Serious games for children in rural Sarawak

The co-creation of a digital tool to support mathematical education at community schools in Sarawak, Malaysia

August 22, 2019

ABSTRACT

In the quest to improve the educational level of primary school students in rural areas, we investigated if it is possible to create a serious mathematical game for children in rural Sarawak. Through this case study, we designed a serious mathematical game which primary school students of rural areas could use to improve their mathematical skills. Following the design science research methodologies, we investigate the possibility to design, develop, and test an application which provides these goals. Using a combination of socio-technical, user-centered and agile methods, we developed a structured approach and methodology for designing, developing, and testing a sustainable serious mathematical game in the context of rural Sarawak.

Keywords

Mathematics, Rural Sarawak, ICT4D, Gamification, Digital Divide

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1. INTRODUCTION

Rural areas of Sarawak face a significant problem in the field of primary education. More than seventy percent of the schools in Sarawak are in poor condition concerning the learning materials and physical environment (classrooms, infrastructure) [14]. This situation is exacerbated as a low performance of schools also leads to even less governmental funding. Personal interviews with teachers and parents have made clear that several primary schools in rural areas are under-performing [9]. According to sustainable development goals (SDGs), every child has the right to good education [17].

Nevertheless, providing a robust educational ecosystem in developing countries is a global problem. The report of the SDGs of 2018 showed that more than half of children and teenagers worldwide do not meet the minimum proficiency standards in reading and mathematics. This result is quite severe due to mathematics is essential for people's finances, calculation the time and need to be used in most jobs [20]. Because of these problems, the government of Malaysia started in 2014 with the "1bestarinet" program. The goal of this program is to provide the possibility of education to every child in Malaysia. However, due to lack of an internet connection and devices is this system not used by most primary schools in Sarawak. Today, only books are available for them to study [9].

Moreover, the News Straits Times state that using only textbooks is challenging for teachers to motivate their students to learn intrinsically [12]. Although, literature study by Hamari [10] showed that using gamification in education has positive results in the experience and engagement of students [4]. Ong [18] argue that gamification helps to address motivational issues that are present in Malaysian school. They suggest that gamification may improve primary and secondary education. Therefore, this research looks into if it is possible to develop an application to expand the necessary mathematical skills for primary school students in rural areas of Sarawak.

This thesis is structured as follows: chapter two discusses the context and background, chapter three discusses why it is essential to do this research in a low resources environment and which methods and strategies were used during the research, chapter four a summarize all requirements of the application and gives an overview of the game, chapter five discusses the design decisions of the application, whereas chapter six discusses the user testing with the participants, chapter seven explains how the application can be made sustainable. In chapter eight, the evaluation of the whole application will be discussed as chapter nine will discuss the conclusion and future work.

2. CONTEXT & BACKGROUND

2.1 Primary education in rural Sarawak

The educational ecosystem of primary schools in Malaysia is divided into six different levels. Based on age, the student will be classified on a level. The children will start at seven years old and finish primary school at twelve years old [8]. The curriculum is established by the Ministry of Education, which consist of the core, compulsory, and additional courses [6]. One of these compulsory courses in mathematics. The mathematical curriculum is organized into four learning domains: numbers and operations, measurement and geometry, relationships and algebra, and statistics and probability. All these subjects need to be learned by the student on specific levels which the government determines what the student must understand [6]. However, primary schools face various problems. The following paragraphs discuss the most interesting problems primary education need to deal with in rural areas of Sarawak.

2.1.1 *Primary educational ecosystem*

The World Bank [2] reported that there is a big divide between urban and rural schools. It is more dangerous for rural students than urban students to go to school due to rural schools are usually far away from where they live. In rural areas there may be no proper roads or children needs to go to school by boat [14].

Teachers in rural areas.

Most primary schools in rural areas must deal with not a lot of well-educated teachers. It is tough for them to find teachers who could deal with not many resources but educate their students well. Salaries and resources are often much better in urban than rural schools. Often much better than the quality of education in rural areas has deteriorated [15]. Only having a few teachers on a large number of students creates larger classes. Many students cannot be helped due to lack of time. However, every student is different, and one-time fits all education does not work. Students must learn based on their current level. If the exercises are too difficult then the student will not understand the material, if the exercises are too easy for the children, then they will get bored and loses interests [22]. Because teachers must spread their attention to an ever-growing group of students, technology can offer a solution to take over various tasks from the teacher so that they have more time to help students with their questions.

Tutoring in rural areas.

It is a common thing in Sarawak that parents find a tutor if their children have difficulties with a particular subject in school. However, parents in rural areas do not have enough money to pay a tutor, which leads to that those children will fall behind in their education at a particular stage which is usually irreversible [9].

Changing educational ecosystem.

In comparison to the previous problems, the rapid change of the primary educational ecosystem has the most impact on the students. Currently, the government plans to convert the primary school curriculum into English. Since most children in rural areas do not fully master the English language, it would be challenging for them to understand the content of these courses when it is not your native language [15]. Nevertheless, from the beginning of 2020, the government will change the language of mathematics and science in English [23]. This change will be a disaster for most students from rural areas because they are not well prepared to learn mathematics or science in English [15].

2.1.2 *Mathematics*

TIMSS (Trends in International Mathematics and Science Study) reported that Malaysian students' mathematics scores declined over time. This situation is worrying because mathematics is the basis of other courses in secondary

school [15].

Math is boring & difficult.

Most teachers have difficulties in motivating their students to learn mathematics. It is hard for math teachers to make the lessons more interesting because of a lack of resources to make a lesson more exciting [12]. Moreover, math is a very abstract subject. Students learn the best if they could relate the things they learn to their real life. As math becomes more advanced and challenging, it could be challenging to explain the exercises in a story where students are interested in. For this reason, most learning methods try to relate a new topic to something the students already know.

Students have a poor foundation.

Math challenges are not always a result of learning difficulty. For many students who struggle with math, do not have a proper foundation of the basics of mathematics. This knowledge is needed to understand new material. Nowadays, they do not understand the new material, which leads to bad grades. Moreover, math is a cumulative subject; every new subject builds on the subjects what the children already need to know. If they do not fully master the previous subject, they will have difficulties with the new subject.

Math is a very abstract subject.

Unlike a lot of other subjects, there is no room for errors when it comes to math. A student will understand or will not understand a particular topic. Because of this, math can quickly become a frustrating and stressful experience. Moreover, most students face that textbooks do not always provide enough explanation. Textual and visual components of the book are not always precise. Unfortunately, during class, there is not enough time available to explain all the exercises of the textbook. Moreover, textbooks have a limited amount of exercises to practice mathematics. In mathematics, it is essential to practice with as many as the students can exercise to expand their mathematical skills [7].

Difference Netherlands & Malaysia.

Mathematics is language-independent. However, the learning methods of mathematics worldwide are not the same, which means that students learn different steps to solve math problems. Therefore, it is possible that translating a mathematical game in another language not enough to use in another country. During this research appeared that some Dutch learning methods from the Netherlands made students very confused while solving a specific math problem. Moreover, the textbook in Malaysia explains the material very formal while in the Netherlands, more visuals are used to explain an exercise in the book.

2.2 ICT4D in rural Sarawak

Although Malaysia can be considered as a highly connected country in terms of high bandwidth internet, in poor rural areas, e.g., in Sarawak, it is still not the case. The uneven technological development is causing a growing "digital divide" between urban and rural areas. The field of information and communication technology for development (ICT4D) aims to increase the gap of the digital divide between urban and rural areas by making use of IT technologies. For example, applications for the local communities will be developed, which helps them to share and enhance knowledge, improves the production with cost reduces [5]. In the ICT4D research field, it is essential to use a user-centered approach, based on three principles: local users set the goals and objectives, co-creation will be done in partnerships, and the technologies are fully adapted to the local context. With this approach, the user is involved in the development process, which means that the technology is precisely tailored to the user, which makes the technology more sustainable for the local context [3].

2.3 IT for education

Many educational learning environments are created to help students and teachers to make teaching and learning easier. Examples of these systems which are used in Sarawak are "Frog-VLE", "Grolier-Asia" and the "OLPC".

2.3.1 *Frog VLE system*

The "1BestariNet" project is developed by the government of Malaysia to connect schools across Malaysia to the internet while providing an online learning platform. This platform is known as the "Frog VLE" system, which is a simple, fun, and engaging system which provides learning tools for teachers, parents, and students. Teachers use this system to teach their lessons, give homework, and keep track of the student's performance. Moreover, the school manages school-calendars and create a notification for children or parents through the system. Parents can use the system to see the performance of their children and will be notified for events. Students use the system to learn as well as complete and submit their homework to the teachers [6].

2.3.2 *Grolier-Asia*

The "Grolier-Asia" company provides a service which children can use to learn in a fun way at home. There service consists of a variety of materials for children between the age of four and twelve years old. This let the children educate themselves at home. The level of the material is precisely customized for different ages where help is not needed. The materials for mathematics consist of a math-key, a logic board, and a digital environment. The key and logic board are used to practice mathematical exercises. However, these materials have a limited amount of exercises. The digital learning environment has endless exercises to practice. On the learning, platform mini-games are used to practice these exercises. Moreover, the platform is locked with a password which only the parents know. This feature prevents children from doing other things on the tablet instead of learning.

2.3.3 *Sugar OLPC*

In 2005, tech visionary and MIT Media Lab founder Nicholas Negroponte created the one laptop per child project (OLPC)[1]. His vision was to create a laptop for every child in the world for only 100 dollars. This price was meager because in 2005 most laptops were ten times more expensive than the OLPC. The OLPC is an open-source platform, which means that everyone could create an application for this system. Furthermore, this device includes peer-to-peer networking for data exchanges in situations where there is no internet connection [21]. In June 2018, the Vrije Universiteit Amsterdam, in close collaboration with UNIMAS, the

[1] http://one.laptop.org/

university of Malaysia in Sarawak, organized a master course for Information Science, Computer Science and Artificial Intelligence students, titled: 'Information and communication technologies for development in the field' in the rural areas of Sarawak. I participated in this course as one of the students. One of the student groups researched the information needs and user requirements of a primary school in small community kampung Pinggan Jaya. This assessment showed that children in Pinggan Jaya have problems learning English as well as mathematics. During the course, they used gamification and education to create a game where children can learn English. Test sessions showed that the children of Pinggan Jaya were able to use the game and liked to learn and play with it [9].

2.3.4 *Sustainability of learning systems in a low resource environment*

Unfortunately, there are several limitations about using these systems in rural areas of Sarawak. Frog-VLE needs a proper internet connection, but due to lack of an internet connection, technological knowledge, and a proper technical infrastructure, rural primary schools cannot use the online virtual learning environment (Frog-VLE) of the government [9]. The Grolier-Asia home is a commercial company which provides several educational resources for primary school students. However, most material physical, expensive, and only for sale in urban areas, which makes it difficult for people to provide these materials in hard-to-reach areas. However, the EduComX project [9] shows that it is possible to create an application on the OLPC for the students in rural Sarawak. However, the hardware of this system is out of date, while the specifications of mobile phones or tablets are getting better while the costs of these devices become cheaper [24]. Moreover, the OLPC did not become the expected successful product for rural areas. Problems with hardware, the infrastructure, and lack of training this product were not fully adapted to rural areas [25].

