it will be scanned by the scanning station, which consists of digital camera that is connected to a laptop.

Figure 16: The set-up of the Tern (Horn & Jacob, 2007)

3.9 T-Maze Method

Another tangible programming game, called T-maze, is proposed by Danll et al. for children of age of 5 to 9 (Wang, Zhang, & Wang, 2011). The main target of this concept is to help the children to gain more skills on basic programming knowledge. Moreover, they acquire new experiences on new technologies such as sensor technology. First of all the maze escaping game is created using the programming blocks, and then the children are ready to control the virtual characters in the maze. As shown in Figure 17, the implemented methodology is based on using digital camera to recognize the blocks through encoding of graphs, which are named TopCode on top of them.

Figure 17: The T-MAZ concept (Wang et al., 2011)

3.10 Tabletop Concept Mapping (TCM)

An interesting tool has been proposed to extract and represent the knowledge in network structures based on tangible semantics and syntax (Oppl & Tary, 2009). The concepts are represented by physical tokens while each one is labeled by adding sticky notes on the top of it and performing an image processing algorithms to extract text as illustrated in Figure 18. However, it can be labelled by using a keyboard. In order to overcome the problems of designing complex TCM, physical tokens can be used as containers of additional information as shown in Figure 19 (Oppl & Tary, 2009).

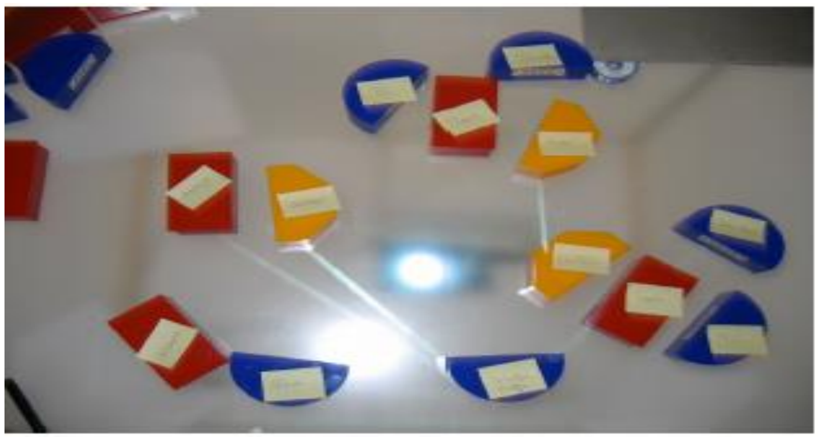

Figure 18: Tabletop Concept Mapping (Oppl & Tary, 2009)

Figure 19: Using Token as a container (Oppl & Tary, 2009)

The TCM provides the users with an interesting feature called design history. It can be used to summarize the modeling steps in order to facilitate joining a session or working on a model created by different participants. The participant can activate the history mode by rotating a round token counterclockwise to go back or clockwise to go forward (Oppl & Tary, 2009). Another interesting advantage of the TCM is to allow the participants to reconstruct the model by using another control token. The implementation methodology, as shown in Figure 20, is based on using a semitransparent acrylic-glass table in order to allow a visual tracking of the tokens. In this methodology, the tracking is performed by using reacTIVision-framework. The system is consisted of two different plates: the bottom plate comprises projector, camera and mirror, which are the essential components for visually tracking the physical tokens. Moreover, a convenient lighting can be performed by adding 4 IR-LED-arrays in the bottom plate (Oppl & Tary, 2009). The middle plate is a diffusion plate, which is utilized to perform a uniform illumination of the surface. This surface contains the physical tokens and a camera that is used as a supplementary input channel for registering data (Oppl & Tary, 2009).

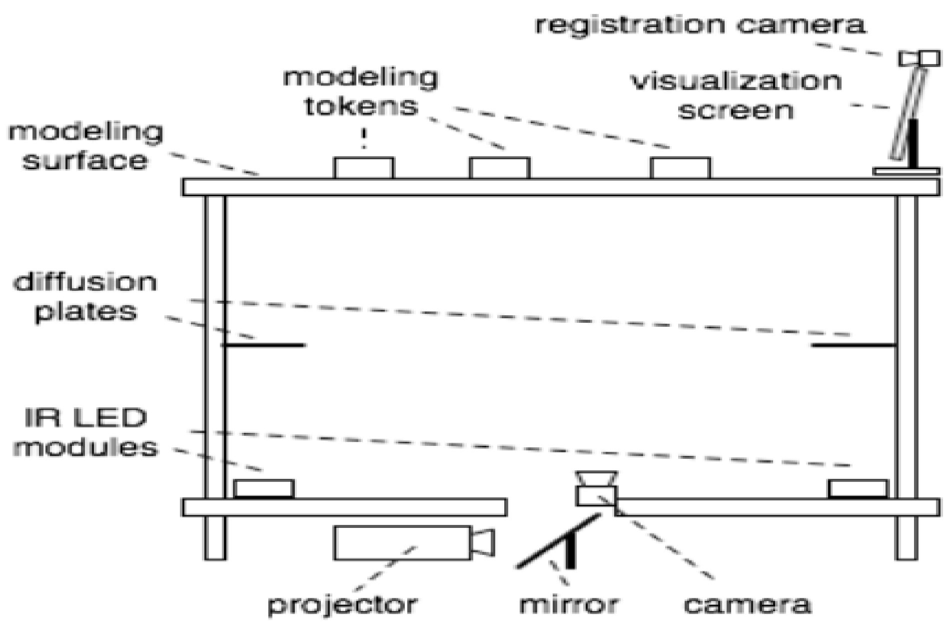

Figure 20: TCP Implementation (Oppl & Tary, 2009)

3.11 The Logic Game (on printed paper):

The Logic game has been proposed by (Daniel Hicks, 2102) in order to provide the students with an effective way to understand and remember logical operators. The game consists of one game board, 48 verify tokens and 24 logical operators tokens that are printed on ordinary papers. Figure 21 illustrates the game board, which is considered the main component of the proposed game where it consists of some squares at the top in order to contain the initial data, moreover the students can add their logical operators on the circles as shown in Figure 21b. In order to set up the game, 8 random verify tokens should be placed over the top squares. Additionally, each player should have only two negation tokens and he can select the other operators randomly from the operator pool that contains all the available logical operators. Based on the type of the selected logical operator, there are some rules that should be considered before placing it on the game board. The winner is the player who finishes the game where the truth-value of the ≡ at bottom of the board is fixed. The game has been evaluated by letting students who followed a logic course at Center for Talented Youth Baltimore (CTY-JHU) to play the game and then evaluate the effect of the game on their understanding. The results of the evaluation have illustrated that the proposed game has a significant impact on improving the student's skills to understand logic.

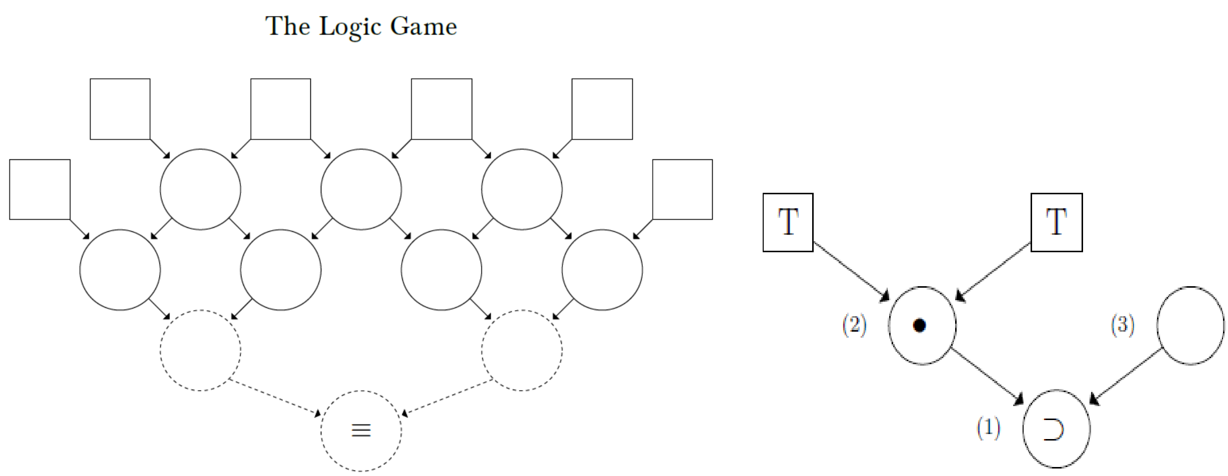

Figure 21: Logic game based on printed paper: a) logic game board, b) part of the game (Daniel Hicks, 2102)

4 Design

4.1 Introduction

This chapter describes the overall design of TrueBiters platform. First, Bluetooth network technology is explained in detail. Second, the different layers of the Bluetooth protocols stack are discussed. After understanding the overall architecture of Bluetooth network, the architecture of our game is fully described and finally the design of the user interface will be explained.

4.2 Bluetooth Technology

Bluetooth technology has been widely used in a variety of applications and communication networks due to its features such as low power, wireless, low interference, low energy and sharing easily voice and data (Haartsen, Naghshineh, Inouye, & Allen, 1998), (Kranz et al., 2006),. It can be also defined as a radio communication technology that has been developed in order to enhance the communication environment with more facilities and provide solutions to the existing problems of the traditional networks. Bluetooth technology allows the developers to create wireless networks by eliminating the cables and replacing them with radio frequency waves. Subsequently, this will reduce the cost, the power and the energy used.

4.2.1 Bluetooth Network Architecture

Bluetooth technology enables the developers to create a small network where the number of devices are ranged from two to eight devices (Haartsen et al., 1998). This network is called Piconet, which refers to a small network. One of the connected devices acts as a master and the other seven devices act as slaves as shown in Figure 22. The master is responsible for initiating the transmissions and for informing the salves which frequencies to use. However, Bluetooth technology provides the developers with the possibility of developing larger networks called Scatternet by overlapping several Piconets (Mettala, 1999), (Vlssit, n.d.), (Song-Joo, n.d.).

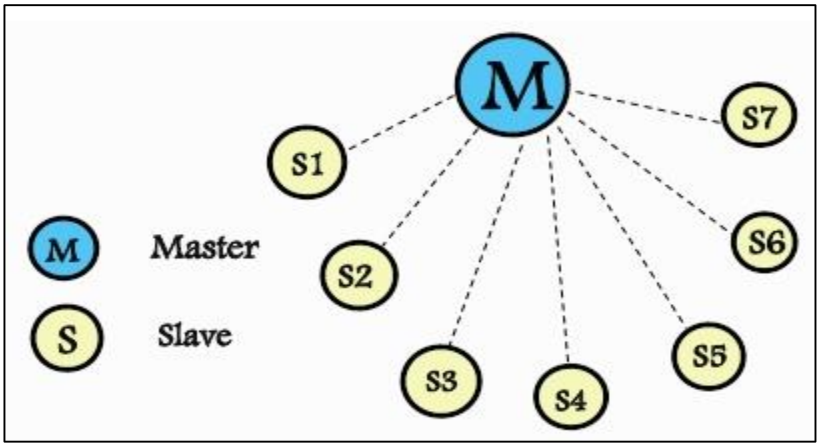

Figure 22: Piconet

Scatternet can be classified into two types based on the used scenario as shown in Figure 23 (Vlssit, n.d.), (Mahmoud, 2003). The first type is Scatternet with Slave/Slave node where the Piconets units are connected with each other through slaves' nodes as shown in the communication between Piconet 1 and Piconet 2. However, in Scatternet with Master/Slave node scenario, one unit acts as a master in one Piconet and a slave in the other Piconet according to the defined rules as shown in the communication between Piconet 1 and Piconet 3.

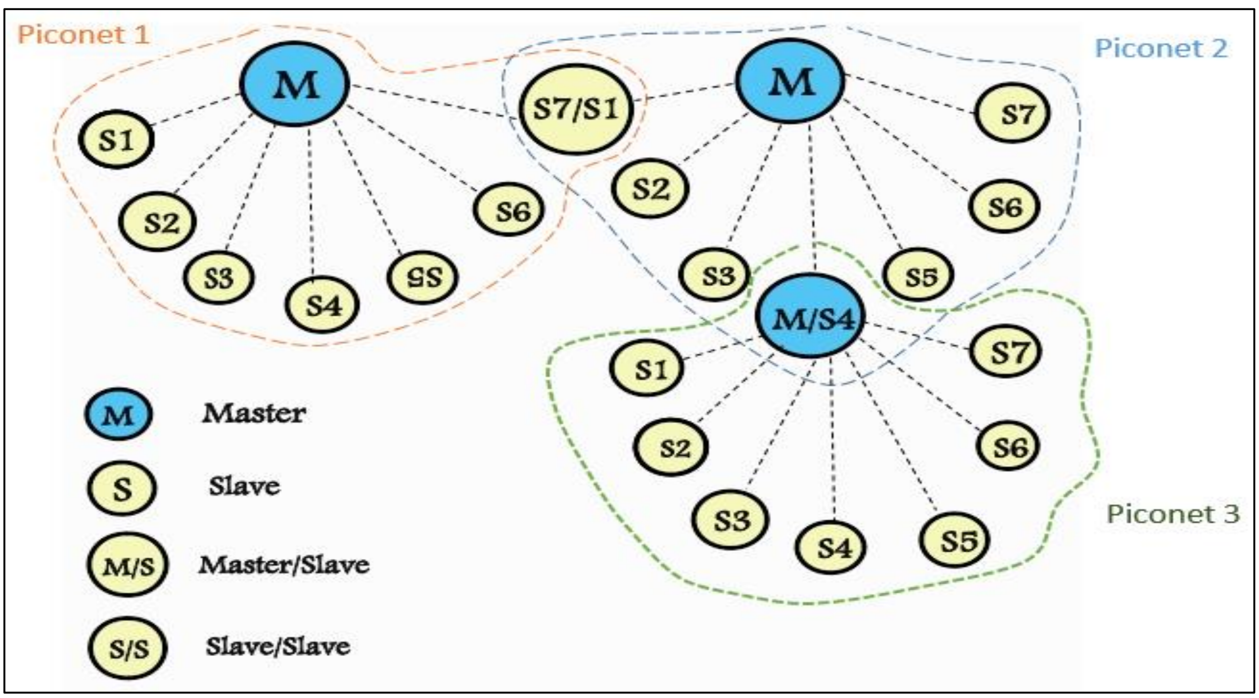

Figure 23: Scatternet

4.2.2 Bluetooth Protocols Stack

Before describing the architecture of TrueBiters platform, there is a need to better understand how the Bluetooth technology works by presenting the Bluetooth protocols stack. The stack can be classified into four protocols types: Bluetooth Core Protocol, Cable Replacement Protocol, Telephony Control Protocol and Adopted Protocol, where each one has a different color to illustrate its type as shown in Figure 24 (Mahmoud, 2003), (Mettala, 1999), (Song-Joo, n.d.). In this section, the first three types will be explained in more detail.

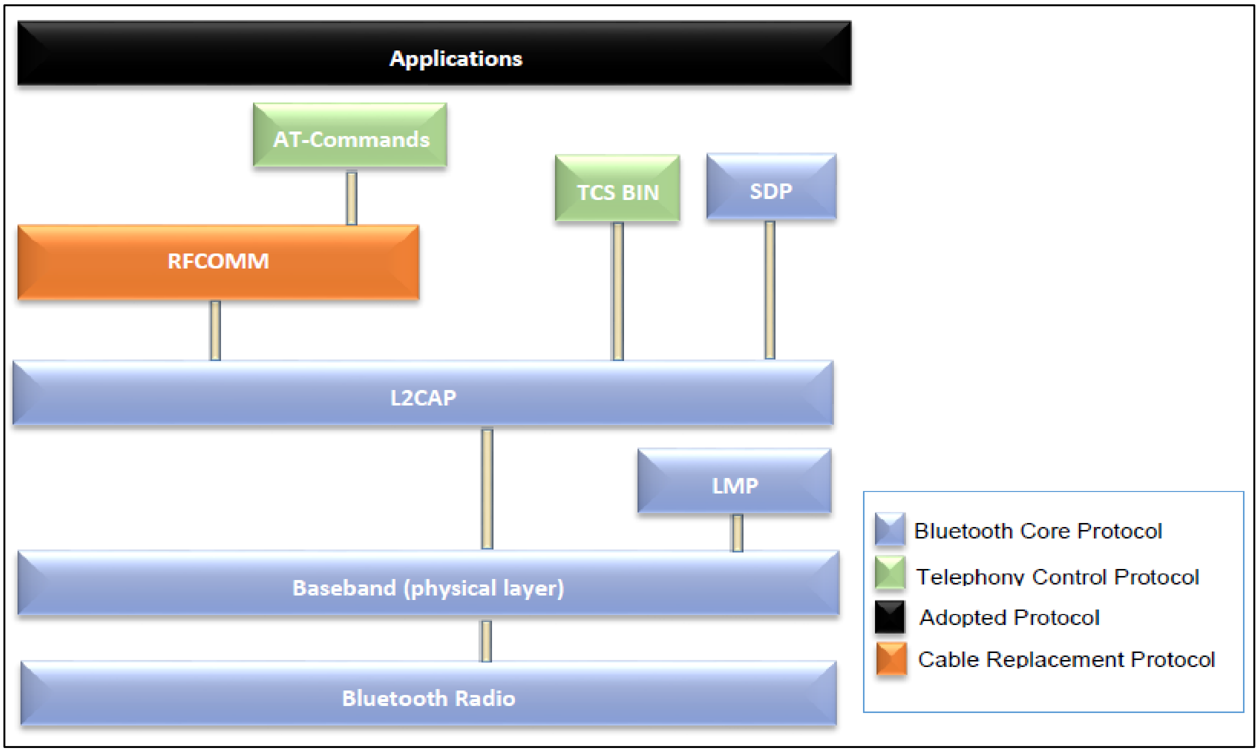

Figure 24: Bluetooth Stack Protocols: edited (Mahmoud, 2003)

4.2.2.1 Bluetooth Core Protocol

Bluetooth Core protocol is one type of the Bluetooth stake protocols, which consists of five layers. These types in the core protocol are mainly used to enable an efficient communication between the Bluetooth devices. However the other three types of the Bluetooth stake protocols are used to allow the applications to run over the Bluetooth core protocol (Mahmoud, 2003).

- ***Radio Layer***

The main role of Bluetooth radio layer is to convert the data into RF signal based on fast frequency hopping in order to avoid interference with other devices. Moreover, it is responsible for moving the data from master to slave and vice versa. The distance is ranged from 10 cm to

10m; however, it can be extended to 100 m according to the variations in the transmission power (Mahmoud, 2003).

- ***Baseband (Physical layer)***

Baseband, which is also defined as a control link, provides a physical layer between Bluetooth devices (i.e. master and slaves) In order to send data between them. It should be pointed out that the communication between those devices is mainly based on defined time slots and frequencies, where the data packets or transmission channels are transferred. This layer is also used to achieve the needed synchronization between the used Bluetooth devices.

- ***Link Manager Protocol (LMP)***

The main responsibility of this protocol is establishing the connection between devices through the transmission channels, which are provided in the previous layer. Moreover, it manages the security and the quality of the service by adding authentication and encryption specifications.

- ***Logical Link Control and Adaptation Protocol (L2CAP)***

The aim of this layer is to link the upper layers with the lower ones over the baseband by receiving the data from the application and adapting it to the form expected by the lower layers.

- ***Service Discovery Protocol (SDP)***

The SDP is a key part in the Bluetooth network. The SDP is responsible for querying the required information (i.e. device information and the services) in order to establish the connection. Once the required information is available, the connections between the devices can be easily established.

4.2.2.2 Cable Replacement Protocol

- ***RFCOMM***

As mentioned before, one of the main advantages of Bluetooth technology is a wireless feature. The RFCOMM protocol is known as a cable replacement protocol, where RFCOMM channels that act as virtual serial ports are designed in order to transfer the digital data among the Bluetooth devices. This will be explained in more detail in the implementation chapter.

- ***Telephony Control Protocol***

Telephony control protocol consists of two layers(TCS BIN and AT Commands) which are responsible for controlling the telephony by defining the call control signals in order to establish the speech calls.

4.3 TrueBiters Platform Architecture

In the previous section, the Bluetooth technology architecture and protocol stack were explained. Based on the Bluetooth technology, this section describes the proposed TrueBiters architecture. The Bluetooth network has been designed as one Piconet. In this Piconet, one device (i.e. large tablet) works as a master, while other two devices (i.e. two smartphones) act as slaves as shown in Figure 25. The interaction between the master and slaves is described in section 4.4.

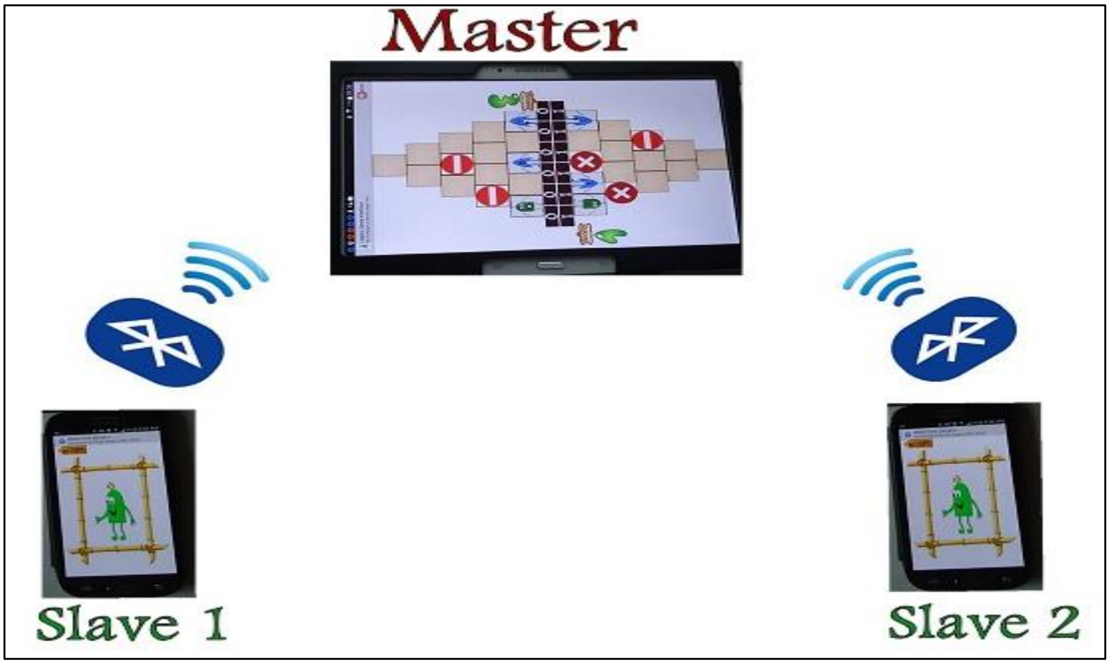

Figure 25: TrueBiters Bluetooth Architecture

4.4 Design of TrueBiters based on Triadic Game Design (TGD)

The TrueBiters game has been designed based on a Triadic game design, which consists of three worlds (Reality, meaning and play), where a balance between the three worlds should be accomplished. Figure 26 illustrates the design space of the TGD (Harteveld, 2011).

4.4.1 Reality

In order to achieve the reality world in designing the proposed game, a model of reality has to be developed.

- ***Defining the problem***

The first step in developing the model of reality is defining the problem. In the real world, the problem, which needs to be improved, is that students struggle to understand abstract topics such as the truth-value of logical expressions in proposition logic.

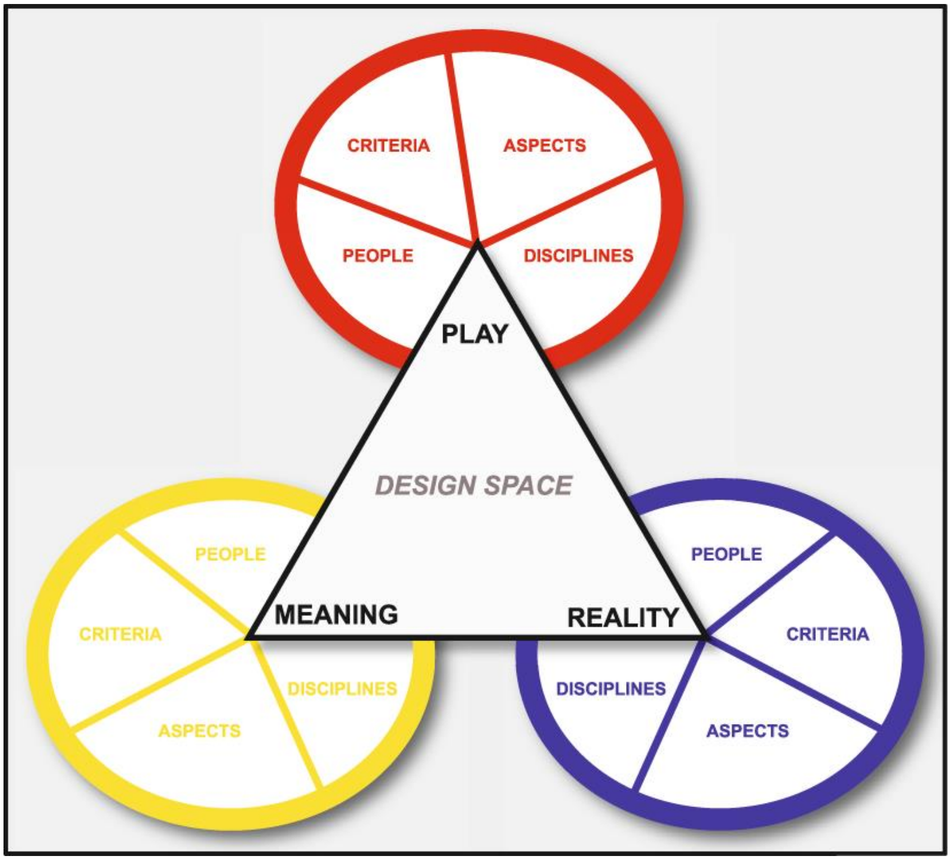

Figure 26: Design space of TGD (Harteveld, 2011)

- ***Who is involved?***

The students are the main persons who are involved in the predefined problem. The four logical operators (OR, AND, Imply and equivalent) are also involved where they are represented as four characters. Each student uses a smart phone to send these logical operators to build the pyramid.

4.4.2 Meaning World

The meaning world consists of following three aspects.

- ***Purpose of the game***

The first aspect of meaning world is to clarify the purpose of the game, which the added value of any particular game could be reached.

The purpose of the TrueBiters game is to help students understanding logic, which is considered in thesis as a difficult abstract topic. The learning objectives of TrueBiters game are given as follows:

- Computing the truth-value of logical expressions in proposition logic;
- Looking for the correct logical operators.

- ***Think of a Strategy***

Once the purpose of the game has been defined, a strategy of designing the proposed game has to be declared. In the TrueBiters game, the strategy is to allow the student to compute the truth-value and send the correct one to build a pyramid at his own side.

- ***Operationalizing the plan***

The next step after declaring the strategy is to operationalize the plan. Harteveld in (Harteveld, 2011) has defined eight insights that can be used to operationalize the proposed plan. The following subsections demonstrates some of these insights in more detail, and how to accomplish them in the proposed game (TrueBiters game).

1) Practice

The Practice insight is very important during designing a serious game, where the players have the opportunity to practice with the game to better understanding the desired subject. In order to accomplish this insight in the proposed game, the self-training option is designed to give the player the opportunity to do practicing with the game.

2) Feedback

The Feedback insight has a significant role in the plan in order to allow the players correct their behaviors and subsequently improve their learning levels. Therefore, the TrueBiters game should provide an immediately feedback that allows the students to monitor their progress. This can be accomplished by increasing and decreasing scores accompanied with a sound effect.

3) *Chunking*

Enabling chunking plays an important role in designing a good serious game, where it is related to human storing and retrieving particular information from his brain through long-term and short-term memories. By enabling chunking, the player can play the game faster with beter understanding. This can be accomplished through connecting the new information with the existing chunks. Moreover, the difficulty of the game has to be slowly increased. In the TrueBiters game, each player reads his own pyramid and understands the tiles' positions and the relation between these tiles. Furthermore, the selected tile can be highlighted with a new color in order to provide the player with a good facility to remember the dedicated tile.

4.4.3 Play World

- ***Goal of the game***

The goal of the game is considered the main aspect of the play world, which should be considered when designing any serious game. It highlights how the player has carried out the game. The goal of TrueBiters game is to build a pyramid of binary bits, where the winner is the player who reduces his/her row of bits to a single bit that matches the right most bit of his/her original row of bit. It should be pointed that the goal of the game is different from the purpose of the game that has been discussed in the meaning world.

- ***Game world***

The main objective of this aspect is to build an imaginative world for the game in order to attract the attention of the players. However, it does not mean that the main goal is just a beautiful game, but the main benefit is to provoke the player in a positive way. This objective can be accomplished by means of graphics, audio and text. In the TrueBiters game, the aesthetics concept of the game world has been accomplished by designing the game based on simple graphics, text and audio. The four logical operators have been designed using Anime studio Pro 7 as real-simple cartoon characters.

The proposed game has used the audio in order to give the player with a positive and negative sound effects based on their answers. Moreover, a congratulation sound effect has been used to indicate the end of the game. Whereas, the text has been used to point out the name of the logical operator at the center of each character.

- ***Technology aspect***

The fourth aspect of the play world is selecting the right technology to design the proposed game. This technology includes hardware and software aspects that can support the proposed game. The required hardware for implementing TrueBiters game is three android devices as follows: One tablet and two smartphones, where the size of the tablet should be 10 inches, while their android version should be 3.0 or higher. Android studio and Anime studio pro 7 are the main software used to design the proposed game.

4.5 User Interface Design (UID)

The user interface design plays a vital role in providing the game with a good and attractive usability. Thus, the TrueBiters game has mainly been designed using **Anime Studio Pro 7 software**, which enhances the game with enjoyable and flexible graphics. The screens have been divided into two parts: Server and player screens, which are explained in detail in the following subsections.

4.5.1 Server Screens

The server side of the game is running on the main tablet (i.e. 10-inch tablet). It consists of the main screens of the game, which are described in the following subsections.

4.5.1.1 Splash Screen

The very first screen of the server side provides the players with multiple options as shown in Figure 27. **Self-training option** gives the players the opportunity to try out the game on his/her own smartphone in order to become familiar with the game, which is explained in the next section. In order to allow the players to play against each other, the players can click on **Start New Game option** and then establish the Bluetooth network connection to start playing the game. Moreover, **Help option** provides the players with more facilities and information that enable them to better understand the game and to find the answers to their questions.

Finally, **About option** allows the players to know more information about the main aim of the proposed game and its authors.

Figure 27: Server Splash Screen

4.5.1.2 Self-Training Screen

In order to allow the players to be familiar with the game platform, the self-training screen enables the players trying out the game on his/her own smartphone in order to become familiar with the game. First, the Bluetooth network connection has to be established between the server (main tablet) and the player device (i.e. smartphones). From the server side, an invitation should be sent to the player, once the player accepts this invitation, he can start his self-training as shown in Figure 28. The dedicated screen consists of a **Pyramid** configuration that has 15 tiles and 6 binary bit cards. Once the connection is correctly established. The player on his turn has to determine the desired place by tapping on the tile, where it will be highlighted with a brown color. This action/feature allows the player to know which tile has been recently selected. Finally, the player should compute the truth table of the logical expression. Then, the player will use his smartphone to select the correct logical operator by swiping it left or right, and send it to the server by swiping it up. If the player sends a correct logical operator to the server, it will be displayed with its output binary bit (i.e. 1 or 0) that appears at the center of the specified character (i.e. OR, etc.). However, when the player sends a wrong answer, a cross mark will be displayed with a music tune as a warning sound effect. Moreover, invalid card image will be displayed when the selected tile has one or null inputs in order to indicate that this tile is not a correct place to send data to it. The game gives the player positive and negative feedback by increasing and decreasing his score respectively on his side, as shown in Figure 28 (at his high left side).