3. GAMIFICATION IN PRIMARY SCHOOLS IN LOW RESOURCE ENVIRONMENTS

Due to the lack of an internet connection, technological knowledge, and a proper technical infrastructure, it is a challenge to use one of the exciting virtual learning platforms in a low resource environment. It is a pity that people from rural areas cannot make use of the advantages of digital learning only because of these constraints. Moreover, changing the learning language makes it even more difficult to learn mathematics as a result that these students will get further behind. Therefore, the focus of this research is to co-design, co-create, deploy and test an educational game to provide new digital learning material that may help to expand the necessary mathematical skills set of primary school students of rural areas in Sarawak. The main research question (RQ) is:

> *Is it possible to design, develop and test an application to expand basic mathematical skills for primary school students in rural areas of Sarawak?*

Three different viewpoints will be used to explore this question. These viewpoints are the user interface, the educational ecosystem, and the technical infrastructure. Three sub-questions will be used to explore these viewpoints. These questions are:

> ***User interface***: Which elements are needed to make a game interesting for children?
> ***Educational ecosystem***: Which educational purpose(s) are needed to let primary school students expand their basic mathematical skills?
> ***Technical infrastructure***: What is needed to let this application work in a low resource environment?

3.1 Research challenges

During the development, there will be several challenges. Wayan Vota [24] argue that using a digital device may be very difficult for people from rural areas. These people need to understand how to use these devices as well as understand the user interface. For example, icons could have a different meaning in different countries [1].

Moreover, using gamification could be a powerful tool for education when implemented correctly. It can enhance an education program and achieve learning objectives by influencing the behavior of students [26]. However, the research of EduComX showed that involving primary school teachers in Sarawak is a difficult task [9].

Furthermore, it must be considered that the technical environment in rural areas is different than in urban areas. Most rural areas do not have an internet connection or access to multiple digital devices. Therefore, selecting a proper device and environment to host the game will be very important for the sustainability of the game.

3.2 Methodology & strategy

During this research, various prototypes had to be made for testing. Because this was time-consuming, Sim Keng Wai and Aparna Patel joined the project help develop the application. Both are Computer Science students at UNIMAS who are very interested in gamifying education. Also, they speak the same language as actors, making communication easier.

3.2.1 *Interviews and Focus groups*

Interviews will be done with Dutch and Malaysian primary school teachers as well as focus groups with Malaysian primary school students of the age of seven until twelve years old to understand the context. This information is needed to understand the mathematical curriculum, learning methods, and the problems children face during their homework of mathematics. With this information, the content can be determined as well as the look of the game.

3.2.2 *ICT4D 3.0 Protocol*

It is essential to use a user-centered approach, based on three principles: local users set the goals and objectives, co-creation will be done in partnerships, and the technologies are fully adapted to the local context [3]. Using this user-centered approach will be done by involving teachers and children closely in the process of defining goals and requirements, testing, evaluating the results in a real-life setting. Therefore I will use the ICT4D 3.0 protocol to understand the context in depth, structure the needs of the actors, find the most important requirements and make the application sustainable.

3.2.3 *Gamification*

Using gamification in education will help students to increase their interests in learning. Gamification provides the freedom to fail, experiment, to self-express and learning while playing a game. As a result, a pedagogical shift will be done for students who are hampered by the conventional teaching methods [22]. However, in a complex infrastructure such as the rural areas of Sarawak is the ICT4D 3.0 protocol not enough to structure the experience of the users.

Figure 1: Structuring development of gamification in education [22]

Therefore, Huang and Somad have developed a framework, shown in figure 1, on how gamification can be designed and implemented successfully in education [26]. This framework will be used next to the ICT4D 3.0 protocol to structure the game experience of the users. Structuring the experience by using storytelling would be an excellent addition to the ICT4D protocol.

To fully adopt the game experience into the local educational ecosystem, the individual elements of figure 2 will be used to select the parts of gamification which are needed for the application. This figure shows all the individual parts of gamification, which are relevant to education.

Figure 2: Elements of Gamification [26]

3.2.4 *Developing the application*

During the development of the game, there will be several stages to create the game. These stages are understanding the target audience and content, defining the learning objectives, creating the gaming story, designing, developing, testing, and an evaluation of the game.

Understanding the target audience and the context.

To fully adopt the content and technology to the local context, first research will be done to understand the level of mathematics and the problems the students face during learning mathematics. Moreover, there will be investigated how the local technical environment is as well as looked into which device fits the best for hosting the application.

Defining learning objectives.

To define the learning objectives, the results of the focus groups will be used to understand with which subject the children have difficulties. Moreover, interview(s) with teachers and literature study of mathematics is needed to define which learning objectives are needed to help the children who have difficulties with the selected subjects. The interviews with Dutch primary school teachers in Appendix A1 will be used as guidance to find out which learning objectives are most important for the primary school students in rural Sarawak.

Structuring the experience.

During the research of how the gaming experience needs to be structure two design, which is shown in section 4.4, Appendix C.1 and Appendix C.2 are created to understand which type of game is most interesting for the students. Moreover, the learning objectives will be structured together with a primary school teacher to understand which subjects are related to each other.

Identifying gamification elements.

To investigate which gaming elements, shown in figure 2, are useful for the game, a couple of mobile mathematical applications will be used for an observation session with students. During this session, there will be looked into which gaming elements students prefer or miss in the game. From the result, a list of essential gaming elements will be created and reviewed by a primary school teacher.

Designing, developing & testing.

During this stage, several prototypes will be created and tested on the participants. These tests will help to improve the game to fit to the needs of the actors. Three point of views are used during these test sessions. These viewpoints are the user interface, educational learning perspectives, and technical environment. To structure these viewpoints, the following six questions [11] will be used during a testing session:

Learnability: How easy is it for the users to accomplish basic tasks the first time they encounter the design?
Efficiency: Once users have learned the design, how quickly can they perform tasks?
Memorability: Are the exercises to easy, to difficult or exactly at the right level so that they can solve these exercises within a certain time?
Errors: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
Satisfaction: How pleasant is it to use the design?
Technical: Are there features who not work in the local technical environment?

After each session, the game will be updated with the results of test sessions.

Evaluation of the game.

At the end of the field-trip, the application will be evaluated based on the comparison with the users' assessments needs. This evaluation will be done in collaboration with several students as well as teachers who helped during the development of the application. Every actor will play the game and evaluate this one by filling in a survey or get interviewed about the game. The result of these surveys will

be analyzed to determine the usability and capabilities of the game. Furthermore, this data will be used for suggestions for further improvements in the game, which will fall outside the scope of this research.

4. MONKEY MATH SARAWAK

The system called "Monkey Math Sarawak" is designed to let primary school students in rural Sarawak practice with mathematical exercises in a playful way while teachers get information about the performance of their students.

4.1 Summary of Key Idea

The name "Monkey Math Sarawak" has been selected, because the main character in the game is a monkey who needs to travel around different areas to earn bananas. During his journey, he will be hunted by animals who want to stop the monkey. To outsmart the animals, the monkey must solve mathematical exercises to continue his journey.

Moreover, this system keeps also track of the subjects where the student has difficulties with and provides an offline learning environment. In this environment, it is possible to watch tutorials about mathematical exercises of the game, get tips to solve exercises easier and get access to an offline dictionary from mathematical English words to Malay and vice versa.

4.2 Scope of the project

During this project, we will focus on making a serious mathematical game. This game will be developed for primary school students from rural areas of the age between seven and twelve years old. Furthermore, this application will only consist of information about the topic numbers and operators of the official Malaysian primary schoolbook [13]. These operators will be addition, subtraction, multiplication, and division, which uses the numbers between one and ten. Moreover, primary school teachers will be involved in the project which teaches children of level one until level three of primary school.

4.3 Actors

Developing a serious game with educational purposes will not only have students as an actor. To fully adapt to the local context, it is also essential to understand the goals of the primary school teachers, the students' parents and the contributor of the application. Without their experience, the game will not be sustainable and will not be adapted to the educational perspectives as well as the hosting and distribution of the application will not be guaranteed. To get an overview of the actors' goals, shown in table 1, explains what they would like to see in the application. The students would like an environment where they can play and learn mathematics. Moreover, it is essential that tutorials could be viewed offline, which helps the students to improve their mathematical skills. Something that scares most students is learning mathematics in English if the application could help them with this would be an enormous reassurance for them.

Actors	Goals
Primary School Students	- Explanation about mathematical subjects - Improving their mathematical skills - Learning mathematics in a playful way - Tools to learn mathematics in English
Primary School Teachers	- Get data overview of the performance of their students
Parents of students	- Improve the mathematical skills of their children
Contributor	- Offline game - Easily to distribute without using of an internet connection - Engaging children to improve their mathematical skills

Table 1: Goals of the actors

Primary school teachers would like to understand the difficulties their students face. With this information, they can help their students to improve their mathematics skills. The parents would like that the application will help to develop the mathematical skills of their children and the contributor would like that the system can be used in an environment without any internet while it is easy to update and distribute the application to other devices.

4.4 Use Case Scenario Script

This section provides scenarios three scenarios of using the Monkey Math Sarawak. It provides a manual about how the users could interact with the game. When the user starts the application, the main menu of the application is displayed. This menu consists of three buttons to navigate through the application. The tutorial button will enter the tutorials section, whereas the player section provides data about the performance of the user as well as a section the possibility to change some settings of the game. The other button is to go to the gaming section. Also, on the top left side, there is a high-score presented of one of the games in the application.

Figure 3: Menu

When pushed the start button to enter the gaming section, a world-map will be showed with five different kinds of options. These options represent four subjects of mathematics and a mixed world where the user could choose which subject he wants to learn. Every subject has its part of the world were the game takes place. For example, multiplication exercises are held in an ice world.

Figure 4: Choose your subject

After choosing the subject first, the user needs to choose easy, medium, and hard for the difficulty of the level. The difficulty of the level will be that the speed of the character will be slow or fast. Easy is the slowest one, whereas hard is the fastest way the character goes through the world.

Figure 5: Choose the speed of the level

After choosing the difficulty level, there need to be chosen, which level the user wants to play. These levels are divided into ten sections, which makes the exercises every level slightly more complicated. For example, for the addition part, there are ten levels (+1,+2...+10). The user starts from level one and needs to complete each level with at least two stars to continue to the next level. Moreover, after five levels, the user needs to do an exam to proof if they understood all the previous exercises. If all levels are unlocked as well as the two exams are done well. The user has the opportunity to test all this learned knowledge to try to pass the last exam. If he also passed this exam, then he will get a special mini-game to play.

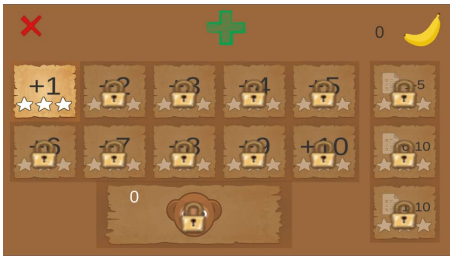

Figure 6: Choose difficulty level

When entering the game, a monkey will go through the selected world. Based on the chosen subject and levels, the user needs to solve exercises to survive. If the user solves the exercise correctly, he will earn bananas, but if the exercises are not correct, he will lose a life. After fifteen questions, the user needs to destroy the end boss by solving five exercises to go to the next level.

Figure 7: The math game

When the player completes all thirteen levels successfully, the mini-game is unlocked. The game-play of the mini-game is different from the main game. This part of the game not only helps the user to practice in the four mathematical operations but also in the simple counting of the numbers as well. The user needs to count the numbers first and then do the calculation. Based on the difficulty, the player has a limited time to play (easy:50sec medium:40 hard:30) when you answer correctly two seconds been added to user's time, while when you answer wrong five seconds been removed from the time.

Figure 8: Mini-Game

When the user selects the tutorial button, four options will be shown with the basic mathematical operations. The user can choose for which operation wants to watch tutorials.