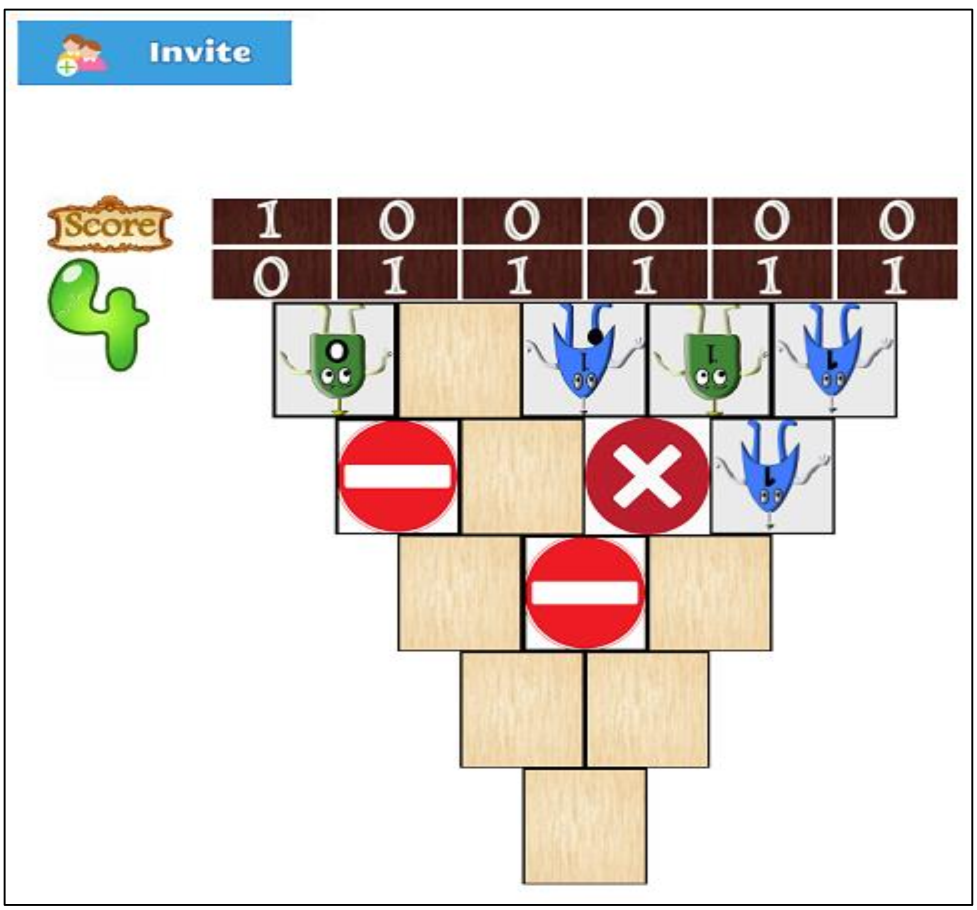

Figure 28: Self-Training Screen

4.5.1.3 Game Interface

Once the player click on start new game, six initial binary-bit cards will be randomly appeared as presented in Figure 29. First of all, an invitation should be sent to the players by clicking on the top right-invitation button of the screen of the main tablet. Second, the paired devices will be displayed as a pop-up menu as shown in Figure 30, where the first player can select his device address from the list and on his own smartphone he should accept the received invitation. The aforementioned last two steps should be repeated with the second player in order to establish the network correctly. Once the connection is established, the game will be started with the first player.

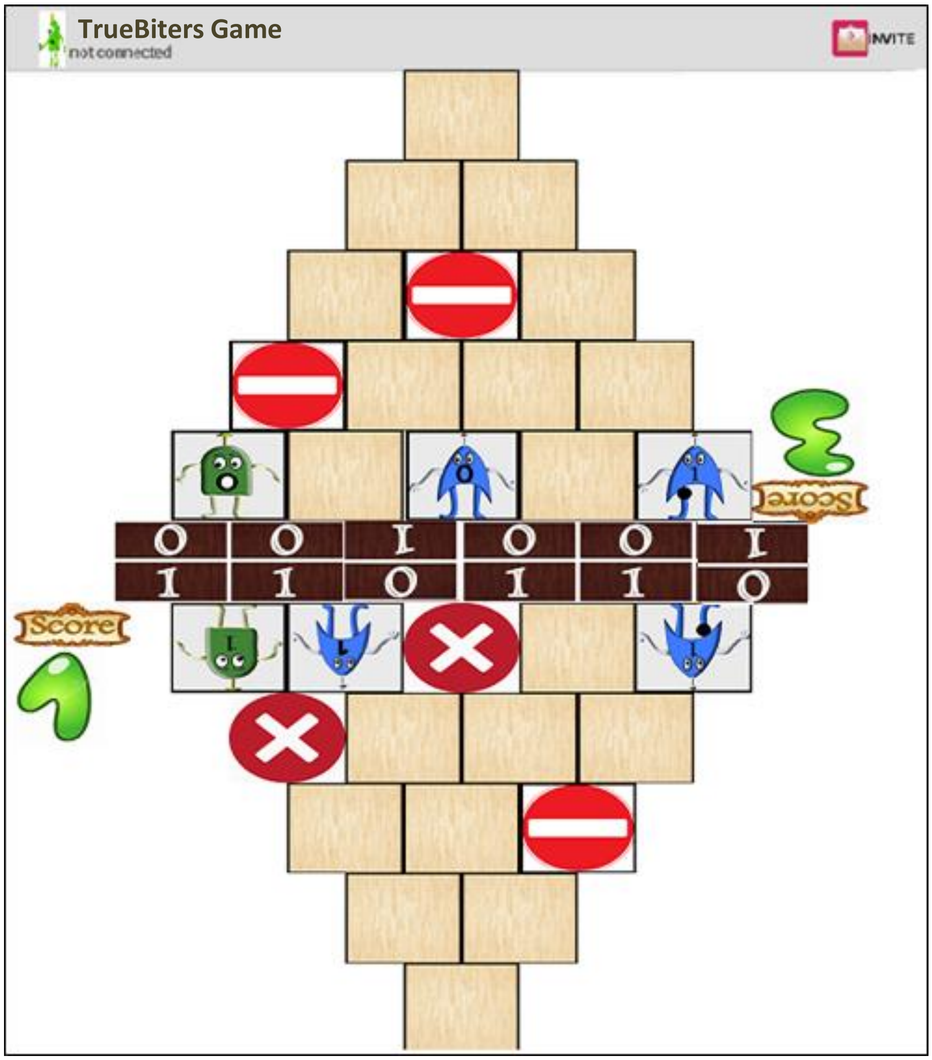

Figure 29: Game Interface

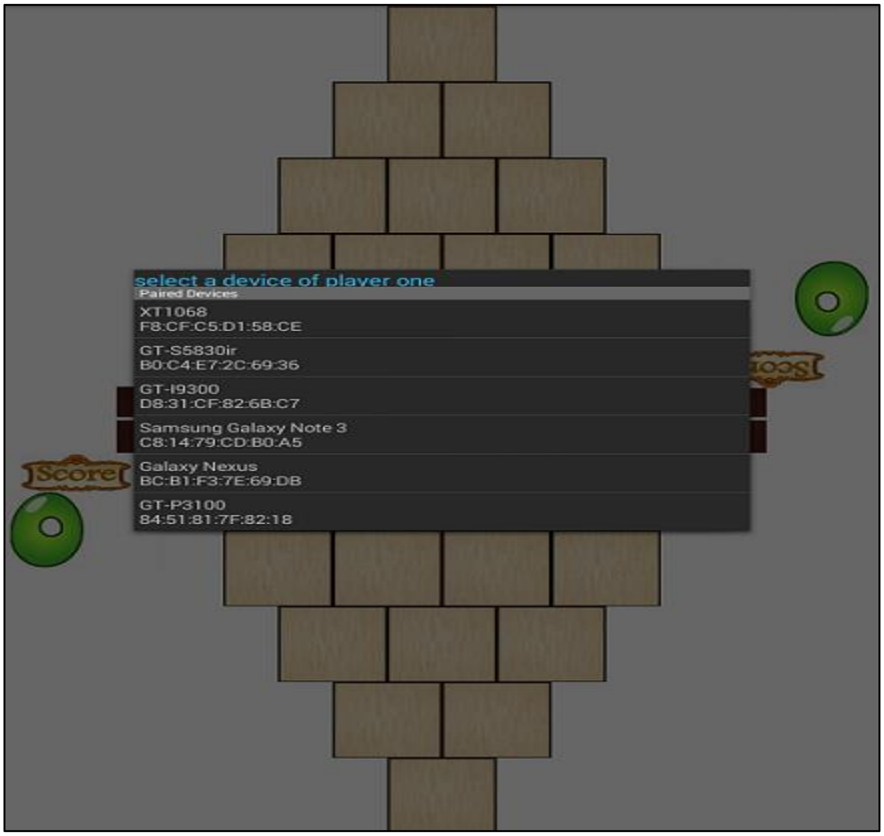

Figure 30: Paired devices pop-up menu

When an invitation is sent from the server to the first player, a textual message "**Sending Invitation to Player One…..**" will appear at the action bar as shown in Figure 31(A). This message allows the players to have an indicator about the status of the current action. Moreover, if the connection is correctly established with the player, another textual message "**connected to the device address**" will be displayed at the action bar as shown in Figure 31(C). However, if there is an error happens during establishing the connection, the action bar is showing a process indicator and will appear a textual message "**not connected**" as shown in Figure 31(B).

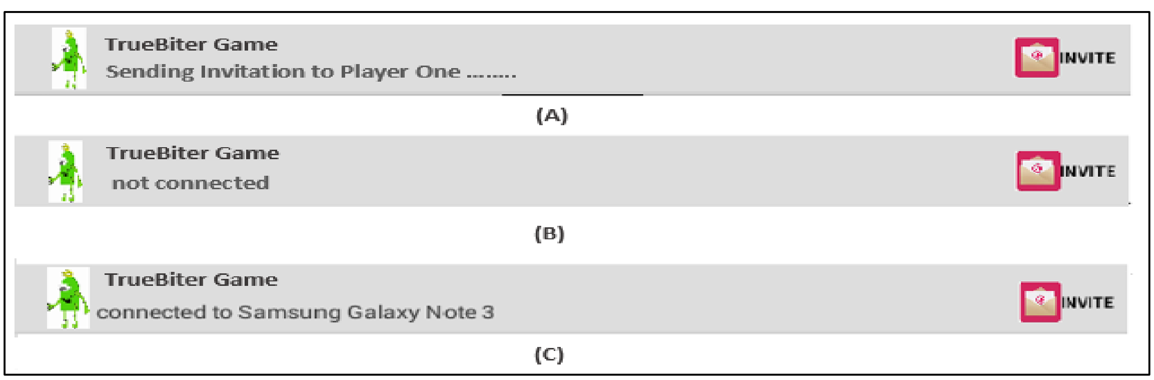

Figure 31: Action Bar Status A) Sending invitation B) Not Connected C) Connected to player

Each player, in his turn, should follow the game procedure, which has been described in detail in section 4.5.1.2.

Moreover, each player has the possibility to reverse/invert the initial binary cards by tapping on the specified data card, which will be highlighted with a red border to allow the player to know the last selected binary card as illustrated in Figure 32. Then, the player has to send the **NOT card** from his smartphone. This action will change the initial status of the located binaries linked to these inputs to be unsigned cards of both players that should be corrected according to the selected logic operator as shown in Figure 33. However, the other player will be able to cancel this action immediately and retrieve the previous binary bits. The winner will be the first player who finishes his Pyramid first, where the head of the Pyramid equals to the right most bit of the initial binary-bit cards. When one of the two players won the game according to the aforementioned condition, a congratulation sound effect would be played and the user interaction is then disabled. It means that any player is unable to change anything in the game (= GAME OVER).

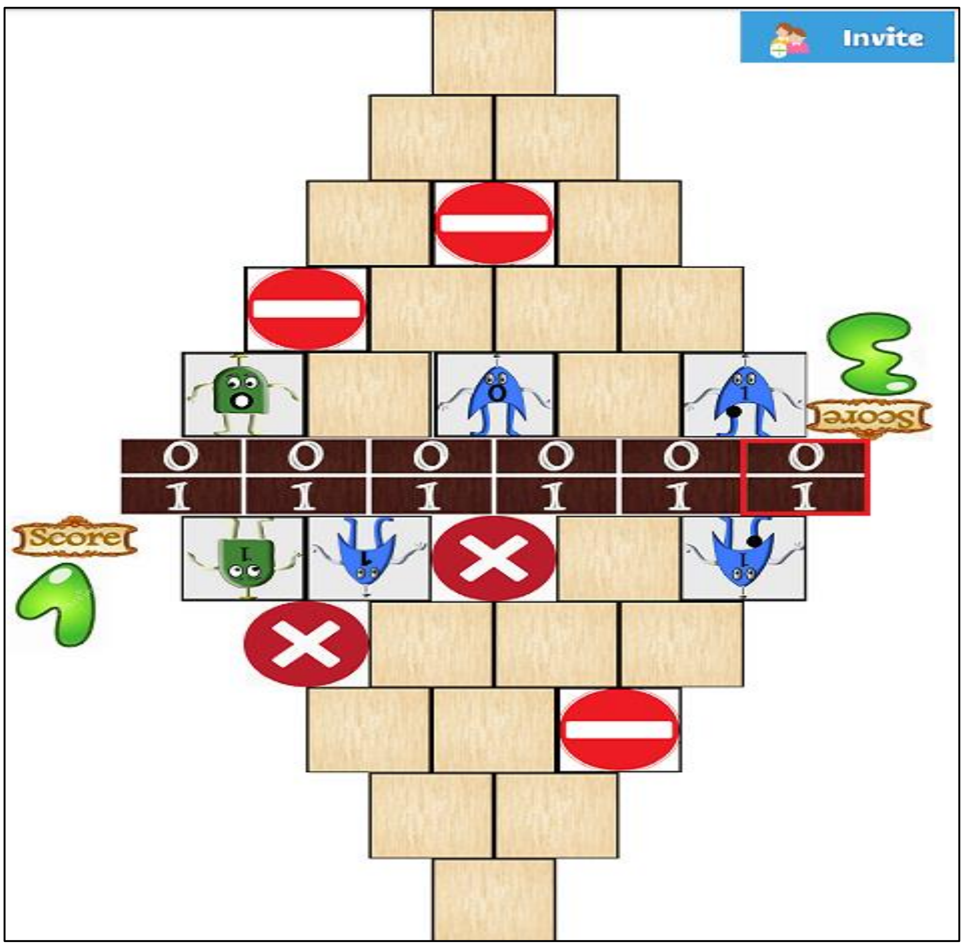

Figure 32: Game Interface with border indicator

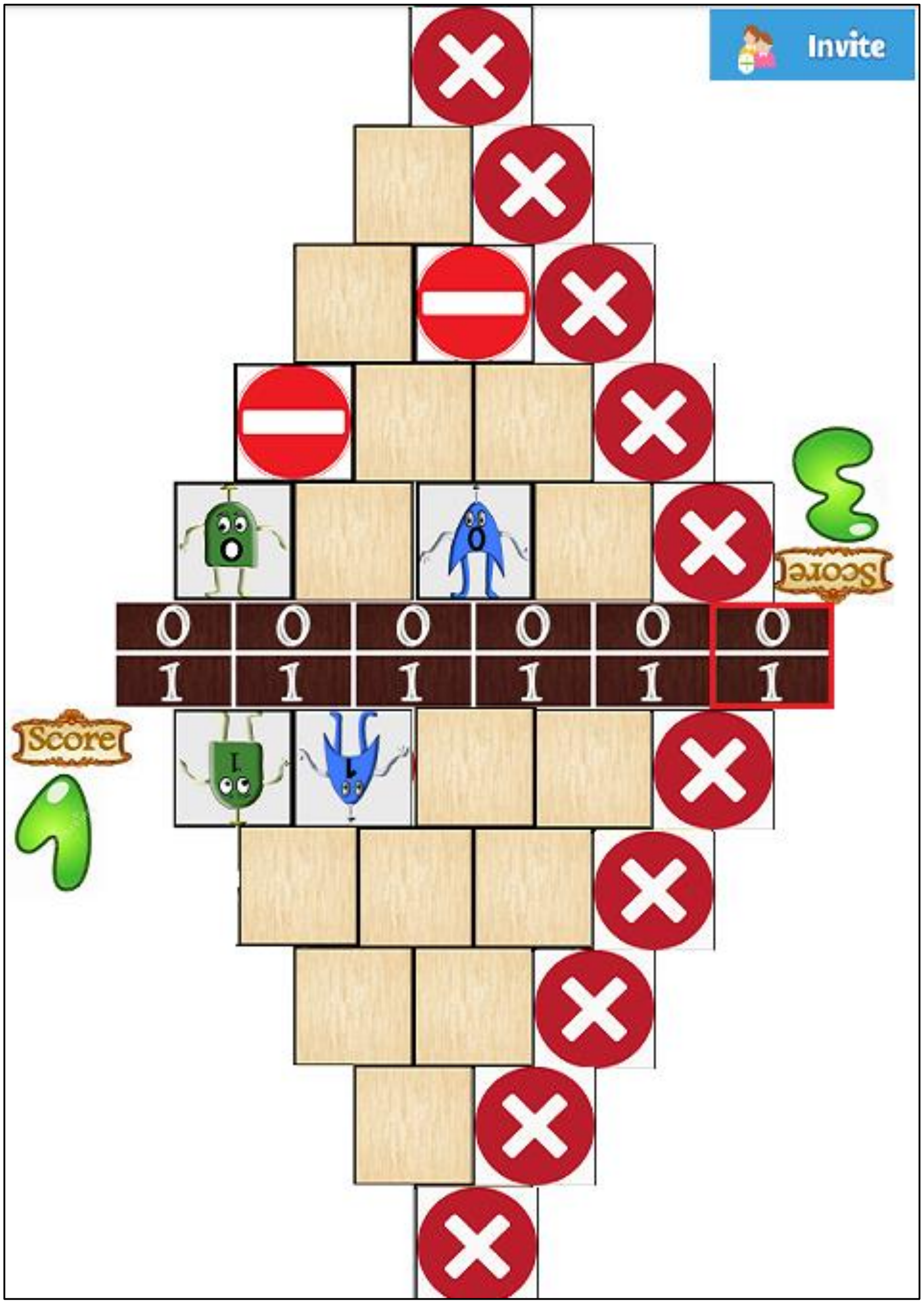

Figure 33: Game Interface with NOT card activated

4.5.1.4 Help Option

Help option enables the players to understand how to play the game and find out the answers to their questions. Help option consists of several pages, where each one has been designed as a letter that is hanging on a wooden wall as shown in Figure 34. The players can navigate between them by tapping on next button, which is carried by the TrueBiters character. The students can figure out the four truth tables that will be used in the game as demonstrated in Figure 35 and Figure 36.

Figure 34: Help Screen (1)

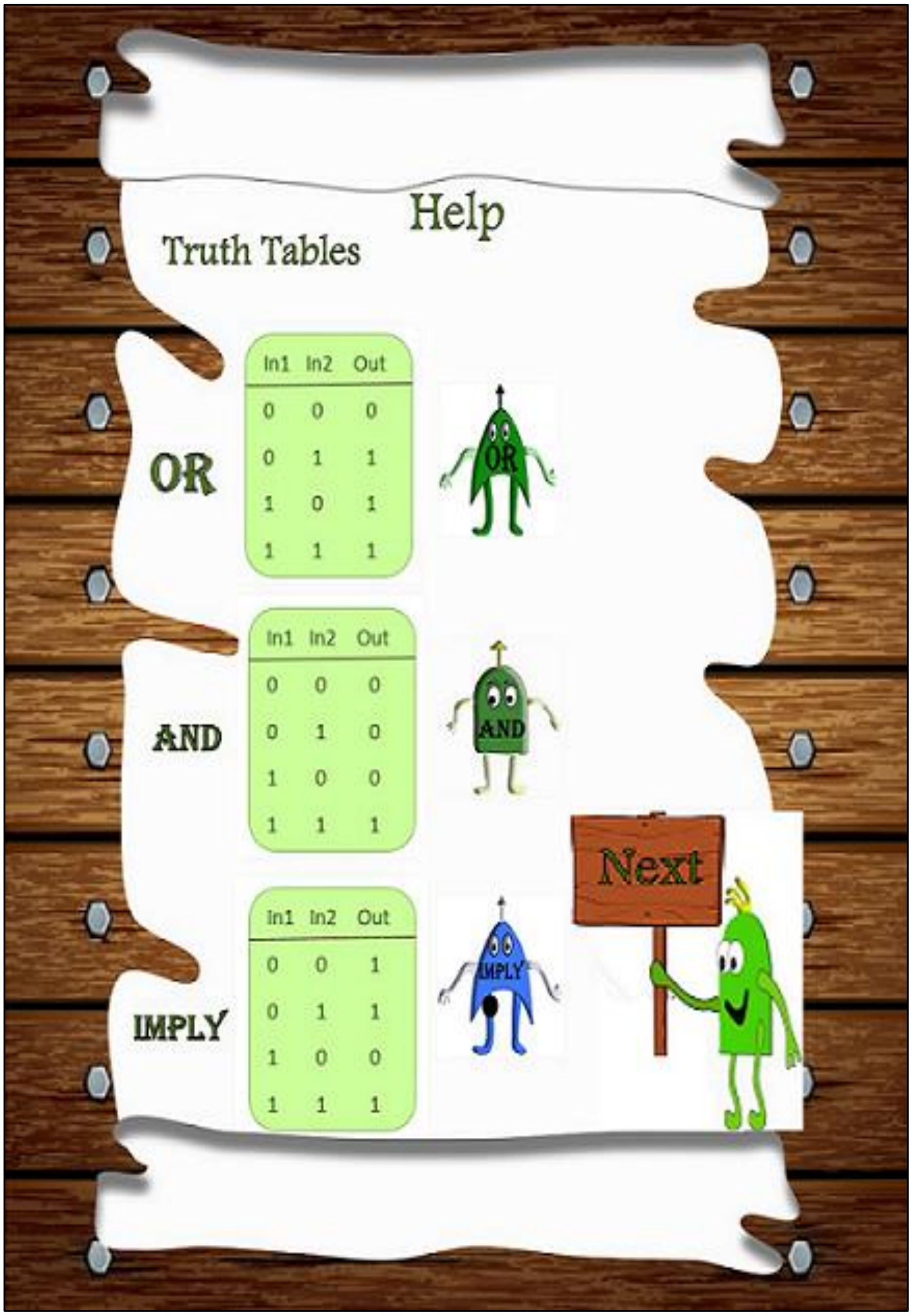

Figure 35: Help Screen (2)

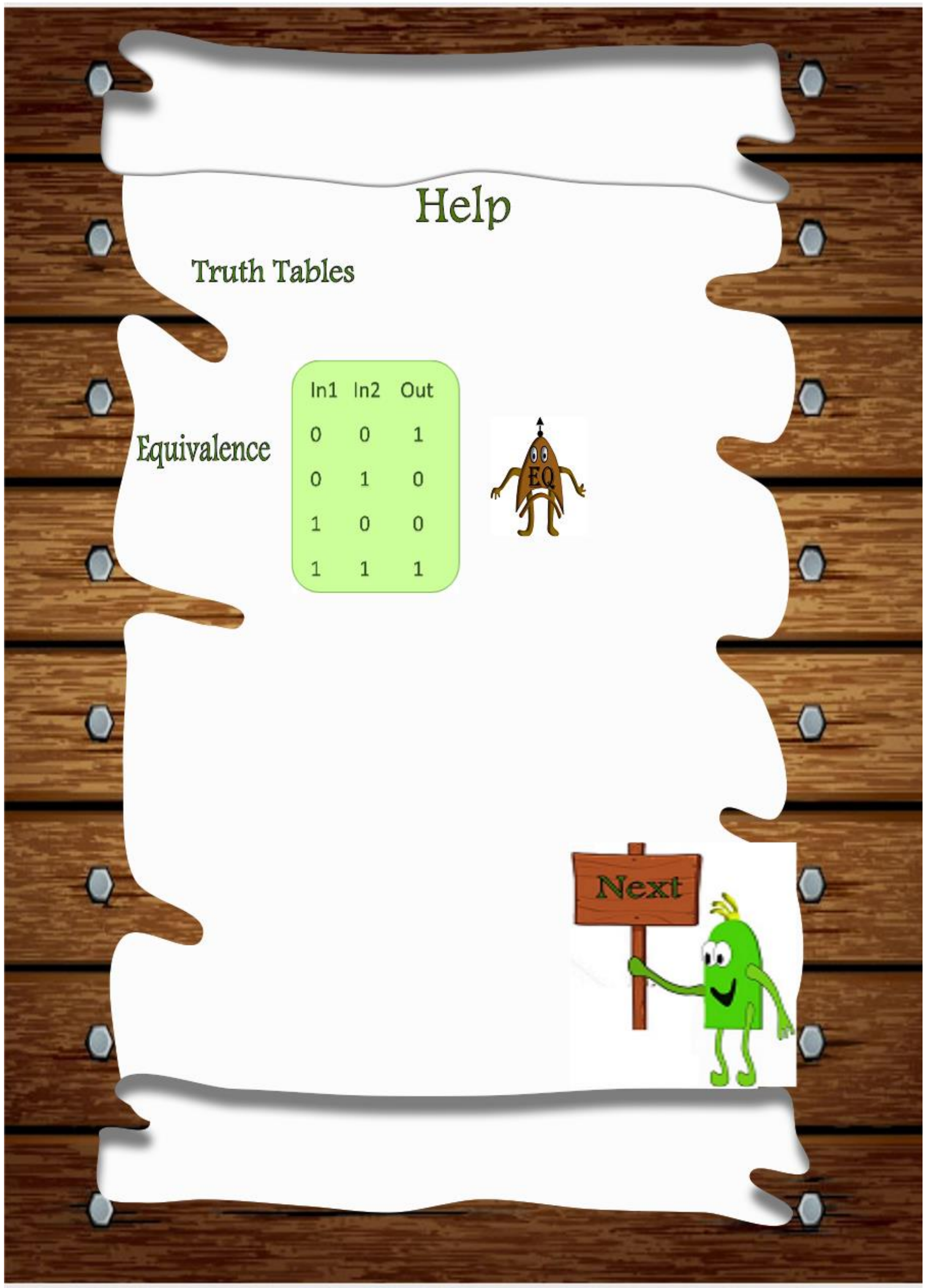

Figure 36: Help Screen (3)

4.5.1.5 About Screen

In About screen, as shown in Figure 37, the players will get more information about the main aim of the game and the authors. The screen has been designed as a wooden border to be homogenous with the other screens of the game.

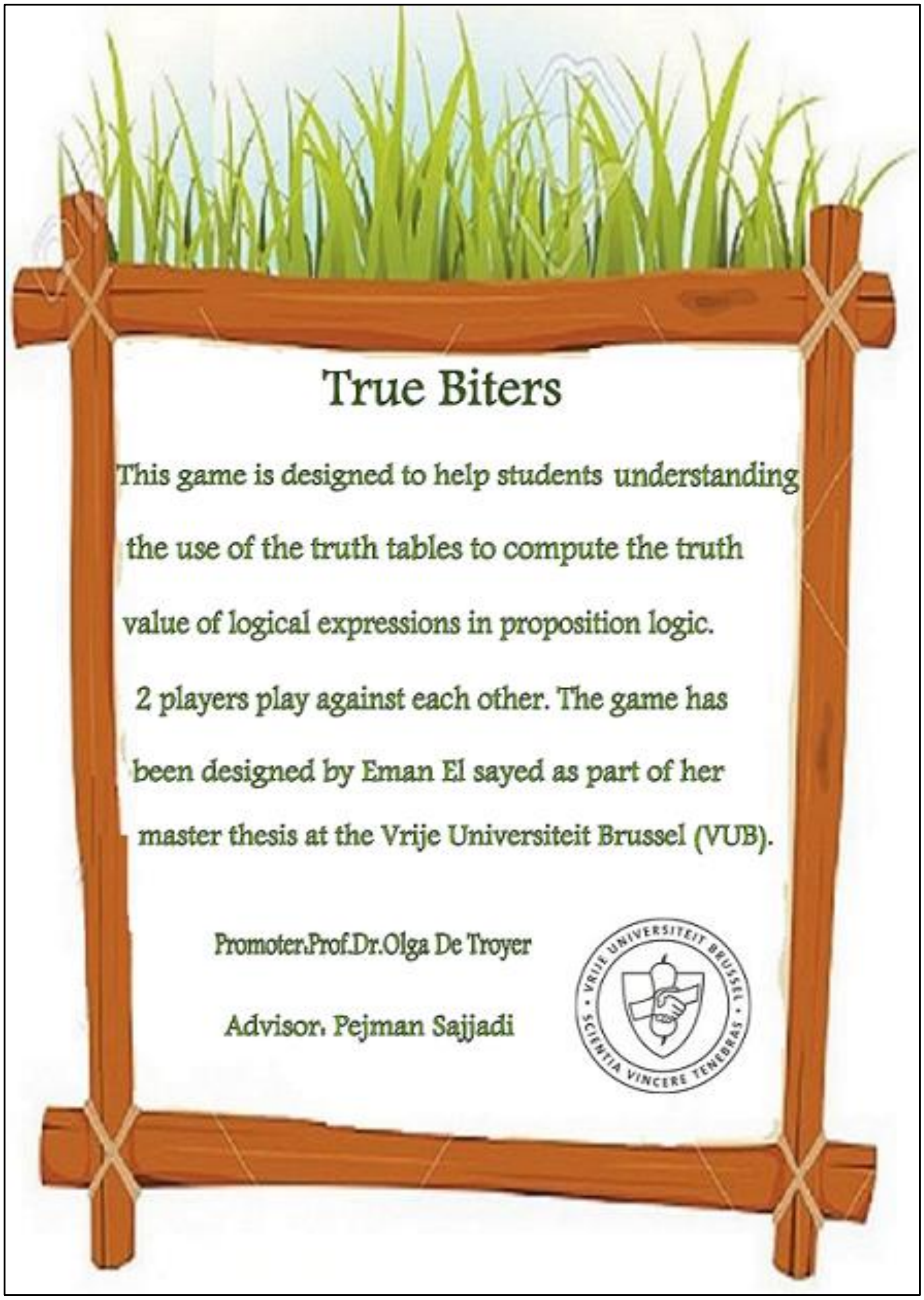

Figure 37: About Screen

4.5.2 Player Screens Design

Due to the importance of having a playful and attractive interface, the logical operators have been designed as funny characters, and all other interfaces have a matching look and feel.

4.5.2.1 Player Main Interface

The very first screen of the player side contains multiple options as shown in Figure 38. It has been designed based on a wooden layout, which matches the splash screen.

Figure 38: Player Main Interface

4.5.2.2 Play Screen

The player should accept the invitation by clicking on accept button as shown in Figure 39, and then the player selects the device address of the server from the paired devices list. Once the connection is established, the player can select the suitable card by swiping left or/and right and then send it to the server by swiping it up. The game has four truth tables (i.e. OR, AND, Implication and Equivalence) and can be easily extended. The characters are also displayed in a wooden border layout. The name of each logical operator is displayed at the center of the character. Moreover, the output binary bit is displayed at the top of the character as shown in the two examples in Figure 39, Figure 40. The input bits are not shown because the goal of the game is that the player knows which inputs bits are required for the given output bit.

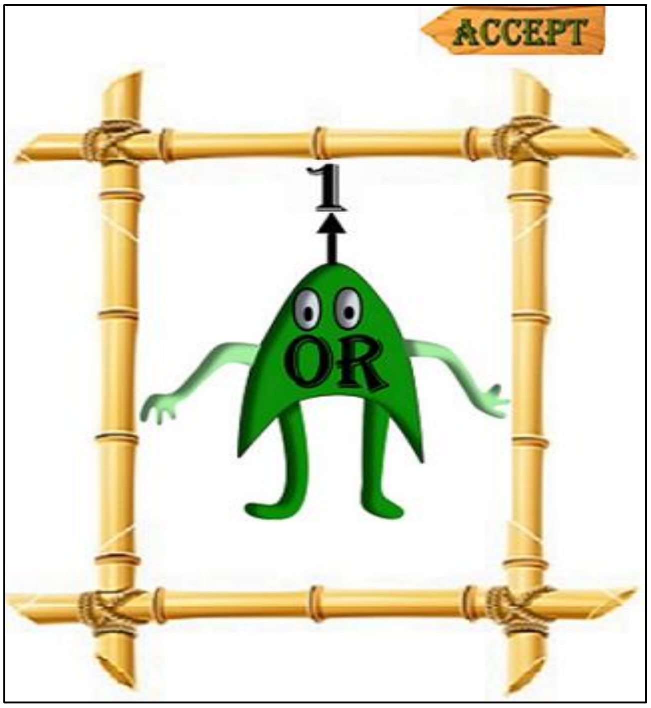

Figure 39: Truth Table Example (1)

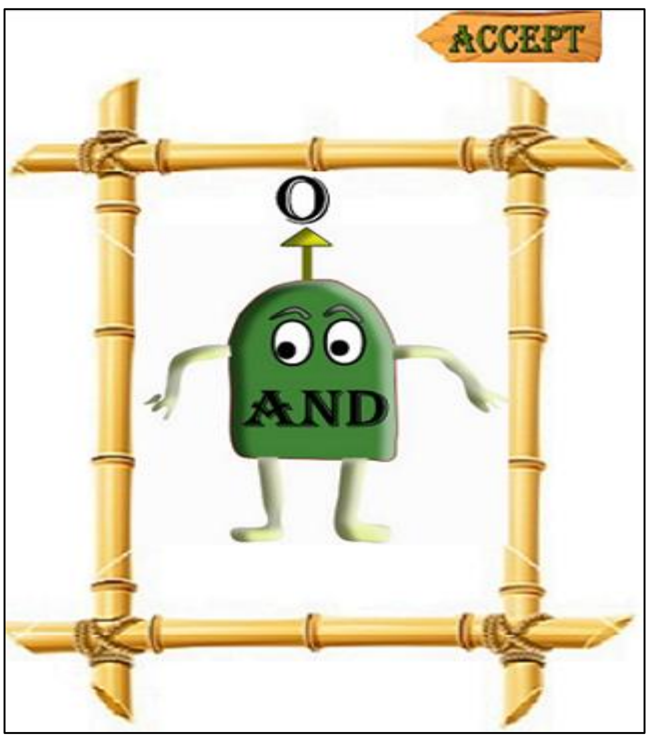

Figure 40: Truth Table Example (2)

5 Implementation

5.1 Introduction

This chapter presents the overall implementation of the TrueBiters game. This chapter is divided into three parts. Part I, **General requirements,** presents the essential requirements that should be available before establishing and implementing the proposed game. Part II, **Organizing the UI structure,** demonstrates how the structure of the user deign interfaces has been organized. Finally, Part III, **TrueBiters game implementation,** illustrates the two main phases in the implementation of the proposed game. These two phase can be divided into two subsections: ***1) Establishing the Bluetooth network,*** which discusses the important steps to establish a Bluetooth network between android devices, and 2***) Development and management of TrueBiters Game that*** highlight the most significant functions that are used in order to manage the game.