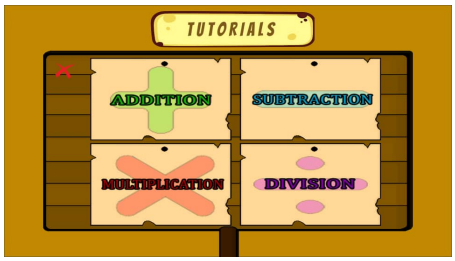

Figure 9: Tutorials Menu

After selecting the mathematical operator, the tutorial menu has three options to choose. He can watch videos, study mathematical tips, or check the notebook. Some videos are downloaded from YouTube, while others are designed by ourselves. The tips section provides different ways of solving a mathematical exercise with the chosen operator. In the notebook section, there are two options to choose from: the mathematical dictionary or the lexicon. Choosing the lexicon the user views all kinds of mathematical words in English to Malay and vice versa. The mathematical dictionary provides for every operation suitable mathematical

content which aims to help the user perform better not only in the game but also in the class.

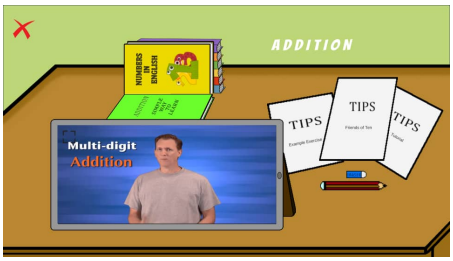

Figure 10: Tutorials of addition

The *"numbers in English"* section is different then other tutorials. In this section, users can look up English mathematical words as well as hear a number in English if they do not know how to pronounce these numbers.

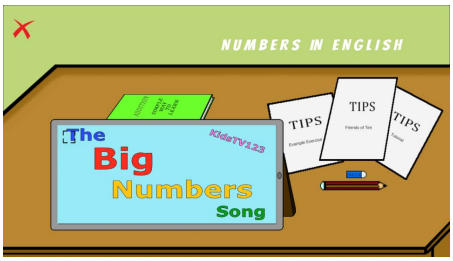

Figure 11: Tutorials of numbers in English

After clicking the player data section, the user will see a school-board provide in figure 12. This section provides an overview of user performance. These user performances are separated the last twenty exercises which the user did wrong as well as the times per subject and level the user went game-over. These data could the teacher use to see the performance of the children. With this data, they can give extra help to the areas where the children have the most difficulty. Moreover, in this section, the user could also change the language of the game to Malay or English.

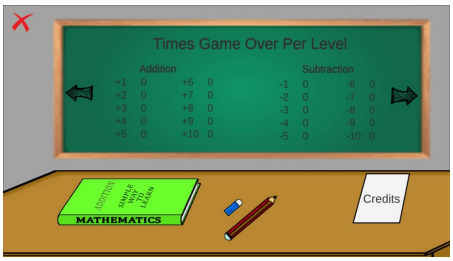

Figure 12: Player data

4.5 Interaction and Communication

Figure 13 shows the use case diagram of Monkey Math Sarawak. This diagram gives an overview of how the users interact with the system.

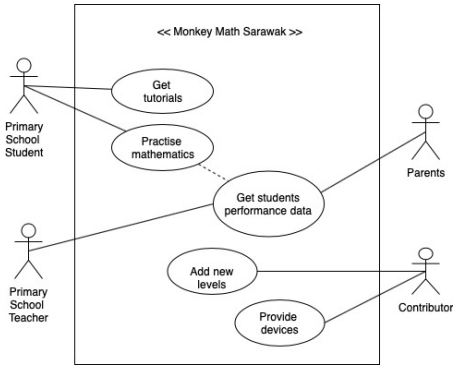

Figure 13: Use case diagram depicting the user interaction with the system

The students can gather scores or bananas by solving exercises while practicing Mathematics. Moreover, they can get access to the tutorials where will be explained how several mathematical exercises need to be solved. The primary school teachers and the parents of the children will get an overview of the performance of the students. The contributor can add new levels and is responsible for providing devices for the students to play the game.

4.6 Information Concepts

Appendix D.2.1 shows the interaction between the user and the system during the flow of the application. When entering the system, the user can choose between three different parts of the application, to play the game, watch tutorials, or get an overview of the users' performance of the game if the user wants to play the game first a subject need to be selected a difficulty level. When this information is filled, the system will provide the game with exercises about that specific subject. After the game is ended, the user has the option to go back to the main menu as well as continue to the next level only if the user still has lives available. If the user has finished all their lives, then he could restart the game or watch tutorials about that specific subject. In the main tutorial section, the user has to option to choose between the subjects which offer tutorials and tips about that specific subject. If the user wants to view his mistakes, then he can view those in the player data section. This section shows all mistakes per subject the user have made. When the user wants to leave the game, he needs to go back to the main menu where they exit the game. In Appendix D.2.2, the class diagram representing the data model of Monkey Math Sarawak is shown. This model represents the information that is stored in order for the application to run. Moreover, it represents the connection between different classes of the application.

4.7 Technological infrastructure

In figure 14, the system architecture is displayed. Because of rural areas of Sarawak have no (proper) internet connection available, the stem in the box is the main component that is required to distribute the application.

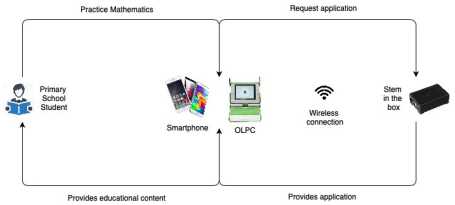

Figure 14: System architecture

The stem in the box is a Raspberry Pi which sent data to another device without making use of an internet connection. Therefore, it is possible to distribute the game to a smartphone or the OLPC. Moreover, the application can also be used in a browser that supports Web GL. When the application is installed on the device, the user can play the game.

4.8 Sustainability

According to Wayan Vota [24], it is necessary to think about the sustainability of the device. In order to achieve this, the usability of the application must contribute to the need of the students. It is essential that the application adapts the educational learning methods of the primary schools in rural Sarawak so that the children can practice mathematical exercises with the learning methods they already familiar with. Moreover, the game must be hosted on a device where participants do not have problems with using the device. Previous research has shown that primary school students can work with an OLPC or smartphones [9]. These devices could be an option to use for the game.

4.9 Summary of the key requirements

As a starting point for further architecture design, system, and component development, this section will give a simplified overview of the key requirements of the Monkey Math Sarawak system. A distinction has been made between function requirements shown in table 2 and non-functional requirements shown in table 3.

Must have	- Basic mathematical content - Tutorials will be required to explain mathematical subjects - Easy to use interface which the children understand how to play the game - Storytelling to make the game more interesting - Rewards system for solving a problem
Should have	- Graphical view of the performance to identify where student have troubles with per subject - Gamification aspects - Sounds & animation - Translation of the main numbers & mathematical words in Malay and English
Could have	- Content based on the syllabus of the primary school - Earning rewards during playing the game - Personalized profile - In-app purchases with the collected bananas - Earning badges based on their performance on completing a level or whole subject. - Shop to buy items to change their character with the earned points during the game.
Won't have	- Advertisement - In-app purchases with money

Table 2: Overview of all the functional requirements according to the MoSCoW ordering of requirements

Must have	- The ability to work without an internet connection - The application can efficiently distribute without using an internet connection - The system is easy to use
Should have	- Language options: Malay and English - Application is possible to run on smartphone as well as on the OLPC
Could have	- An option to secure data privacy
Won't have	- Authorization based on user role (RBAC system) - Exchange data through an Bluetooth with multiple devices

Table 3: High-level overview of non-functional requirements according to the MoSCoW ordering of requirements

5. DESIGN DECISIONS

During the development of the application, several design decisions are made. This section will discuss the rationale of the decisions.

5.1 Selecting the type of game

To understand which type of application will fit the best to the local context. This section will explain which type of game will fit the best to the local context. A summary of the type of game is:

Platform: The game will be available for smartphone, web and the OLPC
Genre: An adventure game
Storytelling: Monkey who travels around and need to solve exercises so that he can earn bananas to survive.
Gamification Elements
- *Mechanical*: Rapid feedback, goals, sub-goals, and quests, on-boarding, progression
- *Personalization*: Leaderboards
- *Emotional flow*: Flow, freedom to fail, freedom to explore, freedom to effort

5.1.1 Platform

To select a suitable platform, it is essential to use the devices where the users are familiar with. During several focus-groups with the students, it became clear that most children in rural Sarawak have access to a smartphone or an OLPC. The OLPC will be provided by UNIMAS. This is why there is chosen to create an application which can be hosted on a smartphone as well as on the OLPC. To develop this kind of application, Unity will be a perfect platform to use. With this gaming engine, it is possible to develop cross-platform games which allow that the game could run on android or laptops.

5.1.2 Genre

To create a game, there are several options to choose how the game interface must look like. However, since the application needs to be hosted on mobile as well as the OLPC, it is important that the application performance will be suitable for both platforms. The OLPC is not suitable for 3D gaming, because of power limit of the hardware. Therefore, the game will be an adventure game in 2D. This type of game will let the user think he is in another world with all kinds of goals to achieve. Research shows that competition and challenging game-play will have a positive effect on the engagement of the player with the game [16]. Adventure games are very suitable to let the player go through a world to solve different assessments.

5.1.3 *Storytelling*

One of the problems primary school teachers have with teaching mathematics to their students is that the students are not motivated to learn mathematics. Most students find it complicated or boring. Research showed that changing the story will change the perspectives of the students [19]. Therefore, using storytelling in the game would children give the opportunity to become enthusiastic about learning mathematics, using a story-line with sound effects and animation to let the game come to life. These gaming elements will help to make the game more satisfying for the user. The story-line of the game is that a monkey flies through the jungle but get hunted by animals. To prevent that the monkey gets killed he needs to solve several mathematical exercises. After a couple of questions, he needs to defeat a boss with solving mathematical exercises. Every time he solves the exercise correctly, then he will earn bananas.

5.1.4 *Gamification of mathematics*

According to Oxford Analytica [22] gamification of education is divided into three different categories: mechanical, personal, and emotional elements.

Mechanical.

The mechanical part of the game consists of various components which are applicable within education. Elements such as goals, challenges, or quests are essential to the structure and directions of the game [26]. For this reason, the goal of the game is to solve mathematical exercises to survive. If the question is answered is correct, then the user will earn bananas. If the question is answered wrong, then the user will lose a life. To challenge the player, the exercises become slightly more difficult each time. The game must be slightly more complicated that the player will not be bored as well as that the challenge is too difficult to player get overwhelmed. By taking this into account, the player will always get a challenge based on their current mathematical skills.

Moreover, when starting the first level, a tutorial will explain the game-play this will save time for the contributor because they do not have to explain the game to every student individually. The tutorials will also provide more information about a particular mathematical subject so that students learn mathematics through the system. Furthermore, the system gives instant feedback about the performance and progress to the student or the teacher [26]. This information allows them to learn about their mistakes. The system's feedback to the teachers will be about the performance and progress of the student. This this information allows them to help these students with problems they encounter more efficiently.

Personalisation.

Personalizing of the game consists is very important to engage the player with the game. Malaysian people are very competitive. Therefore a leader-board would be an interesting feature to let students compete with each other. However, competition could help to get students more motivation to be the number one of the ranking. However, it could also less motivate students, because the challenge is out of their league [26]. On top of that, from a learning perspective, children learn better when they learn in a group [7]. Group activities in the game will improve the engagement with the game, whereas they also become more social. Another form of personalization is that users could choose their character. These options will improve engagement while playing the game [26]. However, due to time limit will the multiplayer option and personalizing of their character be out of the scope of this prototype.

Emotional elements.

To get a great flow in the game, the challenge level must be appropriate. They can neither be bored nor anxious [26]. Furthermore, the game needs to have a balance between difficult challenges and the freedom to fail. The freedom to fail is essential for learning new skills. It gives students the space to learn at their own pace. The challenges allow students to learn while they are answering questions where they have to make some effort. This combination will help students to improve their mathematical skills. Several animations and sound effects will help to make the game-play more enjoyable. Section six will discuss how these components are implemented in the application.

5.2 Design options of the game

During the development of the game are three different designs created to investigate which design the best fits to the needs of the actors and the local context.

5.2.1 *Digital book*

The first design is shown in Appendix C.1 is a simplified design of the application. In this design, the focus is on presenting multiple exercises where students can practice. The design is straightforward without a lot of graphics or gaming elements. There is no story-line or other visual things that can distract from the assignment. In this design, students will go through multiple mini-games to practice a particular subject in mathematics.

5.2.2 *Storytelling with mini-games*

The second design is shown in Appendix C.2 uses storytelling to teach students mathematics. Based on a story-line, students play several mini-games to practice a particular subject in mathematics. The focus group with the students and the parents showed that the students were very enthusiastic when they saw the other design. They wanted to play with the game right away. However, the parents thought the game looked outstanding but did not understand how this game could contribute to the child's development of improving their mathematical skills.

5.2.3 *Storytelling with a reward system*

The third design is shown in section 4.4 uses storytelling as well as a reward system with animation and sound effects to teach students mathematics. Based on a story-line, students play a role-playing game with every time the same kind of game which has different mathematical exercises in a different environment. Moreover, tutorials allow the student to watch a video, view tips about a particular mathematical subject, an overview of all addition, subtraction, multiplication or division tables and tools to translate mathematical words from Malay in English or vice versa. Furthermore, a teacher interface will help the teachers to get an overview of the performance of their students.

6. USER TESTING SESSIONS

In this section, the user testing will be discussed based on the information from the focus groups, interviews, and test sessions with the participants who helped while developing the game.

6.1 Understanding the learning objectives

In order to develop a serious game, first need to be clear which problems the primary school students have while they try to learn mathematics. The students indicated a couple of subjects where they have difficulties with. The focus-groups made clear that practicing with simple mathematical exercises would already be helpful for their development. To get an understanding of the level of mathematics, we did a couple of tests with these children where they needed to solve several exercises which were randomly selected from the mathematical book they use in school. The results of these tests showed that children of seven until nine have difficulties with counting, addition, and subtraction exercises while children often until twelve have difficulties with multiplication, division, fraction, and calculating discount. Unfortunately, it is not possible to create an application for all of those subjects. Therefore, only addition, subtraction, multiplication, and division will be selected and integrated into this game.

Moreover, I used several mathematical learning methods from the Netherlands to see if those tips make it easier for them to solve a specific exercise. This showed that using tips such as the friends of ten years old, drawing a division exercise or showing them that multiplication is only repeated addition where very helpful for them to solve the exercises. However, some tips, such as using the kangaroo method to solve delicate addition or subtraction exercises, were very confusing for them. Therefore, tips and tutorials will also be essential for students to study on their own. Also, they explained that the exercises in the book were kind of boring because most exercises were presented formally.

Figure 15: Understanding the learning objectives

6.2 Designing, developing & testing

In this section, the user testing of the prototypes will be explained. During the test sessions, there were four cycles used to improve the prototype. Every cycle will explain the main results of the test sessions based on three-point of views: the user interface, educational level, and the technical environment.

6.2.1 *First cycle: Selecting design of the game*

After the educational learning objectives where selected. The user interface and technical environment needed to be selected. To understand which interface the participants would prefer we created two kinds of designs which are shown in section 5.2.1 and 5.2.2. The primary school students found the storytelling design much more interesting than the other design. Although it was only a UX prototype, they wanted to play the game immediately. However, it was a pity that during this stage of the development, it was not possible to speak to a Malaysian primary school teacher and ask them which user interface they preferred for the game.

6.2.2 *First cycle: Testing the first functional prototype*

After the learning objectives and design of the game are selected, The first functional prototype is created based on the design of section 5.2.2. In this prototype, there are three mini-games based on counting or addition exercises. The first mini-game is about structuring numbers on a line from low to high. This game will help the children to understand how the numbers are structured. The second mini-game was about finding the right numbers together to create the right question. The third mini-game is about counting the monkey heads. This prototype we tested on urban as well as rural children from seven until twelve. The test with the urban children was done at the Sarawak children's festival. This festival let children experiment with technology, science, and eco-awareness. During this event, we tested the prototype with fifteen children from the age of seven until twelve while the test with the rural children was done in kampung Pinggan Jaya with ten children of the age of seven until twelve years old.

User Interface.

First of all, students liked the interface, especially the world-map, was exciting for them. This world-map divide the mathematical subjects in particular areas. Each area represents a subject with its environment. The students found the design of the game very beautiful, especially the students from rural areas where very excited to play these games. Students from urban areas were bored very quickly when playing the games. Both did not understand immediately what the goal was of the first two games, because of a lack of information. Therefore, it would be beneficial for them if there was an example exercise which explains what they needed to do.

Moreover, the third game was straightforward for every student. They liked this type of game because the feedback loop was very fast. Unfortunately, it was a pity that there was no high-score so they could not compete against their friends or a time-limit which makes playing the game more fun to get the highest possible score within a specific time.

At least, the students indicated that they would only play the third game in there spare time if challenges are added to this game. It indicated that several gamification elements, such as quick feedback, time-limits, high-scores, animations were missing.

Educational level.

The differences between urban and rural students were tiny. Peers from both areas made the same mistakes while playing these games. However, game one and three consisted of straightforward exercises. Students from seven until nine years old had more difficulties with the exercises of these game. On the other hand, students of the age of nine until twelve years old found these games very easy. The only differences between urban and rural students arose in the second game. In this game, all rural students found this game very difficult, but urban students quickly answered the questions.

Figure 16: Testing at Sarawak children's festival

Moreover, counting the heads was an easy game for all students. However, most of the students counted with their finger. Because of this, it was easier than counting by head. However, using their finger took quite a lot of time to answer a question. Therefore, a time-limit could be useful to let the students think faster when counting the heads of the animals.

Technical environment.

All games could be played in an environment without any internet connection. However, a laptop or smartphone is needed to host the application. This could be a problem because not every student has their smartphone or laptop. Also, several bugs were found during the test session. The most interesting bug was the bug where the dropping of a number did not always work well. Because of this bug, the students were confused; they thought that the answer they gave was right. Partly because of this issue, they lost their interests in the game.

6.2.3 *Second cycle: Defining gaming elements*

Since the prototype missed many gamification elements, we wanted to find out which elements were most interesting for the participants. Therefore, we tested four different mobile mathematical games with children from rural areas. During the test, we observed the children playing these games to understand which elements of the game they found interesting. Table 17 shows which gaming elements the tested applications consist. Moreover, Appendix B shows the research of the chosen games.

All games had similar components in the game. For example, all games made use of the freedom to fail and a progression system. Furthermore, the games *"aap rekenen"* and *"mathVSundeath"* visualize the time limit very well. The visualization of the time limit could be useful for the new prototype. Another great feature of all games is that the challenges become every-time slightly more difficult.

	Aap rekenen	Goed Snel Rekenen	MathVSUndead	Arithmetic Wiz
Progression System	x	x	x	x
Avatars	x			
Badges	x			
Collective Responsibilities				
Onboarding	x			
Leaderboards		x		x
Instant Feedback	x			
Flow	x	x	x	
Freedom to Fail	x	x	x	x
Freedom to Explore				
Freedom to Effort	x		x	
Freedom to assume different identities				

Figure 17: Gaming elements of tested applications

Also the interfaces of the *"aap rekenen"* and *"mathVSundeath"* were very easy to use. Only the things which were necessary during the game were displayed on the screen. Because of this, it was obvious for the children to understand the game. In the *"aap rekenen"* game was a tutorial implemented before the first level started. This could also be a good gaming element to introduce into the mathematical game.

Improvements application after the first cycle.

The prototype is improved based on the results of the first test session and the research about the missing gaming elements. These results showed a story-line, a rewarding system, and a quick feedback loop were essential gaming elements which were missing. Also, it was to difficult and took to much time to continue creating several games in one application which each approached a different subject. Therefore we created a new game concept based on storytelling. In this game, a monkey goes through a jungle with a liana but get hunted by several animals. Random addition exercises need to be solved to survive. If the answer is correct the monkey will earn bananas, is the answer is incorrect then the monkey loses a life. After three lives are lost, the monkey dies. This game will be easier to develop within the time-limit of the fieldwork. This game could be used efficiently for all the selected subjects to practice.

6.2.4 *Second cycle: Testing the second functional prototype*

After implementing the results for the first cycle, a second prototype was created to test with primary school students of kampung Pinggan Jaya and Muhibbah.

User Interface.

The students were very excited to play this new game. They enjoyed playing the game and were impressed by the beautiful game-play. When the students first played the game, it was a bit hard to understand the goal of the game. However, after a small explanation about the goal of the

game, it was no longer a problem. The visualizing of the *"time-limit"* worked out well. The students understood that they needed to solve the exercises before they got hit by an obstacle. Moreover, they liked the sub-goal of the game to earn as much as bananas they could earn. Something was missing to get their full attention for the game. At the moment, the game was very static, and there was no animations or sound effects used in the game. Therefore, it would be great if the game could have more animations and sound effects to let the students feel they are playing a real game instead of only practicing mathematics.

Figure 18: Testing several mobile mathematical applications

Educational level.

The group of students from seven until nine were already having problems to solve the most straightforward exercises. The speed of the game was too quick for them to solve the exercises. When we set the speed a bit slower, it was already helpful for these students to solve the exercises. On the other hand, the students at the age of ten until twelve said that exercises were too easy. However, when we made the speed of the game faster, it was a challenge for them to solve the exercises with no mistakes. Although, the exercises of the game were too easy for this group of students, they enjoyed playing this game. However, they would also like to practice with multiplication tables and division because they also had difficulties with those subjects.

Technical environment.

During these test sessions with the students, we tried to let them play the game both on a smartphone and a laptop. After trying both devices, all students preferred playing the game on a smartphone, because it was easier to click a button then dragging the mouse of the laptop to the right button. This took time which they needed to solve the exercises. Unfortunately, during the test with the children, several bugs appeared while playing the game. The most interesting bug was that the monkey did not shoot the coconut accurately. Because of this bug objects were not destroyed before going to the next exercise. This caused much confusion for the children because they could not continue to play the game.

Improvements application after the second cycle.

After these testing sessions, the second prototype is improved based on the children's feedback and our observations during the test sessions. We implemented more levels of additional exercises which are slightly more complicated than the previous one. Also, we added more mathematical subjects to the game allowing the children to practice with subtraction, multiplication, and division. All subjects got their background based on the area on the world map, which is used to separate the subjects. Moreover, navigation though the game will be more straightforward by the implementation of three panels. When playing the game, the system gives feedback if the player is game-over, pauses the game or congratulate the player when the level is finished. Through several buttons on this panel, the user could navigate easily through the application. Also, there was a tutorial added at the beginning of playing level one. In this tutorial, there is a little explanation about how to play the game.

6.2.5 *Third cycle: Testing the third functional prototype*

After implementing the results for the second cycle, a third prototype was created to test with students of Pinggan Jaya and math teachers of the school Srk Chung Hua 4.5 miles.

User Interface.

The tutorial at the beginning of the game was beneficial for the students to understand the game immediately. There was no explanation needed to explain the goal of the game. Moreover, the different background of every subjects also a significant adjustment to the game. According to many students of the test group, it did not feel that they were always playing the same game. Also, the navigation of the panels was helpful to navigate through the application. All pictures and buttons were clear to the students what it means. Only the text was in English, which they did not all understand.

Figure 19: Test session with students from Pinggan Jaya

Educational level.