5.2 General Requirements

Before demonstrating the implementation of the TrueBiters game, there are some requirements that should be available.

The minimum number of the required devices for implementing the TrueBiters game is one large tablet and two smartphones. The size of the large tablet should be 10 inches. During conducting the experiments, two large tablets and four smart phones are used in order to allow the participants to play in parallel to save time. The specifications of these devices have been illustrated in Table 2.

Table 2: Devices list

Device	**Type**	**size**	Android version
2 tablets	Samsung Galaxy Tab4	10.1 inches	5.1.1
	Samsung Galaxy Note	10.1 inches	4.1.2
4 smartphones	Samsung	4.8 inches	4.3
	Motorola	4.8 inches	4.1.2
	Samsung	5.7 inches	5.1.1
	Samsung	4.8 inches	4.3

The first step of implementing any mobile application is to examine the compatibility of the proposed application with android platforms of the available devices. This compatibility can be checked by comparing the API level integer value provided by the mobile application with the API level of the android platforms. A list of the platform versions against API level is shown in Table 3. For The TrueBiters game, API level should be equal to 11 which means the platform version that required android version should be android 3.0.x version or higher.

Table 3: API levels

Platform Version	**API Level**		**Platform Version**	**API Level**
Android 6.0	23		Android 3.0.x	11
Android 5.1	22		Android 2.3.4 Android 2.3.3	10
Android 5.0	21		Android2.3.2 Android2.3.1 Android 2.3	9
Android 4.4W	20		Android 2.2.x	8
Android 4.4	19		Android 2.1.x	7
Android 4.3	18		Android 2.0.1	6
Android 4.2, 4.2.2	17		Android 2.0	5

Before installing the TrueBiters game on android devices, USB debugging option should be enabled. In some android versions, USB debugging option is hidden. Therefore, "*Build Number*" field should be tapped seven times first. Additionally, for each android device, a convenient driver should be downloaded from the OEM (original equipment manufacturers) drivers, as listed in (Studio, n.d.), because TrueBiters game has been developed on Windows.

5.3 Organizing the User interface (UI)

As explained in the design chapter, all the images and graphs have been designed using Anime studio pro 7 software. Moreover, the visual structure of the user design interfaces has been controlled by means of XML files. There are two possibilities of controlling the visual structure of the user design interfaces in android studio. The first one is creating and controlling the structure programmatically. The second type is to create separate XML files that can represent the structure and based on the goal of the proposed application. The UI's behavior can be controlled from the source Code. The TrueBiters game follows the second type where a separate XML file has been created for each UI and saved in the layout folder. The main advantage of creating Separate XML files is to provide the game's developer with more flexibility to modify and evolve the user design interfaces without changing the source code. Moreover, the behavior of each view in the screens is controlled by means of unique ID that has to be defined in the XML. One of the most important strides during organizing the structure of the user design interfaces is identifying (declaring) a unique ID for each element. Our proposed game uses these unique identifiers in order to control the logical operators that should be displayed on the pyramid tiles.

5.4 TrueBiters Game Implementation

Figure 41 illustrates the flowchart of the overall implementation of the TrueBiters game. As summarized in section 5.1, this implementation has been divided into two phases: **1) Establishing the Bluetooth network**, and **2) Development and Management of TrueBiters game.** The latter is to clarify the main functions that are accountable to manage the game between the players and the server.

5.4.1 Establishing the Bluetooth Network

5.4.1.1 Setting Up Bluetooth

The first phase of establishing a network is setting up the Bluetooth. The main goal of this phase is to guarantee that the network devices support and enable Bluetooth features.

In order to check the availability of Bluetooth feature, ***getdefaultadpater()*** has to be firstly called in the main program, and based on the result of this function, a decision is taken about the checked devices. If it returns null, this means the device does not support Bluetooth features. In this case, it cannot be used in establishing the Bluetooth network. However, if it returns a Bluetooth adapter, the next step can be established. The second step is to verify that the Bluetooth is enabled. If the Bluetooth is disabled, the program provides the player with the facility to enable it through a dialog.

5.4.1.2 Querying Paired Devices

The second phase is to query the paired devices and to display their essential information on a list in order to let the players determining their desired devices and establishing the network connection. The paired devices are queried by calling ***getBondedDevices()*** function. The most important returned information is essential in establishing the network connection is MAC address of the dedicated devices.

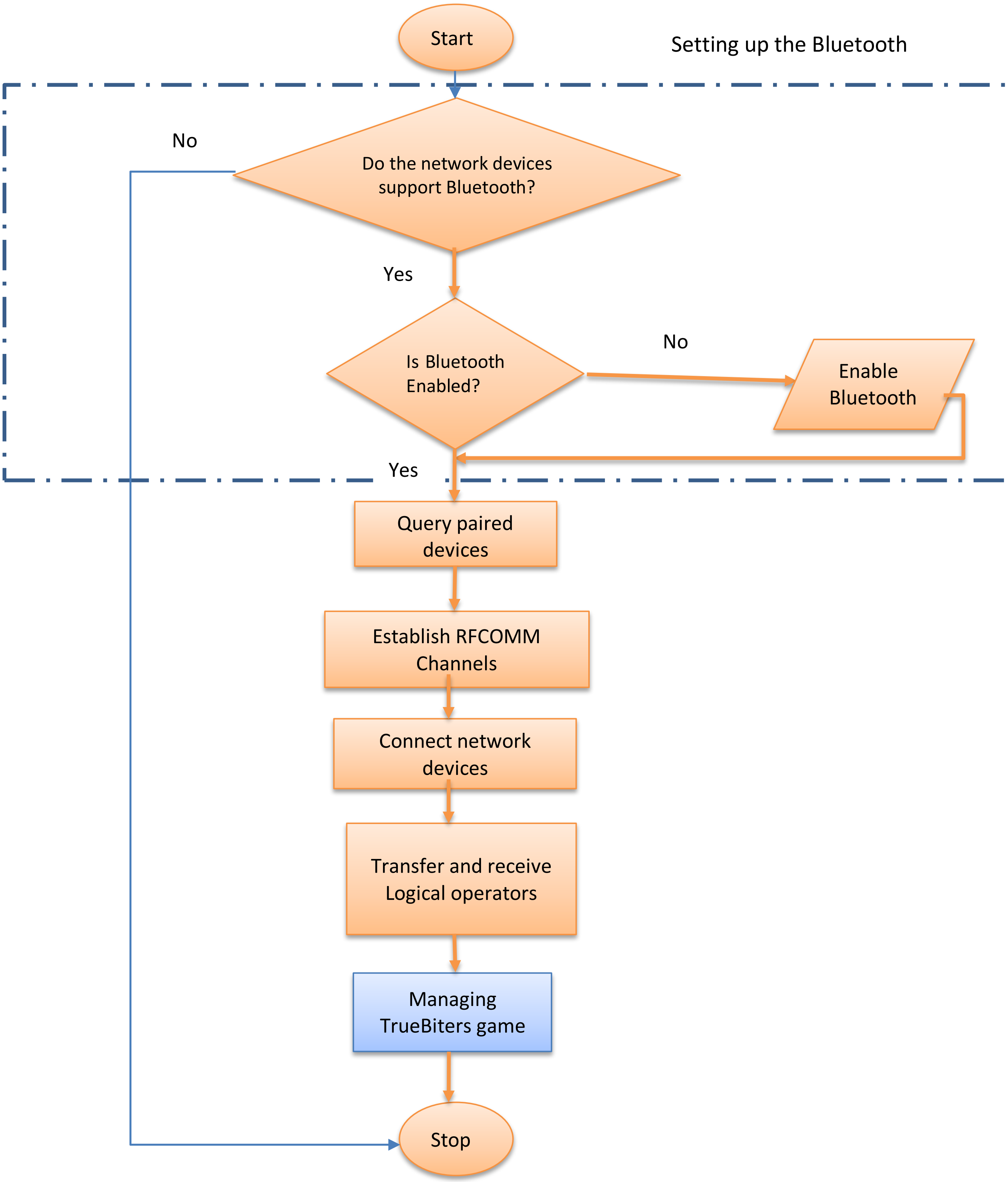

Figure 41: Flowchart of establishing the Bluetooth network

PlayersDevicesList class is the main responsible of controlling all the functions related to paired devices.

- ***Establishing RFCOMM channel***

To transfer data between two devices, the devices should be connected through RFCOMM, which acts as a virtual serial port as shown in Figure 42. One of the connected devices acts as a server while the other acts as a client. Each one has a different responsibility in establishing the network connection. The main responsibility of the server device is to listen for the incoming requests from the clients through opening a server socket. However, the client is responsible for initiating the connection through MAC address.

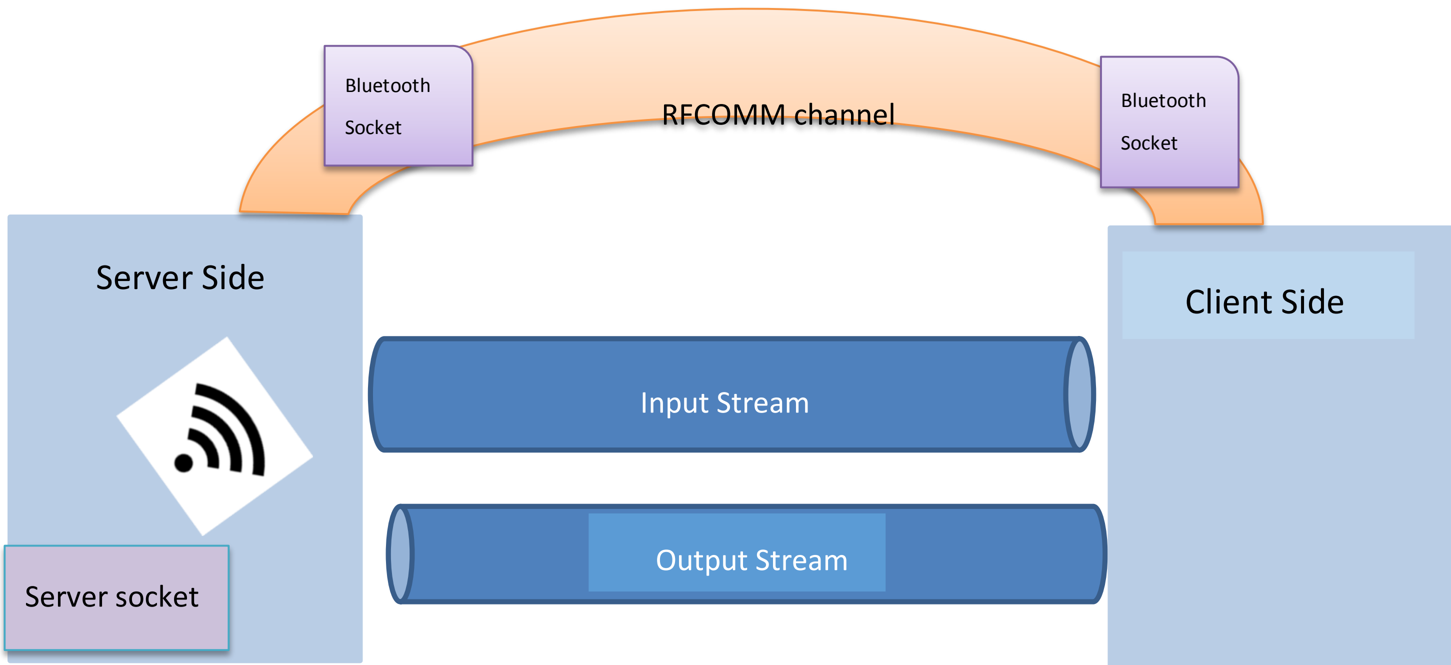

Figure 42: Establish RFCOMM Channel

On the client side, the TrueBiters service has been identified by UUID (Universally Unique Identifier). This should match the UUID that has been registered with server socket in order to endorse the connection. The Bluetooth network is successfully established when each device has a Bluetooth socket on the same RFCOMM channel.

The aforementioned phases are handled through creating three threads: **1) AcceptThread**, which is responsible for listing to the incoming client requests, **2) RequestConnectionThread,** which is to initialize and send client requests, and **3) LogicalTransmissionThread** that is accountable to manage the connection and to control the transferred streams of data. All the threads and functions that control establishing the network are saved in one class called TrueBitersGameService.

- ***Transfer and receive logical operators***

Once the TrueBiters network devices are connected through the RFCOMM channel, the logical operators can be transferred and received using input and output streams. There are two main functions, which are responsible of handling the incoming and outgoing logical operators.

1. ***SendLogicalOperator***

The main objective of this function is to transfer the logical operator from the player side to the server side. First of all, an object of TrueBitersGameService class is created in order to use the LogicalTransmissionThread. Based on this object, the output stream is retrieved from the Bluetooth socket and the desired logical operator is written to it.

2. ***ReceiveLogicalOperator***

Once the logical operator is sent from the player side, the server keeps reading the data stream. Similar to the aforementioned function, the logical operator can be read by means of Logical transmission threads that can be accessed via the created object of TrueBitersGameService.

5.4.2 Managing TrueBiters Game

After establishing the Bluetooth network between the players and server, the game session should be managed. This session is handled through creating some different functions

- ***CheckNullData***

After receiving the logical operator from the player, the first thing that should be checked is the preselected tile on the server suitable for sending a logical operator or not. CheckNullData function is responsible for checking the input data tiles for the preselected tile. The preselected tile is not suitable if the one of the input data or both is null.

- ***CheckPlayerAnswer***

When the player sends his logical operator, it should be checked on the server side by comparing the sent logical operator with its truth table data. CheckPlayerAnswer function is responsible for checking the answer and providing the players with the convenient feedback. Based on the result, an appropriate feedback will be rendered to the player. Then, if the answer is correct, the logical operator will be presented on the preselected tile accompanied by the convenient sound effect and his score is increased by one digit. Moreover, if his answer is incorrect, a wrong sign will be displayed on the preselected tile by the convenient sound effect and his score is decreased by one digit. Figure 43 illustrates the main flowchart of the TrueBiters game implementation.