Students enjoyed the more substantial amount of levels; all students could now play the game based on their level. We immediately noticed that the older students of the test-

ing group had difficulties with the more advanced levels. Even though the levels were more complicated, some students would like that they could set the speed of the game to make it more challenging.

The primary school teachers were very interested in the game. However, they missed a section where the students can look up things if they do not understand something or want to learn a topic first. Some kind of tips or tutorials of the exercises would be beneficial. Moreover, addition, subtraction, multiplication, and division tables would the student help to learn and practice the exercises of the game. Furthermore, the game would not only be helpful outside the class but also during class if the teachers could make their tests in the game which are checked by the system. Then they could look up the results and have more time to help the students with their questions.

However, when asking which tutorials or tips, the students would need to have to learn quickly they did not know. Also, they did not know which learning method they used but just followed the book. However, after looking through the book and the exercises it was clear which type of tutorials where needed in the game. Moreover, A. Abdul Taib, student tutor of UNIMAS reviewed the tutorial section and gave us several options which we could implement. She told us that it was important that her students prefer an example exercise before they do the exercises on their own. Also, visual components will be helpful to learn a new subject. During this interview, we developed several tutorials and tips for the students to learn more about addition, subtraction, multiplication, and division.

Also, a fun side-note is that when we showed the friends of ten methods to the primary school teachers, they were impressed by this method. This method is the first thing that students need to learn before they are going to practice with an addition or subtraction exercises. In Malaysia, first students learn to calculate with numbers by separating numbers to create an obvious question. However, there is never told them why this is important. The friends of ten methods explain the separation of numbers very quickly.

Technical environment.

Adding tutorials and tips would be hard to implement because using videos to explain would need much storage, which is not always available in a low resources environment. Moreover, it is not an option to host this data online because there is no internet connection in these areas. Therefore it is essential to find a way that tutorials and tips could be added easily when the storage of these data will not affect the storage of the game.

Improvements application after the third cycle.

Since the teachers advised to not only focus on creating a fun game, but it would be beneficial for students to watch or read tutorials about a particular subject to learn. Therefore, we implemented a tutorial section which provides videos and tips which the children could watch or read to learn from. Every subject got their tutorials and tips specifically intended to make it easier to solve the exercises of the game.

Moreover, it seemed like a good idea to show the students the exercises which they did wrong after their character died and they where game-over. Students can learn from this information so that they can solve these problems in the future. Also, a Malay-English dictionary was added to the game, because the students indicated in one of the first focus groups that they find it confusing that the mathematical books will be in English without them being able to read or speak English well. This section would help them to look up some English mathematical words which they do not understand. With this, we hope to narrow the gap between mathematics in English and Malay.

Other things that were added in the third prototype is a logo of the game, several animations and sounds to make the game more interesting, speed up the game and a new city-world in the game. In this world, there will be asked questions about all subjects randomly. It will be the most challenging part of the game. The endless world is different from the other worlds. In the endless world, the exercises are endless, but there are no lives. If the user makes one mistake, the game will end. In the meantime, a score will be kept to identifies how good the user is. This score could be held as a challenge between classmates.

Also, the idea of the teachers to implement exams and an overview of the performance of the student is an excellent idea to improve the game. However, due to a time limit, these features are implemented in the fourth prototype. Other things the teachers would like to see in the application is to get an overview of all students performance on one device, more difficult questions for higher levels of primary school and other mathematical subjects. However, these features are hard to implement and will be out of the scope of this project.

At least, the application is now also hosted on the STEM in the box and the OLPC which helps to distribute the application more efficiently.

Figure 20: Testing session with students of Pinggan Jaya

6.2.6 *Fourth cycle: Testing the fourth functional prototype*

After implementing the results for the second cycle, a third prototype was created to test with students of Pinggan Jaya and math teachers of the school Srk Chung Hua 4.5 miles.

User Interface.

The students did not understand how to use the remover button. When they answered a question incorrectly, they were clicking the right answer, but this did not work be-

cause the past answer was still stored in memory. It was very confusing for the students. Also, both groups thought that the tutorial section had a fantastic design. Only it was not clear that they needed to click on the screen to view tips, a video, or more tutorials. Moreover, they also did not know that they could view mathematical words in English if they clicked on the *"numbers in English"* book.

Educational level.

Furthermore, the students were very excited about the new city-world game. Especially the students of the Srk Chung Hua 4.5 miles school liked the endless running game. They tried to compete with their friends to get the highest high-score. However, the students of Pinggan Jaya found this section very difficult since they cannot yet calculate fast enough to answer these sums, which makes this part of the game too difficult for them.

Moreover, changing the speed of the game was also for the students of the Srk Chung hue school great to make the exercises more difficult for them. They were outstanding in mathematics. Especially one of the students did all the exercises of the game without making any mistake. It was beyond any expectations.The tutorial section was for the students of Pinggan Jaya very helpful, only some videos were in English, and without any subtitle, the students did not understand anything of these videos. Moreover, they found using English in the game challenging; therefore, they would prefer to have the game also in Malay. The section was they could find mathematical words would be helpful for them only more words need to be added to this section. Also, the addition, subtraction, multiplication, and division tables were beneficial for them. Only most of the students of Pinggan Jaya wanted to play the game instead of looking at the tutorials. The wrong answers section of the game did not work that well. Most students did not look at this information to learn from. They immediately restarted the game to play again.

Technical environment.

In this test sessions it was the first time that the game also could be played on the OLPC. The test session showed that the students preferred to play the game as tablet. This made it easier to push the buttons then using the a mouse of the laptop. Unfortunately, the OLPC is much slower then a smartphone which means that the game is sometimes slower than the game being played on a telephone. Hosting the application on the STEM in the box was an amazing adjustment to this project. With this device it was easily to distribute the application to the smartphones from the students without making use of the internet. Installation of the game would only takes less than a minute.

Improvements application after the fourth cycle.

In this prototype, several bugs fixes were solved. Moreover, an player data interface was implemented so that the student or the teacher could view which exercises they did wrong as well as all the levels they went game-over. With this information, they could learn from their mistakes. Moreover, the game has now a multi-language option. During several test sessions, we found out that the English of most students from rural areas were not that good. However, they need to learn English; therefore, we created the multi-language option, so that the student could choose the language they prefer to use. Another improvement an exam added to the game. Now every student could test their skills-based a couple of exams.

Moreover, the remove button is no longer necessary to clear the wrong answer. Now the system will clear a wrong answer automatically. Furthermore, a mini-game in every world is added to practice the assignments differently. In this mini-game, the player needs to count the animal heads, and based on the subject they need to add, subtract, multiply or divide these numbers calculate the answer. This mini-game was added because the students could learn to count and to calculate at once. At least, all interfaces of the game got one clear design, so that there were no differences in strange differences in the game.

7. SUSTAINABILITY PLAN

Improving mathematical skills will take more time than only doing it once. Therefore it is necessary to think about the sustainability of the game so that the students could practice the exercises and improve their mathematical skills. The University Malaysia Sarawak (UNIMAS) is very interested in gamification of education. In September 2019, they organize a whole event about gamification of education in rural areas of Sarawak. They would like that gamification helps the students to learn. Therefore, this game will be used as an example of how gamification in rural areas could work. Furthermore, the application is multi-language making it very easy to translate it into another language, allowing other students to play the mathematical game. However, in every country there are different mathematical learning methods so it is possible that the tutorial could confuse the students. Also the application will be hosted in the app store of apple and android allowing multiple people to use it.

Moreover, technical sustainability is essential in a low resource environment as in rural areas in Sarawak. The application needs to run in an environment which is not normal. Therefore, the application will be hosted on the STEM in the box of UNIMAS. They created a device, the STEM in the box, which can set up local WI-FI network to access data from a Raspberry PI without making use of an internet connection. Because rural areas do not have a (proper) internet connection, the STEM in the box is a perfect device to host and distribute the game. Also, the game is developed with Unity that allows that this game could be used on multiple platforms. The cross-platform game makes it easier for UNIMAS to distribute the game to several devices which the users have. Because of that, UNIMAS have the most experience with ICT4D in rural areas of Sarawak and the perfect solution to host the game. UNIMAS will be the contributor of the game and will maintain and update the game when needed.

8. EVALUATION AND DISCUSSION

To evaluate the system, we wanted to evaluate the system with all the actors. Unfortunately, we could not evaluate the application with primary school teachers who were involved with creating the tutorial section. Therefore a dutch primary school teacher M. Edens and N. A. Abdul Taib, a student tutor mathematics of UNIMAS, who was involved in the initial process wanted to participate in this evaluation. Moreover, the primary school students of Pinggan

Jaya and N. E. Binti Mogan who will be the contributor of the application by UNIMAS.

8.1 Setup evaluation

The evaluation will consist of observation and questionnaire with the students of Pinggan Jaya and an interview with the teachers and the contributor. The observation and questionnaire with the children will be with fifteen primary school students. Sim Keng Wai will help to do the observation and the questionnaire with the students. During this session, we will look into the usability of the system. Therefore, the questionnaire will include system usability scale questions intended to evaluate the usability of the system. The content of the questionnaire is shown in Appendix E. The interview with the teachers will look into the educational perspectives of the game and which elements of the game will they use in the class. The interview with the contributor will look into the technical part of the application. All participants are first going to play with the game to get familiar with it. During the time that the students will play the game, there will be observed what they are doing and which mistakes they are making. After this time, they will receive a questionnaire with simple questions about the usability of the game as well as if they learned anything from it.

8.2 Results & Discussion of the evaluation

From the evaluation with the test panel came the following results. These results will be discussed based on three points of view. These viewpoints are the user interface, the educational ecosystem, and the technological environment.

User Interface.

From the observation session with the students came that it was easier for them to answer the questions because it was not necessary anymore to remove the wrong answer before entering the new answer. With this new feature, the students made a lot fewer mistakes than in the previous test sessions. Because if they made a mistake, they now had enough time to correct it. Also, the multi-language option was beneficial for the students. With this prototype, they could choose to play the game in English or Malay. Most of the students preferred the Malay language because they were not familiar enough with reading in English.

Moreover, 75% of the students indicate that the English translations were useful for them. However, they told us that they would like to have more offline content which they could watch to get help with their homework. However, the current videos were not translated in Malay yet. However, against expectation, they preferred to have a subtitle in Malay so they could understand the videos better. However, some of the students did not notice that there were tutorials in the application. 80% of the students did not need any assistance during playing the game and while only two out of the fifteen children needed to have assistance during the first time they played the game. They understood the game very well what they needed to do. They liked the small tutorial at the beginning of the first level so that they understood the game of the game. There were also differences in playing the game on different devices playing the game on the OLPC was slower than playing it on a smartphone. Therefore, the students preferred to play the game on the smartphone. Furthermore, most parents had a smartphone which they could borrow to play the game. No one of the students had access to an OLPC. Eleven of the fifteen students would like to play this game in their spare time. They liked the game-play, but not all of them will use the tutorials while they are playing the game.

At least, suggestions that were made were that they would like the game would be personalized. A suggestion that was made was a shop to buy new clothes for their character.

Educational ecosystem.

Both teachers found the game very impressing. They told us that they would let their students play the game if it was ready. Only for some of the students, it would be still hard to play the game because they need to have more thinking time to answer a question. The tutorial section would be a beneficial section for students to view some tutorials and tips. However, it would be great if more content could be added to the system by the teacher easily so that she could provide more information to the students. Also, the teachers suggested that it would be great if they could make their tests in the game. With this, it will let the student do a test in a fun way. The player data section was a proper adjustment, but the teachers needed more information to understand the performance of their students. They would like to have an overview of the student's performance in comparison to the whole class, the student's performance per subject over a more extended period and that all the data is connected to the application of the teacher.

Technical Environment.

The contributor was surprised that the STEM in the box also could be used for hosting a mobile game. However, it was an excellent solution to use efficiently distribute an offline game into a low resource environment without an internet connection. Implementing this game in an educational ecosystem would be very hard. Therefore the contributor had made some suggestions to use this application. They could use this application when UNIMAS let children from rural areas get familiar with the technology. At the moment, they let them play with games like angry birds. However, it would be great if they could use a game where those children could learn something from. Another suggestion that was made was that using STEM in the box could not only be used for hosting the application but maybe also to use as storage of large files.

9. CONCLUSION

This research aimed to investigate if it was possible to design, develop, and test a serious mathematical game in a low resource environment. We have through this study, delivered an approach for developing a mathematical game under these circumstances, while combining different existing methods such as the ICT4D protocol in combination with a development structure for gamification in education and elements of gamification to structure the game. This study takes a step forward to deliver a method for developing a serious mathematical game for children of rural areas of Sarawak.

Through this study, we have learned that creating a serious mathematical game is that this environment will be challenging. Not only the development of an application in a low resource environment was difficult because we have to

need to take several things into account. However, also, the cultural differences were sometimes a challenge to receive the right information to improve the application. One of the most challenging tasks was to involve Malaysian primary school teachers closely in the development of the application.

However, to develop a serious mathematical game in Sarawak, some things need to be taken into account. Depending on the goal of the game, there need to be thought about the platform which will be used. Will it be a mobile or desktop game. Also, there need to be thought about which type of game as well as how the story of the game will be. Moreover, several gamification elements need to be selected to contribute to the goal of the game. As probably already noticed, every game could be different, but having the same kind of goal. However, elements which make the game more enjoyable for children are a rapid feedback loop, goals and sub-goals during the game, leader-boards to make the game more competitive as well as a good flow in the game. If the game is not going smoothly, then children will be will drop out quickly. Also, the game must be challenging, but not too difficult. Children in Sarawak like to compete with each other, but if the tasks are too complicated, then it is difficult to motivate them.

Also, there was a significant difference in educational purposes between primary school students in urban and rural areas. Urban students, especially on the Srk Chung Hua 4.5 miles school were much better in mathematics than students from rural areas who have the same age. The students of this school could solve almost all exercises in the game very quickly. However, students from rural areas had difficulties with the same exercises. Moreover, they needed more time to think about a particular exercise. Also, in rural areas, there was a difference in the mathematical problems the students had. Students from seven until nine had difficulties with addition and subtraction, but students of the age of ten until twelve years old had difficulties with multiplication and division. With this, it is quite reasonable, because on different ages have different kind of problems they need to solve. However, we found a way to help both groups by practicing more by playing the game.

Moreover, the lack of low resources in rural areas was not a significant obstacle to develop a game for these areas. By using a game engine which could build an application for several devices will help with the distribution of the application. Hosting the application on the STEM in the box will also contribute to distribute the game efficiently in rural environments where there is no internet connection.

To conclude, it is possible to design, develop, and test a serious mathematical game in a short amount of time. However, it is also tough to do something like this project in an unknown context and cultural environment.

Future Work.

Since it was challenging to get Malaysian primary school teachers involved into the project more research is needed to look if the game the mathematical support provides to the students so that they improve their mathematical skills, as well as more subjects or more difficult levels about the existing subjects, could be added.

Moreover, the results of the last test session with the students of Pinggan Jaya showed that the multi-language option needs to be improved. At the moment, only the labels are translated, but images also need to be translated as well as video's need to be subtitled. Also, the students liked the city-world; however, the exercises were to difficult for them, and the tutorials to explain the exercises could be improved by adding more content to this section. Besides, the game could be more personalized by implementing a shop where it is possible to change their character. Also, an achievement board could be added to let students compete with each other. With this, it could give the students more motivation to work harder for mathematics, but could also cause the students to become less motivated because they find it too challenging to learn. Also, more research is needed to look into which technology and interfaces are needed to synchronize multiple games in a performance overview of the students

10. ACKNOWLEDGEMENT

Firstly, I would like to express my sincere gratitude to my supervisors A. Bon, C. waiShang, and H. Akkermans, for the continuous support of this research. Moreover, a special thanks to C. waiShang for his guidance during my stay in Kuching. Besides my supervisors, we would like to thank Sim Keng Wai and Aparna Patel for helping with designing and development the application. I would also like to thank the residents of Pinggan Jaya and Muhibbah, teachers and all students of the school Srk Chung Hua 4.5 miles for their co-operation during the development of the application. Moreover, we would like to thank M. Edens, A. Bertrand, A. Rensink, and N. E. Binti Mogan for their co-operation during the development of the game.

11. LINKS OF THE APPLICATION

Github: https://github.com/AVG-Apps/MonkeyMathSarawak
Resources: https://www.dropbox.com/sh/xgn7wlilcv69due/AADNgEi9TEkJGLf01iLEGYpWa?dl=0

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APPENDIX

A. INTERVIEWS AND FOCUS GROUPS

This section discusses all the interviews, focus groups and test sessions with all the actors. Every section represents a summary of a particular interview, focus group or test with one of the actors.

A.1 Interviews with primary school teachers or companies

A.1.1 Interview teacher A. Bertrand - Dutch mathematical learning methods

Teacher: A. Bertrand

Primary school: de Achthoek

Location: Amsterdam, Netherlands

Every year is divided into eight blocks where the students take a test at the end of each block. This test must show what the student has learned and what is difficult for them. For these students, we have another book where they can make exercises of subjects with which they can practice. Every week there is in math class an instruction and a week task. Most of the time the students will first do some exercises to automate their math skills. This will be done for ten minutes at the beginning of the lesson. The second part of the lesson it is time for a new instruction or repeating a previous topic. During this phase, we explain a topic to the students. In the third phase of the lesson, the students are dealing with independent exercises of their book.

On primary school the achthoek we work with "wereld in getallen". This method works with stars every star is a level. Exercises with one star provide more information about the exercise, while the exercises with three-star are a bit more difficult with less information about how to solve the exercise. On my previous primary school, we use the method "pluspunt". This method is almost the same as "wereld in getallen". However, fewer illustrations are used in this method to make it look nice. In addition, the students of school the web application of "wereld in getallen". In this application, they do more exercises than in the book. However, this application is only a digital version of the book with more exercises. Unfortunately, the material is not based on the student's level. Besides the application of "wereld in getallen", we are also using the application "rekentuin". This application helps the students to do exercises of math based on their level and it has many exercises per math subject so that the students can practice endlessly with the exercises. Another application which we use during class is "taalzee". This application is similar to "rekentuin" based on grammar. Therefore, we use this application during a grammar lesson. However, maybe you will be inspired by the exercises they use in their application.

To prepare a lesson, it is essential to think about how students can learn while they are playing. Mathematics can be complicated and sometimes boring. However, if you playfully present the information, then they will understand it sooner. For example, if they need to learn about how much something weighs. Then we let them search in class how much a certain amount weigh. After they found something, we test it so that they learn how much something weighs. Problems we face with the method is that we use assumes that the students have mastered the subject if they go to the next subject. However, due to lack of time sometimes for some students, the curriculum goes a bit too fast. As a result, that the students do not understand what they are

doing in the next subject, because they did not master the last subject. Examples of that are that they face difficulties with reading time; they are confused by multiplication tables or have trouble doing exercises within a particular time.

A.1.2 Interview teacher M. Edens - Dutch educational ecosystem for mathematics

Teacher: M. Edens

Primary school: Dom Helder Camaraschool

Location: Groningen, Netherlands

In primary school education, we work with various vital objectives. These key objectives are divided into three categories: mathematical insight and action, numbers and operations; and measuring and geometry. Each category objective guarantees specific knowledge which is essential for the student. Every year, the student needs to achieve their goals so that they understand the curriculum of the past year(s). This information is essential for achieving the new learning objectives. On the SLO website you can find all objectives for primary school students of the Netherlands subdivided per group. There are several learning methods for math which you can use. Which method we need to follow differs per primary school. This is in line with how the school wants to teach the students. The learning methods we have used are "wereld in getallen" and "reken beter". When you want to create an app, we suggest to look into the methods and consider which elements are useful. Every method has its advantages and disadvantages for the various key objectives.

When the students need to learn new material always consists of three different phases. First, we want to let the students understand the material while they are playing. we regularly use various materials for this. For example, if we want to teach them about dividing, we buy a baguette or pizza and break it parts while we am explaining what diving is. Then we let the students play with it so that they can understand how it works. Secondly, we write the schematic representation of it by making use of images. In the third phase, we write the exercise in numbers on the whiteboard and let the students think about it. After that, we let the students practice with the exercises.

If the student finds something difficult that we make use of visual components to explain the exercises if a student has difficulties with the math exercise. In addition, we often try to link it to the student's interests. we notice that storytelling is exceptionally essential. The students are always sincere and if you are explaining something that is boring. Then it is my job to make it interesting for the students. What we find particularly essential is that children learn in a way that you do not realize that you are studying. However, every student has difficulties with different aspects of math. In general, it is essential that students understand what they are doing. Some children learn a list of exercises by heart. However, if they exercise is a bit different then they do not understand anything of it. As a result, if they have to work with other exercises which are more difficult, they do not know how to express that. Therefore, it is essential that students understand what they are doing and why they do something wrong. Unfortunately, we do not always have enough time to give individual students enough attention because of the growing classes.

If students do not understand the exercise, it is essential to find out why they do not understand something. There are several reasons why they do not understand the exercise. Some examples are that they did not understand a previous part of last year, that they do not understand the current part, or that there is a combination of several older and new parts are merged into one exercise. After all, it is challenging for the students to learn dividing if they have not mastered the subjects: addition, subtraction, and multiplication. Dividing a number is the opposite of multiplication, while consists of repeated addition or factions consist of repeated subtractions. To help these students, we often try to explain why a specific answer is wrong. First, use visuals to explain the exercise. Secondly, the student and we look at the wrong answer and compare it with their answer. With this comparison, we try to explain how it should be done. However, this takes much time to do this with all the students in the class, so we don't always have full time for all students. It would be helpful if the application first explains what the student must do when they have a wrong answer than only say it is wrong. This feature will save a tremendous amount of time in comparison if the students need to ask the question to me.

A.1.3 Interview teacher A. Rensink - Gamification in primary school

Teacher: A. Rensink

Primary school: Archipel

Location: Jisp, Netherlands

On this primary school, we use different methods, because we use a various amount of materials and applications in mathematics. The overall method we use is the "wereld in getallen" method. The application of the method "wereld in getallen" is not in line with the current range of applications. We think this application is a digital copy of the book. Therefore, we use the application of "gynzy" which provides an unlimited amount of online math exercises by making use of gamification. This application is delightful to work with. It is well-structured, and we can let the children practice individually with the parts they have difficulties with. Besides that, it is educational and playful at the same time, as a result that children do not realize that they are learning while they play a game. For every part, it is essential to start to present the information visually. For each component, it is essential to start with presenting the information visually. The children learn best if they can link this to their environment. You can start with pictures of animals. The students have to count how many animals are on the farm. After this phase, you can present the information more formal. For example, you divide the animals on the farm in two groups and you add a plus in between. This exercise makes it visible to the students that a calculation can look like this.

The structure of learning mathematics is essential. An example is that you must first learn to count before you can learn to solve addition and subtraction sums. The children must be familiar with the different numbers that exist. It is essential that the children know the numbers zero until nine.