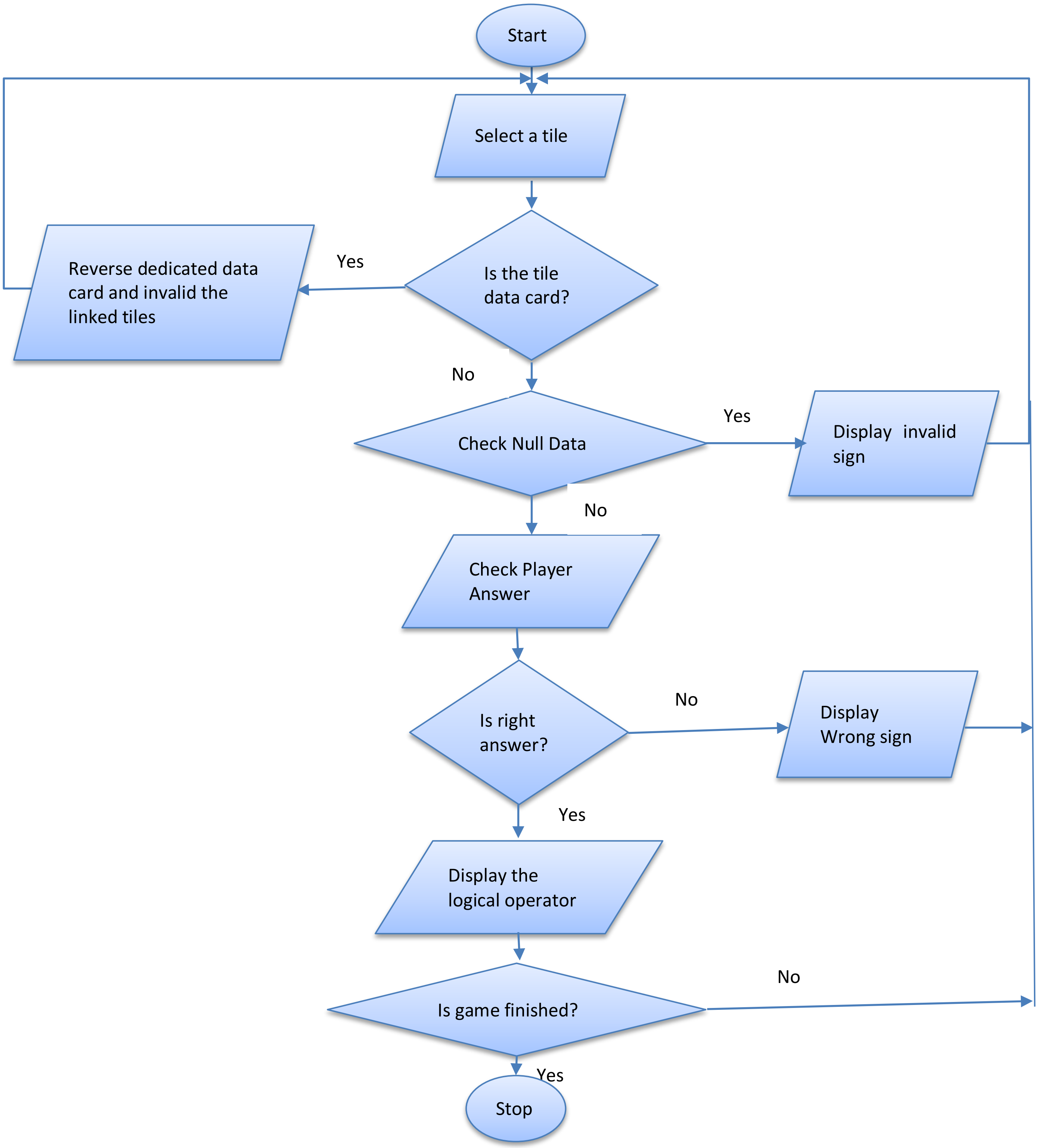

Figure 43: Flowchart of TrueBiters game implementation

6 Experiments and Evaluation

6.1 Introduction

This chapter presents the experiments done using the TrueBiters game to investigate our research question, as well as an evaluation of the game based on the work of Sajjadi (Sajjadi, n.d.) which provides a mapping between MI dimensions and game mechanics. This last evaluation has been performed to evaluate whether the game is following the recommendations given by Sajjadi. This result can be taken into consideration to either confirm or explain some of the experimental results. In principle, it would have been better to follow the recommendations during the design of the game, however at that moment the recommendations were not yet available.

The main objective of this chapter is to present the methodology used to evaluate our hypotheses using this game, the analysis method used to analyze the data, the results of the analysis and the discussion of the results, as well as the evaluation concerning the used game mechanics. This chapter is composed as follows. We start by reviewing our main research question from which the hypotheses for the two experiments were formulated. Next, we explain the methodology used for the experiments. Then we present the results of the experiments and discuss them. Then we explain the game mechanics evaluation done and discuss the results in combination with the results of the experiments.

6.2 Research objectives

As illustrated in the introduction chapter, the main research question is:

Can the TueBiters game improve the learning outcome of its players and result into a better gameplay experience for the audiences most suited for the game with respect to their multiple intelligences profile?

The objective of this chapter is to evaluate the following two hypotheses:

H1: The use of TrueBiters will result in an improvement of the learning outcome of its players.

Since the content of the game is focused on logical intelligence, while the interaction modality focused on the kinesthetic intelligence, it is expected that players having high values for both intelligences would have a better gameplay experience compare to the rest.

H2: Players with high logical intelligence and high kinesthetic intelligence will have a better gameplay experience than others.

6.3 The Experiments

The TrueBiters has been used in two experiments, each aimed at evaluating a hypothesis. A visual overview of the two experiments is given in Figure 44. Before conducting the experiments, the game was deployed on six devices (2 large tables and 4 smartphones) in order to allow the students to play the game in two parallel sessions.

6.3.1 Experiment 1

The first experiment was aimed at evaluating H1: “the use of TrueBiters will result in an improvement of the learning outcome of its players”. During this experiment, four students played the game against each other in a kind of tournament. It should be pointed out that these participants had followed the “Logica en formele systemen” course, but unfortunately failed to pass the course on the exam. The main goal of this experiment was to evaluate the impact of the game on understanding the logic operators and to study how the proposed game improves the students’ knowledge and skills on this matter.

6.3.1.1 Participants

In this experiment, VUB students from introductory 1st year Bachelor Computer Science with similar demographic characteristics have been participated, where they are four males (100%) and zero female (0%) and ranged in age from nineteen to twenty. As mentioned before they followed the “Logica en formele systemen” course and they failed to pass it.

6.3.1.2 Methodology

As already indicated, the evaluation per student consists of three phases: Pre-experiment, Experiment and Post-Experiment. Each of these phases will be described in more detail in the following subsections.

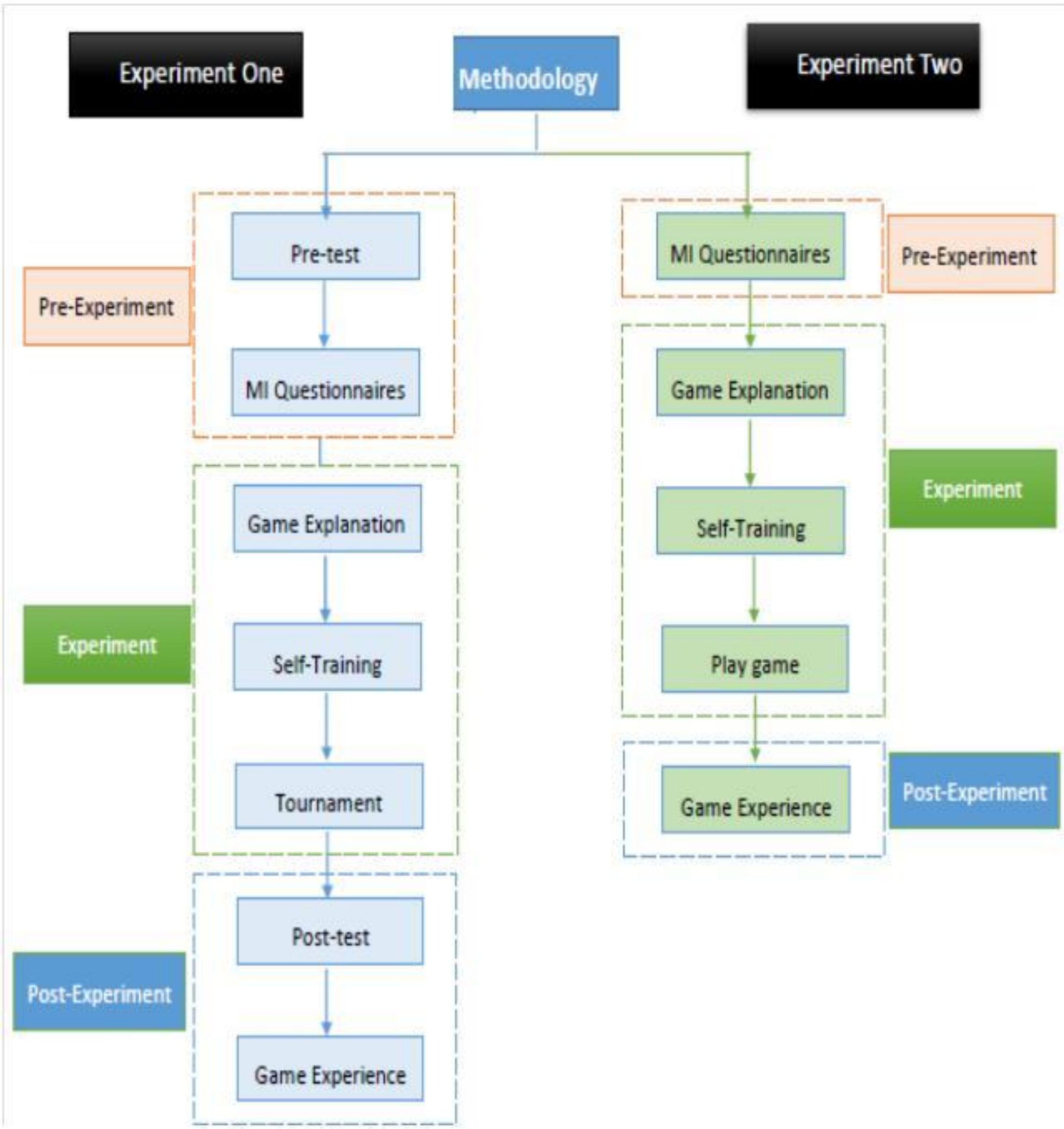

Figure 44: Structure of the methodology

6.3.1.3 Set up

With four players in total, it was decided that each player would play against all other players. Tournament style has been chosen in order to evaluate the students' progress in competitive coevolution way. It was decided that everyone would play against everyone else in order to be sure that no weak or strong player would only affect one player. Therefore, a tournament has been scheduled for two days as shown in Table 4 .

Table 4: Tournament Schedule

Session No	Player Matches	
Session 1	player1 Vs player2	Player 3 Vs Player4
Session 2	Player 1 Vs Player 3	Player 2 Vs Player 4
Session 3	Player 1 Vs Player 4	Player 2 Vs Player 3

6.3.1.4 *Pre-experiment Phase*

The pre-experiment phase consists of two main parts: 1) a logical pre-test and 2) a Multiple intelligence questionnaire.

- ***Pre-test***

In order to establish a proper baseline on the knowledge level of the players about the topic of the game, the participants were asked to perform a written test. This test has been prepared and evaluated by Prof. Olga De Troyer (the lecturer of the Logic course). The duration of the pre-test was 30 minutes. The test was in Dutch (the language of instruction of the course) and can be found in the **Appendix**.

- ***Multiple intelligence questionnaire***

The next step consisted of identifying the MI dimension levels of the participants**.** The intelligences of the participants were identified using a self-assessment questionnaire called MIPQ. This questionnaire consists of **31** statements (Quarterly, 2008), and the participants were asked to rate each on scale of **1 to 5**, where **1: Strongly agree, 2: Agree, 3: I do not know 4: Disagree, 5: Strongly Disagree.**

6.3.1.5 Experiment Phase

- ***Game Explanation***

Before the play session started, the game was explained to the participants. Moreover, during playtime each player had the opportunity to navigate to the help pages section 4.5.1.4.

- ***Self-Training***

After explaining the essential features of the game, each student was given some time to try out the game in order to better understand how the game works. This was facilitated through the self-training option provided by the game in section 4.5.1.2. Each player was given 10 minutes to train. Moreover, since the training could be performed individually, two players could train in parallel.

- ***Tournament***

The tournament was completed within two days as shown in Table 4. During the first day, the players finished sessions 1 and 2 (in table 2), while on the second day, session 3 was finished.

6.3.1.6 Post-Experiment Phase

After the tournament, each player was asked to do a logic post-test, which was similar to the pre-test and had the same difficulty level. The players were given 30 minutes to finish the test. The goal was to compare the results of the post-test and pre-test to see whether there would be any improvement of the players knowledge after using the game.

To properly measure the game experience (GX) of the students, they were asked to answering the GX questionnaire. The GX questionnaire consisted of 33 statements as mentioned in the **Appendix**, which were rated on a five-point scale, where **0: not at all, 1: slightly, 2: moderately, 3: fairly, 4: extremely.** The assessment of Game experience is based on the scores of seven components: Competence, Immersion, flow, tension, challenge, positive affect and negative affect.

6.3.1.7 Results

- ***MI Results***

The MI results of the participants showed that 75% were logically intelligent and one was linguistically intelligent as shown in Figure 45.

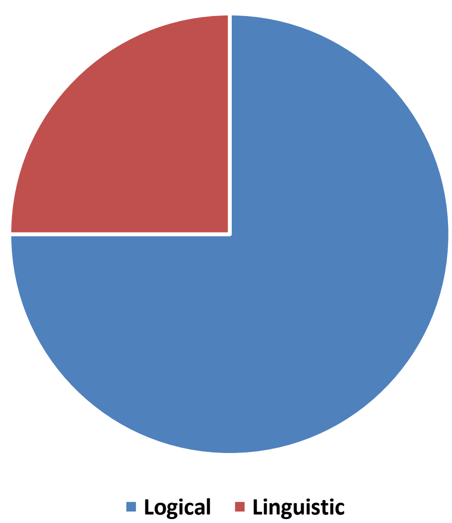

Figure 45: MI Results

- ***Pre-test Results***

The results of the pre-test of the participants are shown in Figure 46. One student had a score less than 50%, while students 3 and 4 had the same score of 63.6%. Furthermore, student 2 had the highest score (72.73%).

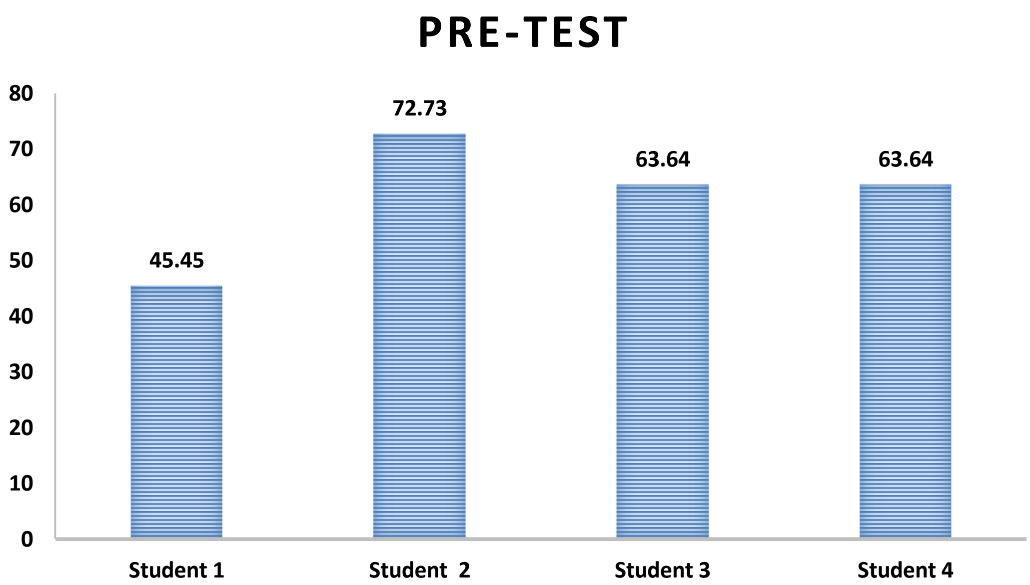

Figure 46: Pre-Test Results

- ***Tournament Results***

As mentioned previously, the tournament was completed within two days. The winners in the first day were student 2 and student 3; they won two times against players 1 and 4. The result of the final session showed that student 1 won against student 4, while student 2 won against student 3. Therefore, the winner of the tournament is student number 2 as shown in Figure 47 (green color).

However, it should be pointed out that observation suggests there was no significant difference between the competences of the students. Sometimes, the students lost their turn because of the use of a wrong gesture during the selection process of the correct logic operators, resulting in swiping up the wrong card.

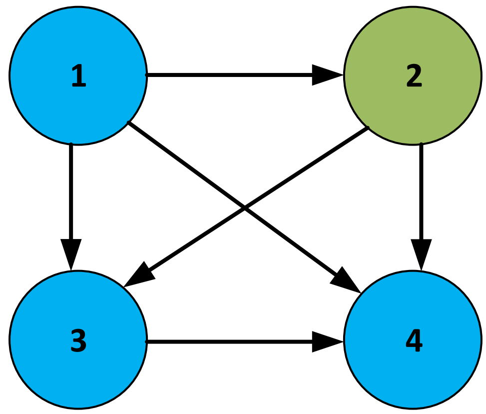

Figure 47: Directed graph of the tournament

- ***Post-Test Results***

The results of the post-tests are shown in Figure 48. The bar chart in figure 5 illustrates that two students have obtained the full mark, while one student has obtained 80%. However, one student has just passed the test with 60%. It was observed that the students managed to finish the test in less than the expected time, and they seemed to be more competent.