From these numbers, all figures are created. While the students learn to count, we use number lines and shapes. It is essential that what the structure of every number is. This structure will help them to make calculations easier with the numbers. First, they all start by counting jumps of one. The following are jumps two, five and ten. These jumps are essential to know when the children will start with calculating. After the student understands how to count, the student will create the number ten from two other numbers; these numbers are also expressed as the friends of ten. The next phase is to calculate with two numbers which are less than ten. After which they calculate the answer which is more than ten. This phase is often experienced as difficult. This because the students need to divide the numbers into two other numbers to make the exercises easier. For example, $7 + 6$ can be divided into $7 + 3 = 3$, then you have three left, and if you add 3 to it, you get thirteen. If the children are familiar with the addition exercises, they do the same with subtraction exercises. We notice that if the children understand the addition exercises, they also understand the subtraction exercises. An excellent exercise for this is the kangaroo method. With this method, the student divides the exercises in several exercises to make the assignment easier. The next phase is multiplication. Multiplication exercises are actually double addition, so we first explain $2 + 2 + 2 = 6$, after that we explain that $2 * 3 = 6$. So, you do the same thing but then easier. In this phase students start with exercises of 1 - 10 - 5 - 2 - 3 - 4, because they also learned to count in this particular order, so that they will recognize a lot causing the effect that they understand it easier. However, many people find the tables from 6 to 9 often difficult. We tell them that most of these exercises they already know, because they mastered the multiplication tables of 1 - 10 - 5 - 2 - 3 - 4, only the exercise is showed they another way around. If they start with dividing exercises, we teach them that they are reversed multiplication exercises.

It is sometimes frustrating that there is not much time to help the children who find mathematics very have. Therefore, applications like "gynzy" is extremely useful. They can exercise based on their level and subject. Moreover, "gynzy" gives me the overview of all the children performance. This statistical overview is great to understand which parts of mathematics the children have difficulties with and which parts is easy for them. From this data it is interested to understand how many exercises the student has done per subject within how much time, an overview of subjects which are hard or easy for the student, what kind of progress the student made during his study time and the progress of the student in comparison to the rest of the class. With this information the teacher understands if the student has mastered a particular subject. However, if we create an application from scratch, we would like to implement a support feature where the students can look at while they do not understand a specific part of mathematics. It would be very useful so that the children can see how it works. Sometimes the children do not remember everything they have learned. Therefore, we have a "calculation wall" in the classroom which has various explanations about mathematics that the students can look at if they forgot something. For this reason, we suggest creating several cheat sheets, for example, the multiplication tables and the friends of ten list.

A.1.4 Interview Grolier-Asia – E-learning system for home

Company: Grolier-Asia.com

Manager Sales operation: Deedee Wan Koh

The Grolier-Asia company provides variety of materials for primary school students between the age of four and twelve. They focusing on that children can learn at home if they have difficulties with a particular subject. Therefore, they provide for every subject on primary school a couple different materials so that the children can learn more about the subjects where they have difficulties with. However, to get the interested of these students it is a must that they play while they are learning. Therefore, these materials are designed for the primary school students so that they play while they learning. For mathematics they designed a math-key, a logical board and an online device to learn mathematics in playing environment.

The math-key is created for children to learn addition, subtraction, multiplication or division. The student needs to take the rope across de key while they solve the exercises on the key. After they are finished the student checks if the answer is correct by looking at the back of the key. The logical board is used to do exercises where the answer of the exercise needs to match they color of they exercise. The student needs to move a button to the right area on the logical board. With this game the student needs to solve as much as exercises as the board is given. Both exercises make it more fun for children to learn, because they need to do something while they are solving mathematical exercises causing the effect that the children are more dedicated to learning mathematics.

However, these materials only have a certain amount of exercises. Therefore, Grolier-Asia have developed a digital learning environment which the children can use to learn. This learning environment has endless exercises available on every level for the children. Moreover, the exercises are mini-games where the children need to solve a particular exercise to go to the next challenge. Furthermore, the platform is built on an android device. However, the learning environment is locked with a password which only the parents know. With this feature the student cannot go to YouTube or other social media which lead to that he only can use the device to learn. But if the exercises are done then the parent could allow that the student could watch YouTube or use other social media. With this feature Grolier-Asia wants to trigger children to do a hard task where after he can do something he likes to do.

At least, more research is needed about which information need to be explained if the student opens the application for the first time. For example, the tutorials section need a one-time explanation about the use of the buttons on the screen. Sometimes it was not clear that you could click on parts of the screen.

A.2 Focus groups with primary school students

A.2.1 Understanding the local context

Participants: Aron van Groningen (chairman), daughter of the chief of the village, 8 primary school students (age 8 – 12), 4 UNIMAS students

The focus group consisted of eight children, a group of four UNIMAS students and the daughter of the chief of Pinggan Jaya. The children were from the age between eight and twelve years old, and their level of primary school was between three and six. The reason for that a group of UNIMAS students joined the focus group is that most children of Sarawak do not fully master the English language. Especially speaking in English was very difficult for them. Therefore, these students helped to translate everything in Malay so that the children fully understood what the intentions were. During the focus group, we wanted to find out which levels there are in primary school, which interests they have and how exercises of math are presented in their school books. The daughter of the chief of the village told me that in Malaysia the primary school is divided into six different levels. The children are classified on a level based on their age. The first year in primary school the children are six to seven years old, and in the last year of primary school, the children are between eleven and twelve years old. Every year the children go up one level after which the mathematics exercises also become more complicated.

Moreover, it was interesting to see the differences in problems the children face with mathematics are linked to their level of primary school. After the children filled in the form, they showed me which exercises they find hard. During this conversation, we gave the children various exercises to understand their level of a specific mathematical subject. The results of these exercises showed that the children from primary school level three and four had difficulties with counting, addition and subtraction exercises whereas the children from primary school five and six had difficulties with multiplication and fraction. In addition, we noticed that the exercises were presented very formally. There were almost no images used to explain the mathematical exercises. The children also indicated that the exercises of their school books were sometimes a bit boring. Therefore, we showed the children several interfaces about how an exercise in the game could look like. Most interfaces were not clear for the children. The problem was that there was a lack of information, so the children do not immediately understand what they needed to do to answer the exercise. For example, in one of the exercises, the children thought that they needed to add all numbers on the interface. However, the exercise was that the children needed to structure the numbers in a line.

A.2.2 Multiple designs of interfaces

Participants: Aron van Groningen (chairman), 9 primary school students (age 8 – 12), 2 UNIMAS students

The focus group consisted of six children from primary school, three children of secondary school and two UNIMAS students. The UNIMAS students helped me with the translation of the information so that the children understood what the intentions were. During this focus group, we wanted to show several interfaces which we created and test these interfaces on if the exercises were clear, level of difficulty and if they liked the interface. These exercises consisted of structuring numbers, counting animals fill in missing numbers and using the kangaroo method for challenging addition exercises. When we showed the idea of the mathematical game, the children were very interested in. They liked how the interfaces were to build and were excited to play with the game — however, the game designs were not interactive yet. Therefore, we showed a couple of exercises to test if the children understood it. All the children understood the exercise where they needed to structure the numbers and count the animals. A little explanation at the top of the interface was enough for the children to understand what they needed to do to answer the exercises.

Moreover, these exercises were very easy for the children. The test with the additional exercises of the animals and filling in the gaps was a bit more difficult for the primary school students. Especially when they needed to search for the numbers who are together a specific number. However, when we showed them an example exercise and gave them some tips, they found the exercise more comfortable to answer. This information could be used to improve the design by giving an example exercise of what the user needs to do to answer the question and adding a help button with tips if the user does not know the answer. The kangaroo method was for almost all children complicated. In the beginning, the children did not understand what they needed to do, because of a lack of information. Moreover, this method was very confusing with the method the children always use. After trying several exercises, the children became familiar with this method; however, it was still very confusing with the method they were learning in school.

A.2.3 Developed application in comparison with other applications

Participants: Aron van Groningen (chairman), 5 primary school students (age 8 – 12)

The focus group consist of five primary school students which all will play a couple of mobile games to understand which parts of the games they like to be seen in a mathematical game. Some of these game are mathematical game while some of these games have other perspectives. The selected games are *"aap rekenen"*, *"goed snel rekenen"*, *"mathVSundeath"* and *"Arithmetic Wiz"*. During the session all children played the games while we observed them which parts of the games where interesting. Moreover, we also wanted to find out which elements of the game they found interesting for them.

All these games had similar components implemented in the game. For example, all games made use of if you made a mistake you lose a live, but if you answer the question correct then you will earn something. Moreover, *"aap rekenen"* and *"mathVSundeath"* made make use of visualizing the time limit for a task in the game. There is not a physical time which counts down but still you feel the pressure to answer the questions quickly as possible. Another great feature of these games was that the challenges become slightly more difficult if you solve a particular challenge. The interfaces of the *"aap rekenen"* and *"mathVSundeath"* were very easy to use. Only the things which where necessary during the game where displayed on the screen. For example. in the *"mathVSundeath"* game there was only the player, the question, three answers and time limit was visualized by zombies who are trying to kill the player. This made it very clear for the children to understand the game. In the *"aap rekenen"* game was a tutorial implemented before the first level started. This tutorial explained how the game worked, this was very useful for the children, because they understood quickly what the tasks where in the game.

A.2.4 *Understanding the needs of children from kampung Muhibbah*

Participants: Aron van Groningen (chairman), 5 primary school students (age 10 – 12), 3 UNIMAS students, 2 Vrije Universiteit students

The focus group consists of five primary school students and five students from Vrije universiteit and UNIMAS which helped to translate and gather information the children. During the focus group we talked about several subjects such as their hobbies, the games they played and how an game could help them improve their mathematical skills. The results from this discussion was that most of the children borrow the phone of their parents to watch YouTube or movies. Girls also liked to listen to music or playing puzzle games whereas boys uses the phone to play mobile games as automated ninja, need for speed or shooting games. When we showed them several games they liked to play games where they needed to solve a task in a short time. Sometimes they got hunted by zombies or sometimes they needed to solve a question to not lose a live. These games where more interesting for them. Moreover, they preferred the games with a lot of animation which consist of interfaces that do not exist in the real world. Moreover, they would like to play a game which have challenges to solve and where they can do a competition with their friends.

B. RESEARCH ABOUT DIFFERENT MATHEMATICAL MOBILE GAMES

To understand which gaming elements are interesting for the children to use in a new game four games are selected. These games are analysed in the following sections.

B.1 Aap rekenen

The *"aap rekenen"* game is a dutch game where a monkey needs to solve mathematical exercises while he is hunted by animals. The children of the test group found this game the most interesting and fun game. However, this game was in dutch causing the effect that they did not understand any instructions in the game.

In this game, there is a freedom to fail, because they only lose a life if they do not answer the question correctly. The children found this very pleasant because it did not feel like a test, but you can practice with maths. Also they could can still change your answer before they hit an obstacle. If the answer is still correct then you will not lose a life. In addition, this game has implemented the visualization of time limit very well. In this game you have an certain amount of time to solve an particular exercise. However, there is no physical time who counts down. This element was working very good for the children. Even there was no timer the still tried to solve the exercise as quickly as possible. After they lost all there lives they got instant feedback about which questions they have answered wrong. Unfortunately, this game has no further explanation about how the user can answer these questions correctly in the future. The rewarding system encouraged the children to continue playing the game. On top of that, this game makes use of an rewarding system to earn coins when you answered a question correctly. Because they found out quickly that from these coins they could personalize their character by buying clothes in the shop. Furthermore, the flow of the game is as you aspect when you have finished an level you can continue to the next level which is slightly more difficult. Moreover, the tutorial at the beginning of the game would be very useful for the children if this was in Malay. In this small tutorial the game will be explained very smoothly.