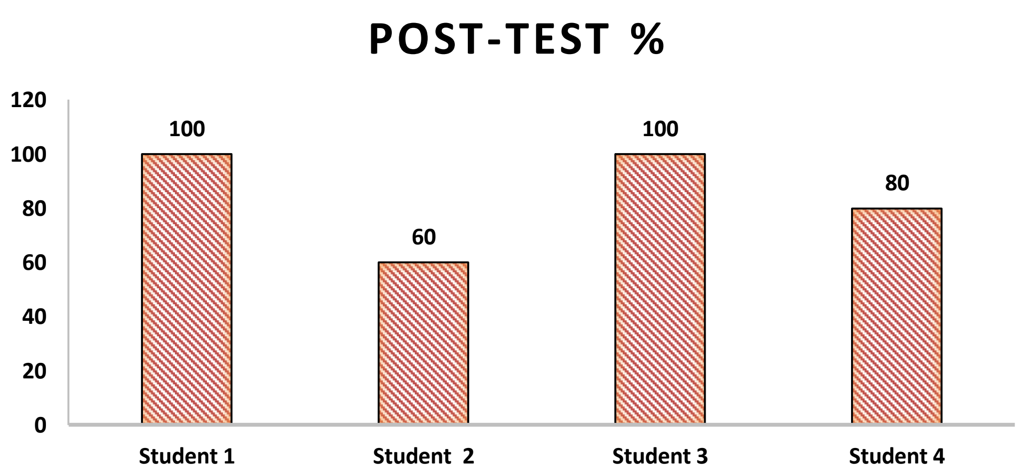

Figure 48: Post-Test Results

- ***Pre-Test and Post-Test Comparison***

To visualize the improvement of the students' learning outcome, a comparison between the aforementioned results of pre-test and post-test has been presented in Figure 49 . The results highlighted the positive impact of the game on the students' results where all the students have improved their levels except one student (Student 2). As was demonstrated before, the majority of the students who participated in the first experiment were logically intelligent, and all of them have improved in their test scores after using the TrueBiters game.

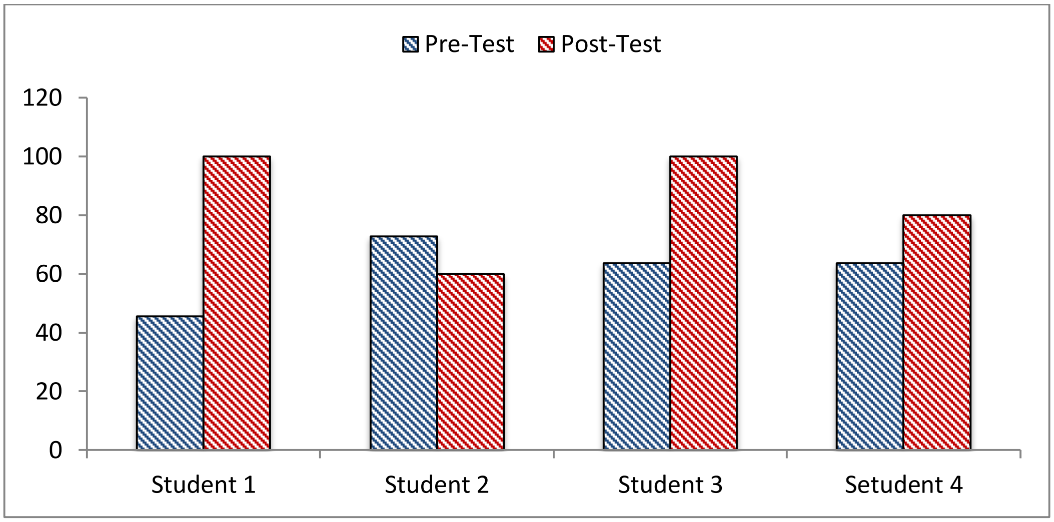

Figure 49: Pre-Test and Post-Test results

- ***Game experience (GX)***

The game experiences answers of the students have been analyzed using IBM-SPSS statistics 24 program, the game experience results are shown in Figure 50. The results were very positive, where the competence score is high (2.75). Moreover, the immersion and the flow scores are high 2.2 and 1.95, respectively. The graph elucidates a positive evaluation, where the negative affect (0.31) and tension (0.41) factors are less than one.

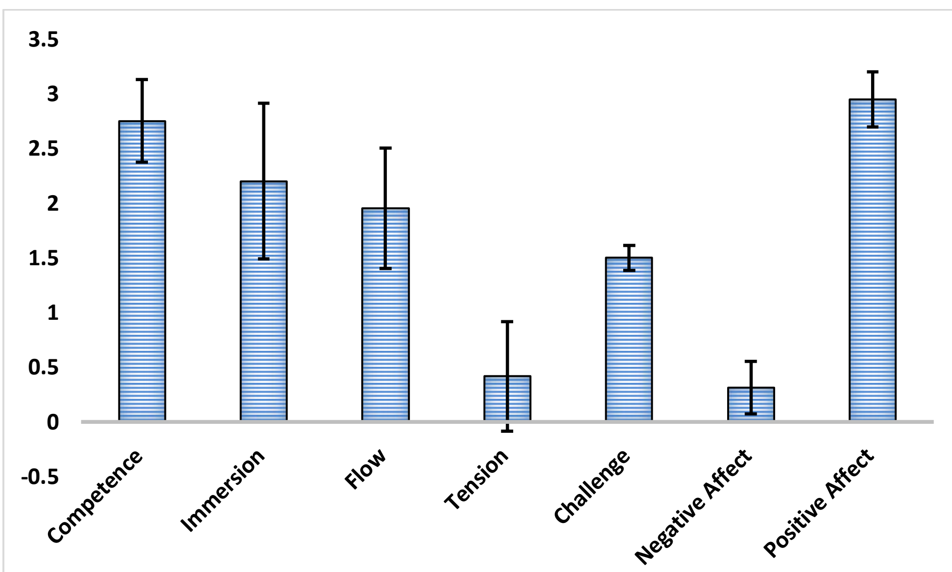

Figure 50: Descriptive analysis of experiment 1

6.3.1.8 Discussion

The results show that the TrueBiters has a significant impact on the progress of the students for understanding logic. All the students have improved their level except one student. The only student who did not improve his score (and actually his score decreased) is neither logical nor kinesthetic. Therefore, the correlation between the positive results and the logical type indicates that the TrueBiters game mechanics provide the students with a good medium to learn. It is very important to mention that two students (especially students 1 and 3) obtained a full mark in the post-tests, which has highlighted the major influence of the TrueBiters game on their understanding of logic. Additionally, the game experience results show that the proposed game has a positive game experience where the competence, immersion and positive affect factors have high scores and moreover, the negative affect and tension have low scores.

6.3.2 Experiment 2

As explained before the main objective of this experiment was to evaluate our second hypothesis" Players with high logical intelligence and high kinesthetic intelligence will have a better game play experience than others." which is related to game play experience.

An additional seven participants with different intelligence types have been invited to play the game in order to measure their game experiences. This was done by means of a game experience questionnaire.

6.3.2.1 Participants

The participants in this experiment are seven VUB students from the 2nd year Bachelor Computer Science. Their demographic characteristics are as follow:

Six males (90%) and one female (10%) and they ranged in age from twenty to twenty-one.

6.3.2.2 Methodology

Similar to experiment one, the evaluation per student consists of three phases but with different structure as shown in Figure 44.

6.3.2.3 Set up

In this experiment, the students with different intelligence types have been invited according to their schedule to play the proposed game.

6.3.2.4 Pre-experiment Phase

The pre-experiment phase consists of the multiple intelligence questionnaire

- ***Multiple intelligence questionnaires***

Each participant was asked to fill on the MIPQ in order to determine his/her intelligences. As mentioned before the tests consist of 31 statements (Quarterly, 2008), where the participants had to rate on a scale of 1 to 5, where 1: Strongly agree, 2: Agree, 3: I do not know 4: Disagree, 5: Strongly Disagree.

6.3.2.5 Experiment Phase

- ***Game explanation***

Due to scheduling conflicts, not all seven participants could attend at the same time. Therefore, the game was explained to the participants at different times according to their availability for participation in the game evaluation.

- ***Self-Training***

Each student had the opportunity to do some training sessions on the TruBiters game to be familiar with the game. The period of the training is around 10 minutes.

- ***Game Playing***

Each player was asked to play against another player two times in order to experience the game fully.

6.3.2.6 Post-Experiment Phase

After the players played the TrueBiters game, they were asked to answer the game experience questionnaires.

6.3.2.7 Results

- ***Pre-experiment***

The MIPQ results of all participants, from both experiments have been considered. Figure 51 a illustrates the percentage of logical students who participate in both experiments. It is revealed that nine students out of eleven (82%) are logically intelligent. Furthermore, four participants out of eleven who participate in both experiments are kinesthetic students (36%) as shown in Figure 51 b.

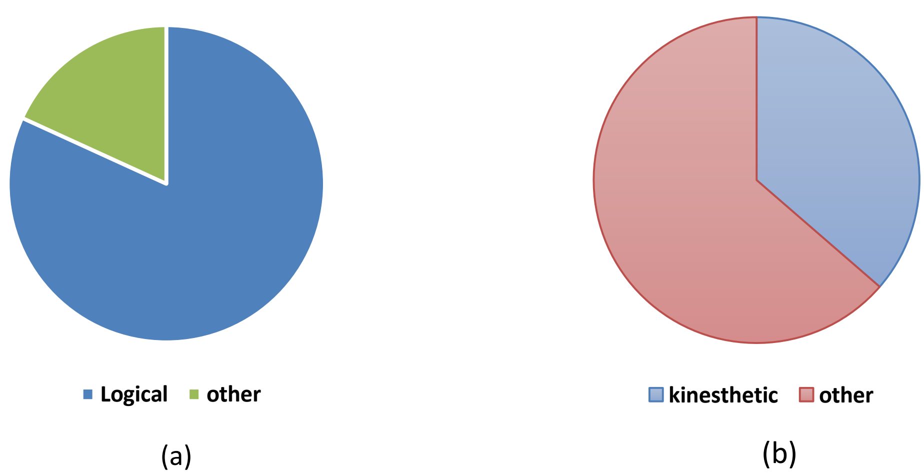

Figure 51: MI results: a) Logical vs others and b) Kinesthetic vs others

- ***Game Experience Results***

This section presents the results of the game experiences of all participants in both experiment based on different scenarios: 1) Comparison between kinesthetic participants and the others, 2) comparison between logical participants and others, 3) GX descriptive analysis of logical participants and 4) investigation of the correlation analysis of logical participants. These different scenarios are used to investigate the research question and to identify the importance or benefits of the TrueBiters game for kinesthetic and logical intelligence types.

1) Comparison between Kinesthetic and other types

The comparison between seven GX factors of kinesthetic participants against other participants is illustrated in Figure 52. The negative affect and tension factors of the kinesthetic participants, which are 0.5 and 0.16, respectively, are lower than the relevant factors (0.53, 0.52, respectively) of other participants. Moreover, the flow factor of kinesthetic (1.95) is greater than the flow of the other participants (1.77).

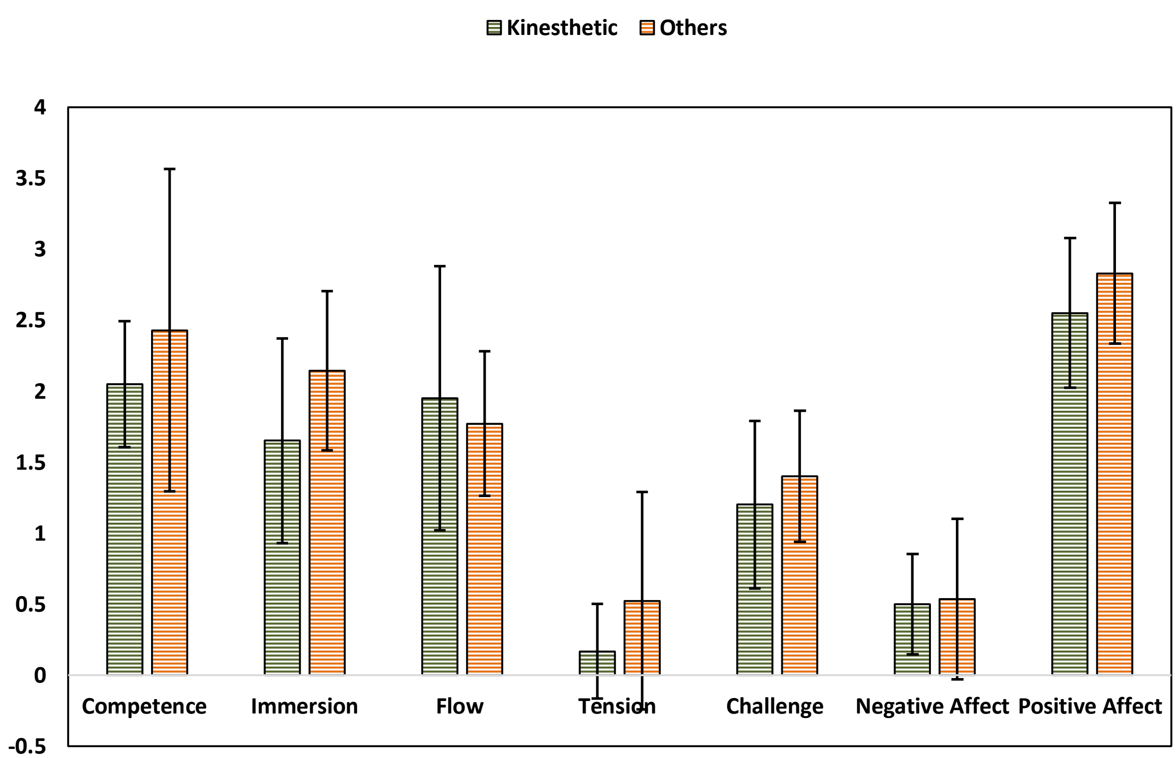

Figure 52: Comparison between Kinesthetic type and other types

Furthermore, there is a slight difference between the kinesthetic participants and other participants in the positive effect (2.55 and 2.8, respectively). This small difference indicates a positive evaluation for all participants. It is shown that the competence and immersion of the non- kinesthetic participants (2.4 and 2.14, respectively) are higher than those for kinesthetic participants (2.05 and 1.65, respectively).

2) Comparison between Logical and other types

In this section, a comparison between the logical and non-logical participants will be discussed in more detail. Figure 53 illustrates the difference between the game experience factors of both participants' types. The logical participants have higher competence and immersion (2.3 and 2.1, respectively) than the non-logical participants (1.9 and 1.1, respectively). Moreover, the flow factor of logical participants (1.88) is higher than the flow of non-logical participants (1.6). However, the tension and negative factors of logical participants (0.4 and 0.58, respectively) are higher than those of non-logical participants (0.33 and 0.25, respectively).

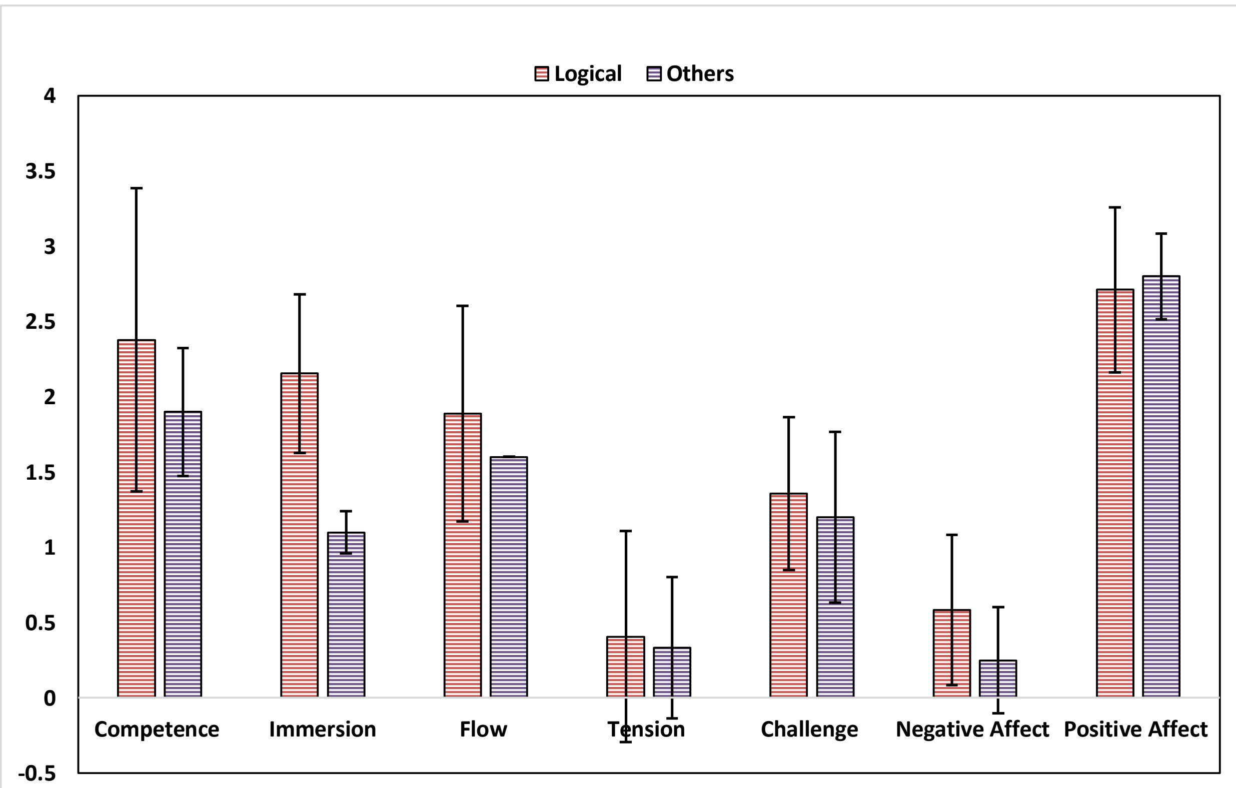

Figure 53: comparison between Logical and other types

3) GX descriptive analysis of logical participants

By discussing the GX descriptive analysis of the logical participants, the game can be evaluated with respect to the logical participants. Figure 54 presents the descriptive analysis of the logical participants. This graph illustrates that the game experience is positive where the competence, immersion and flow factors are slightly high (2.3, 2.1 and 1.88, respectively).

Moreover, the game has a positive affect (2.7). Furthermore, the tension and negative effects are lower than one (0.4 and 0.58, respectively), which leads to a positive evaluation.

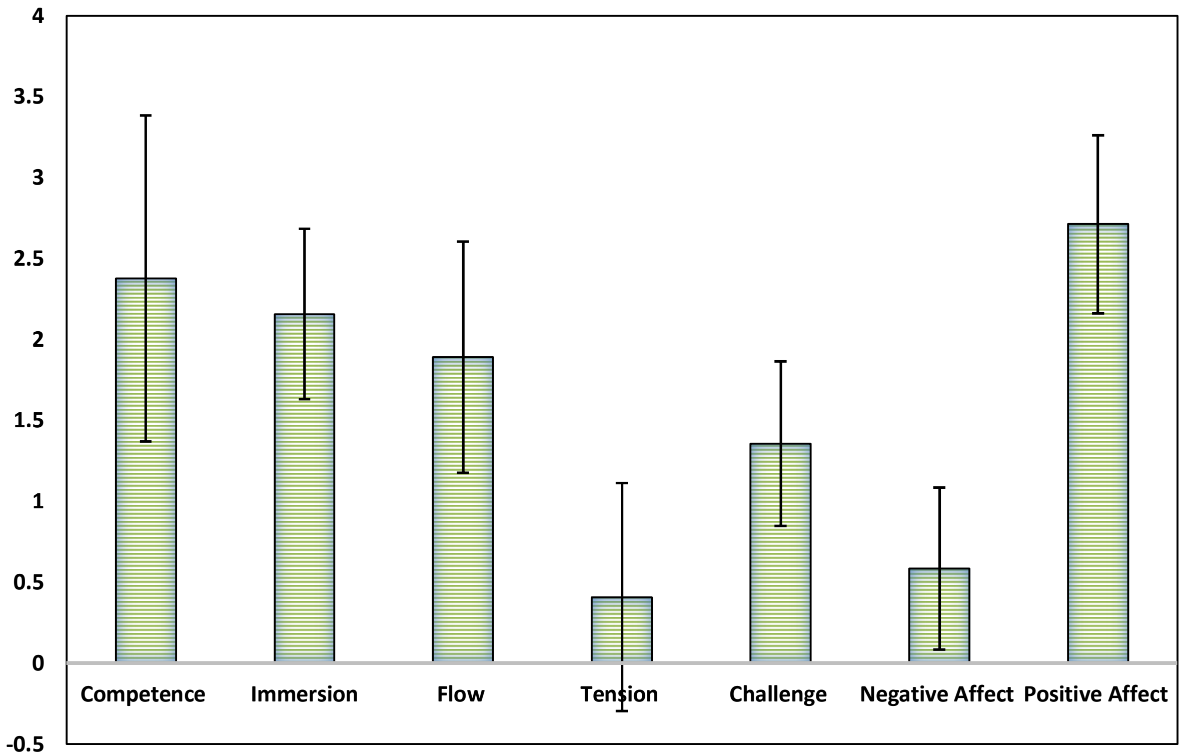

Figure 54: Descriptive analysis of logical students

4) Correlation analysis of logical students

To identify the correlation between the seven factors of game experience of logical participants, Pearson Correlation is used as shown in Table 5. There is a significant positive correlation between competence and positive affect (ρ =0.729). Moreover, there is a negative correlation between the competence and negative affect (ρ= - 0.914). Additionally, a significant positive correlation is found between immersion and challenge (ρ=0.758). Furthermore, a positive correlation is observed between tension and negative affect (ρ=0.692).

Table 5: Correlation analysis of logical students

Correlations

		Competence	Sensory and Imaginative Immersion	Flow	Tension	Challenge	Negative Affect	Positive Affect
Competence	Pearson Correlation	1	-.200	-.011	-.657	-.423	-.914**	.729*
	Sig. (2-tailed)		.606	.978	.055	.257	.001	.026
	N	9	9	9	9	9	9	9
Sensory and Imaginative Immersion	Pearson Correlation	-.200	1	.436	.483	.758*	.395	.140
	Sig. (2-tailed)	.606		.240	.188	.018	.292	.719
	N	9	9	9	9	9	9	9
Flow	Pearson Correlation	-.011	.436	1	-.247	.646	.029	.380
	Sig. (2-tailed)	.978	.240		.522	.060	.941	.314
	N	9	9	9	9	9	9	9
Tension	Pearson Correlation	-.657	.483	-.247	1	.267	.692*	-.435
	Sig. (2-tailed)	.055	.188	.522		.487	.039	.242
	N	9	9	9	9	9	9	9
Challenge	Pearson Correlation	-.423	.758*	.646	.267	1	.410	.092
	Sig. (2-tailed)	.257	.018	.060	.487		.273	.814
	N	9	9	9	9	9	9	9
Negative Affect	Pearson Correlation	-.914**	.395	.029	.692*	.410	1	-.653
	Sig. (2-tailed)	.001	.292	.941	.039	.273		.057
	N	9	9	9	9	9	9	9
Positive Affect	Pearson Correlation	.729*	.140	.380	-.435	.092	-.653	1
	Sig. (2-tailed)	.026	.719	.314	.242	.814	.057	
	N	9	9	9	9	9	9	9

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

6.3.2.8 Discussion

The results of the second experiment have showed that both logical and kinesthetic participants have better game play-experience than others do, which accepts the second hypothesis. This means the TrueBiters game is suitable for both logical and kinesthetic students. Additionally, it was noticed that some players made no error when selecting the cards thanks to their intelligence type, which is kinesthetic. Moreover, the results have illustrated that the interaction modality of the game is more compatible to the kinesthetic people where the flow factor of kinesthetic (1.95) is greater than the other participants (1.77).

6.4 Evaluation of Game Mechanics

As explained in the introduction of this chapter, the game has been analyzed using the game mechanics recommendation tool of Sajjadi (Sajjadi, n.d.) in order to evaluate whether the composing mechanics are adapted to the MI dimensions that we targeted, i.e. kinesthetic logical intelligence. Therefore, we extracted the information given by the recommendation tool, for the logical and kinesthetic dimensions (see Table 6).

The mapping shows that the majority of mechanics used in the TrueBiters game have a positive correlation with logical and kinesthetic MI. However, there are some mechanics that have a negative correlation with the logical MI, such as browsing and choosing which are essential aspects of the kinesthetic interaction modality. Moreover, the game uses disincentives mechanic, which also has a negative correlation with both the logical and kinesthetic MI. The results of the aforementioned comparison illustrate that most mechanics that are used in TrueBiters game are adapted for both logical and kinesthetic intelligence. These results supports the findings of the second experiment.

Table 6: Game Mechanics for logical and kinesthetic intelligence

Kinesthetic Intelligence		Logical-mathematical Intelligence	
Challenge	Motion	**Challenge**	Logical thinking
	Repeat Pattern		Strategizing
	Memorizing (negative)		Repeat pattern
Involvement	Submitting	**Involvement**	Browsing(negative)
			Choosing(negative)
Motivation	Points	**Motivation**	Modifier
	Quick feedback		Points
	Modifier		Quick feedback
	Disincentives(negative)		Disincentives(negative)
	Companion gaming		
Assistance	Tutorial/first run scenarios	**Assistance**	Tutorial/first run scenarios

6.5 Overall Discussion

The aforementioned results have demonstrated that the TrueBiters game is suitable for both kinesthetic and logical participants. However, it is more oriented towards logical participants. As observed from experiment one, the majority of the students are logical and they improved their scores after playing the TrueBiters game. The only student who did not improve his level, was a non-logical student. Moreover, the results of their game experience were significant good.

Additionally, as highlighted in the different scenarios that have been discussed for the GX, the logical students of all participants in both experiments had a good experience. We observed that during conducting the dedicated experiments, the students were excited and enjoyed playing the TrueBiters game. There was a good competition between the students, who participated in the tournament. This competition inspires the students to do their best to win. The non-kinesthetic students had some difficulty during the selection of the proper logical operator when swiping left and right, which causes sometimes losing their turn. This may be explained by the negative correlation for the browsing and choosing game mechanics from game mechanics recommendation tool.

7 Conclusions and Future Work

7.1 Conclusion

Nowadays, there is a growing trend to use educational games and recent technology (smartphones and tablets) in the education process. Digital educational games can combine learning with game entertainment. However, it is important to ensure that these digital games enable the students to understand and solve difficult and serious problems in an effective way.

In this thesis, the TrueBiters game has been designed in order to help students understanding logic. The proposed game has been implemented using a Bluetooth network between android devices. Two experiments have been conducted in this thesis. The first experiment has been conducted by letting students who had followed the "Logica en formele systemen" course in the 1st Bachelor Computer Science but unfortunately failed to pass the course on the exam, play the game. This experiment used the tournament style where each player plays against each other. The results have demonstrated that the majority of the students were logical and they have improved their scores after playing the TrueBiters game. Only one student, who did not improve his level, was a non-logical student. The second experiment allowed participants with different intelligence types to play the game and to evaluate their game experience. The results have showed that the proposed game is suitable for both kinesthetic and logical participants. Moreover, the game has been analyzed using the game mechanics recommendation tool of Sajjadi (Sajjadi, n.d.) in order to evaluate whether the used mechanics are adapted to the MI dimensions targeted. The results show that most of the mechanics that are used in TrueBiters game are adapted to both logical and kinesthetic intelligence.

7.2 Prospects for Future Work

The aforementioned results show the impact of the proposed game on improving the students learning levels. Therefore, the TrueBiters game could be considered as a step forward to improve the educational process. As a continuation of the present research work, some interesting topics that could be considered in the future work are:

- **Using one device**

The minimum number of the required devices to play the game is one smart phone and one tablet of 10 inches. This condition prevents the students to play the game with one device such as their smartphones. In the future work, the game can be adapted by using a smaller pyramid with lower number of tiles to be compatible with the size of the screen of a smartphone.

- **Standalone application (Apps and games)**

To install the game software, the mobile devices should be connected to the development computer. This action will limit the game usage. Therefore, it would be better if this game could be converted to an App that can be directly downloaded from the play store for smartphones based Android.

- **Next generation for iOS**

Some students have an iOS smartphone or tablet. They cannot use the Android version. Therefore, we could adapt the current game to be suitable not only for Android operating systems, but also for iOS (originally iPhone OS). This will allow more students with different devices types to play the game.

- **Game for other logic topics**

It would also be interesting to investigate whether we could design similar games for other topics from the “Logica en formele systemen” course, such as semantic tableaux and natural deduction which are two of the other obstacles of the course.

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Appendix

- ***MI questionnaires***

  - **Please answer these questions on the specified scale**

1. **Writing is a natural way for me to express myself.**

   Strongly agree | Agree | I don't know | Disagree | Strongly disagree

2. **At school, studies in native language were easy for me.**

   Strongly agree | Agree | I don't know | Disagree | Strongly disagree

3. **I have recently written something that I am especially proud of, or for which I have received recognition.**

   Strongly agree | Agree | I don't know | Disagree | Strongly disagree

4. **Metaphors and vivid verbal expressions help me learn efficiently.**

   Strongly agree | Agree | I don't know | Disagree | Strongly disagree

5. **At school, I was good at mathematics, physics or chemistry.**

   Strongly agree | Agree | I don't know | Disagree | Strongly disagree

6. **I can work with and solve complex problems.**

   Strongly agree | Agree | I don't know | Disagree | Strongly disagree

7. **Mental arithmetic is easy for me.**

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

8. I am good at games and problem solving, which require logical thinking.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

9. At school, geometry and various kinds of assignments involving spatial perception were easy for me.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

10. It is easy for me to conceptualize complex and multidimensional patterns.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

11. I can easily imagine how a landscape looks from a bird's eye view.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

12. When I read, I form illustrative pictures or designs in my mind.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

13. I am handy.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

14. I can easily do something concrete with my hands (e.g. knitting and woodwork).

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

15. I am good at showing how to do something in practice.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

16. I was good at handicrafts at school.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

17. After hearing a tune once or twice I am able to sing or whistle it quite accurately.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

18. When listening to music, I am able to discern instruments or recognize melodies.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

19. I can easily keep the rhythm when drumming a melody.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

20. I notice immediately if a melody is out of tune.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

21. Even in strange company, I easily find someone to talk to.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

22. I get alone easily with different types of people.

Strongly agree | Agree | I don't know | Disagree | Strongly disagree

23. I make contact easily with other people.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

24. In negotiations and group work, I am able to support the group to find a consensus.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

25. I am able to analyze my own motives and ways of action.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

26. I often think about my own feelings and sentiments and seek reasons for them.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

27. I spend time regularly reflecting on the important issues in life.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

28. I like to read psychological or philosophical literature to increase my self-knowledge.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

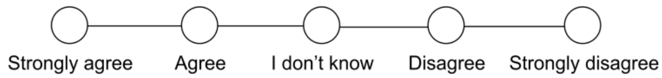
29. I enjoy the beauty and experiences related to nature.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

30. Protecting the nature is important to me.

○ Strongly agree ○ Agree ○ I don't know ○ Disagree ○ Strongly disagree

31. I pay attention to my consumption habits in order to protect environment.



- ***GX questionnaires***

  - Please indicate how you felt while playing the game for each of the items,
  - on the following scale:

not at all	slightly	moderat ely	fairly	extremel y
0	1	2	3	4
< >	< >	< >	< >	< >

1 I felt content

2 I felt skilful

3 I was interested in the game's story

4 I thought it was fun

5 I was fully occupied with the game

6 I felt happy

7 It gave me a bad mood

8 I thought about other things

9 I found it tiresome

10 I felt competent

11 I thought it was hard

12 It was aesthetically pleasing

13 I forgot everything around me

14 I felt good

15 I was good at it

16 I felt bored

17 I felt successful

18 I felt imaginative

19	I felt that I could explore things
20	I enjoyed it
21	I was fast at reaching the game's targets
22	I felt annoyed
23	I felt pressured
24	I felt irritable
25	I lost track of time
26	I felt challenged
27	I found it impressive
28	I was deeply concentrated in the game
29	I felt frustrated
30	It felt like a rich experience
31	I lost connection with the outside world
32	I felt time pressure
33	I had to put a lot of effort into it

Post-test Logica

Deelnemersnummer:

1. Bepaal de modellen (dit zijn de waarden van de propositieletters waarvoor de formule waar is) voor de volgende formules:

$((p \lor \neg q) \rightarrow (q \leftrightarrow p))$

$(\neg s \land (q \rightarrow \neg p))$

2. Zijn de volgende formules equivalent (m.a.w. ze hebben altijd dezelfde waarheidswaarde)?

$(\neg p \land q)$ en $\neg(\neg q \lor p)$

$(\neg p \rightarrow q)$ en $(q \rightarrow p)$

3. Zijn de volgende formules tautologieën (m.a.w. ze zijn altijd waar)?

$((\neg t \wedge \neg r) \vee (t \wedge r))$

$((p \leftrightarrow q) \rightarrow (q \rightarrow p))$

Pre-test Logica

Deelnemersnummer:

1. Bepaal de modellen (dit zijn de waarden van de propositieletters waarvoor de formule waar is) voor de volgende formules:

$((p \lor \neg q) \leftrightarrow (q \rightarrow p))$

$((\neg q \rightarrow \neg p) \land r)$

2. Zijn de volgende formules equivalent (m.a.w. ze hebben altijd dezelfde waarheidswaarde)?

$(r \land q)$ en $(\neg q \lor \neg r)$

$(p \rightarrow q)$ en $(\neg q \rightarrow \neg p)$

3. Zijn de volgende formules tautologieën (m.a.w. ze zijn altijd waar)?

$((p \lor q) \lor (\neg p \land \neg q))$

$((p \rightarrow t) \lor (t \rightarrow p))$