B.2 Goed Snel Rekenen

The *"goed snel rekenen game"* is a dutch game where you can practice mathematical exercises. This game is a simple created game with a lot of advertisements. The children found the menu of the game very hard to understand. There was to much information of the menu and too many options to choose. Also there is no time limit for answering an question causing the effect that some children where cheating by using an calculator to calculate the answer. Moreover, most children thought the game was a boring game, because the interface was very similar to the textbooks.

B.3 Math vs Undead

The *"math vs undead"* is an English game where the user needs to solve mathematical exercise to survive. If he do not answer the questions correctly then he will be killed by zombies. The children found this game very interesting because this game also visualize the time limit very good. To be hunted by zombie will encourage the user to solve the questions quickly. However, there is still time to fail. When you answer an question incorrect then you only need to wait a couple of seconds for the next question. After you finished the level then the next level will be slightly more difficult then the previous one. Moreover, according to the children the game was very easy to use and only the necessary components where showed on the screen. Unfortunately. this game had a lot of advertisement during the game-play which the children found annoying.

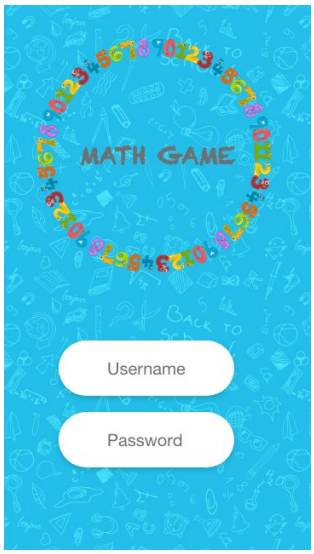
B.4 Arithmetic Wiz

The *"Arithmetic Wiz"* looks very similair to the *"goed snel rekenen"* game. Both have an very simple interface where mathematical exercises need to be solved. An essential difference between the games is that this game uses a time to let the user solve the exercises quickly. However, in contrast to most games who uses an timer, this game an counts only the time the user is playing the game. Because of this there is no time limit for solving the exercises which makes give the freedom to fail for the users. Moreover the good and wrong answers will be counted as well as the time which are together used for the high-score of the game. The children did not liked this game because it did not feel like playing a game, but more like solving random exercises.

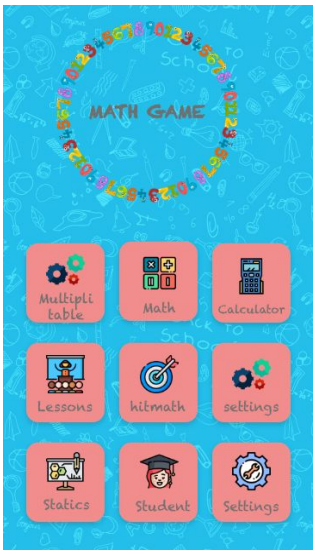
C. Designs of the application

C1. Design of digital exercises of the book

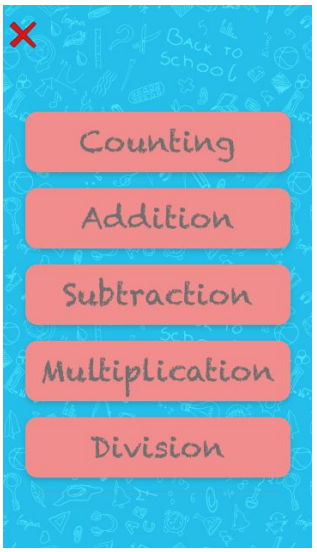
Login screen



Main Menu

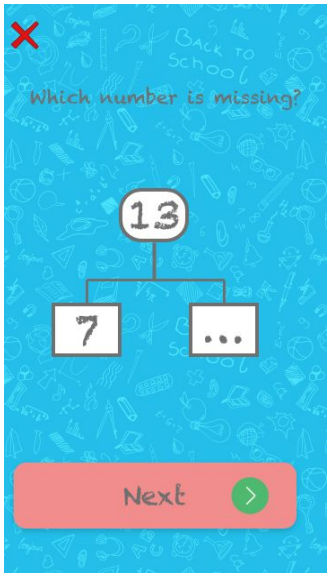


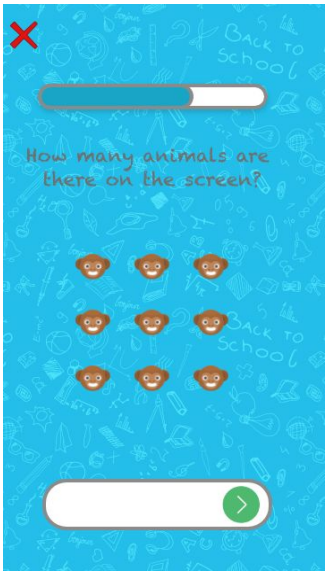
Course overview

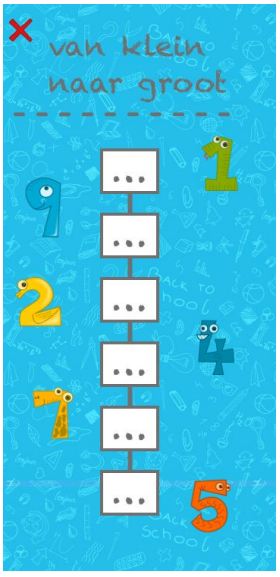


Level course

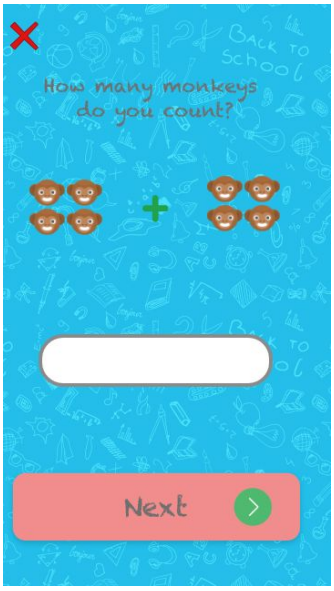
Counting exercises



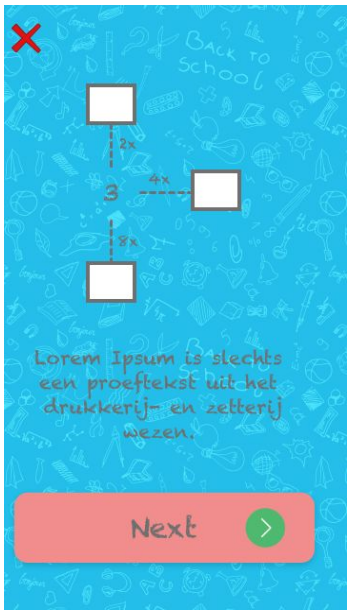


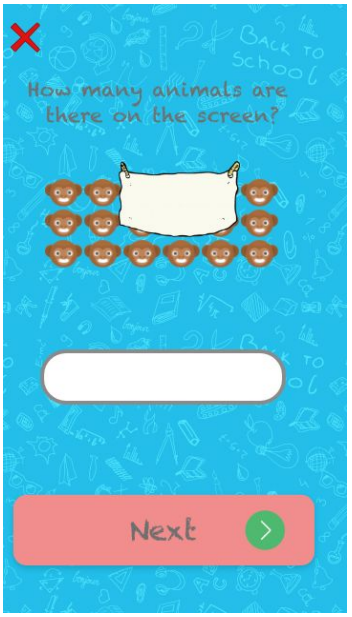


Addition exercises



Multiplication exercises





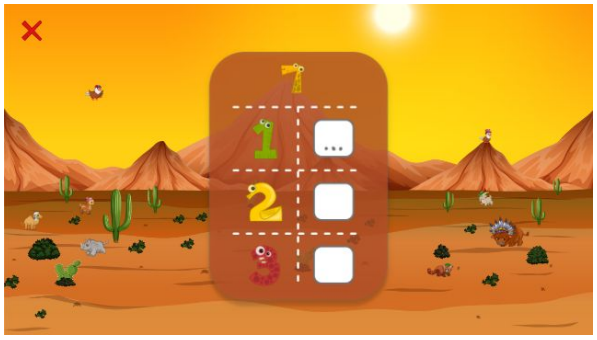
Cheat sheet: friends of ten

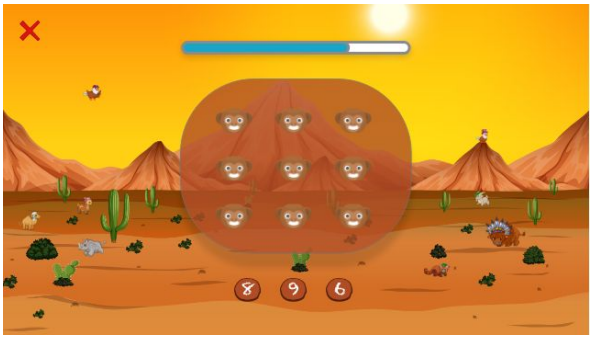
C2. Design of a storytelling application with a reward system

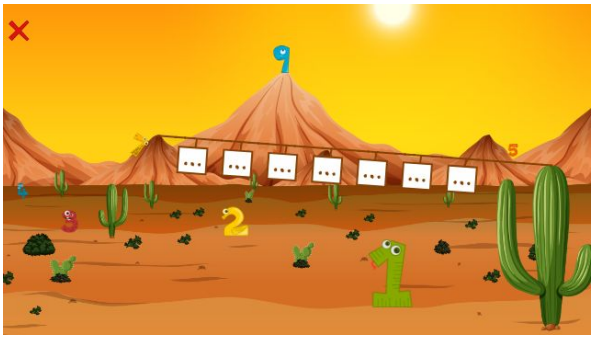
Main Menu

Course overview

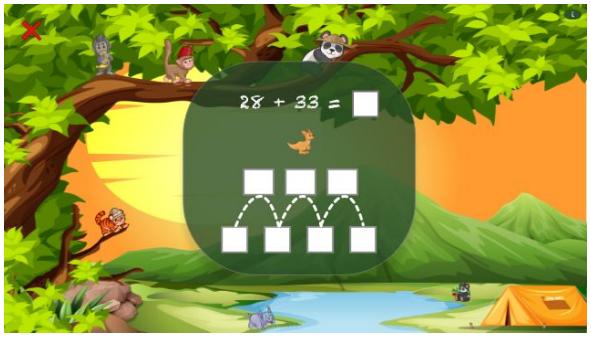
Exercises for counting



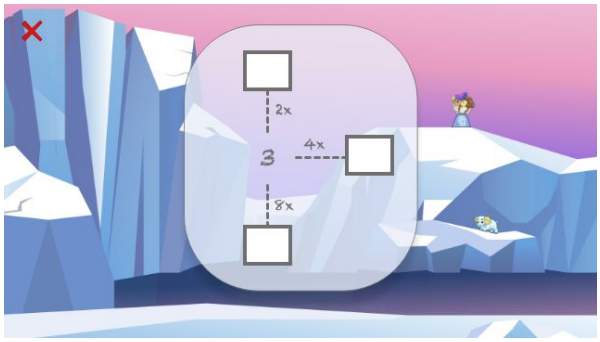


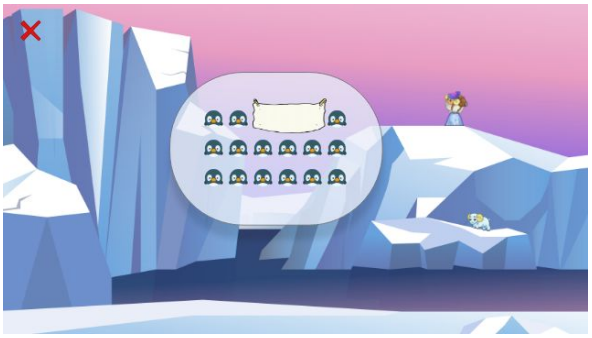


Exercises for addition



Exercises for multiplication

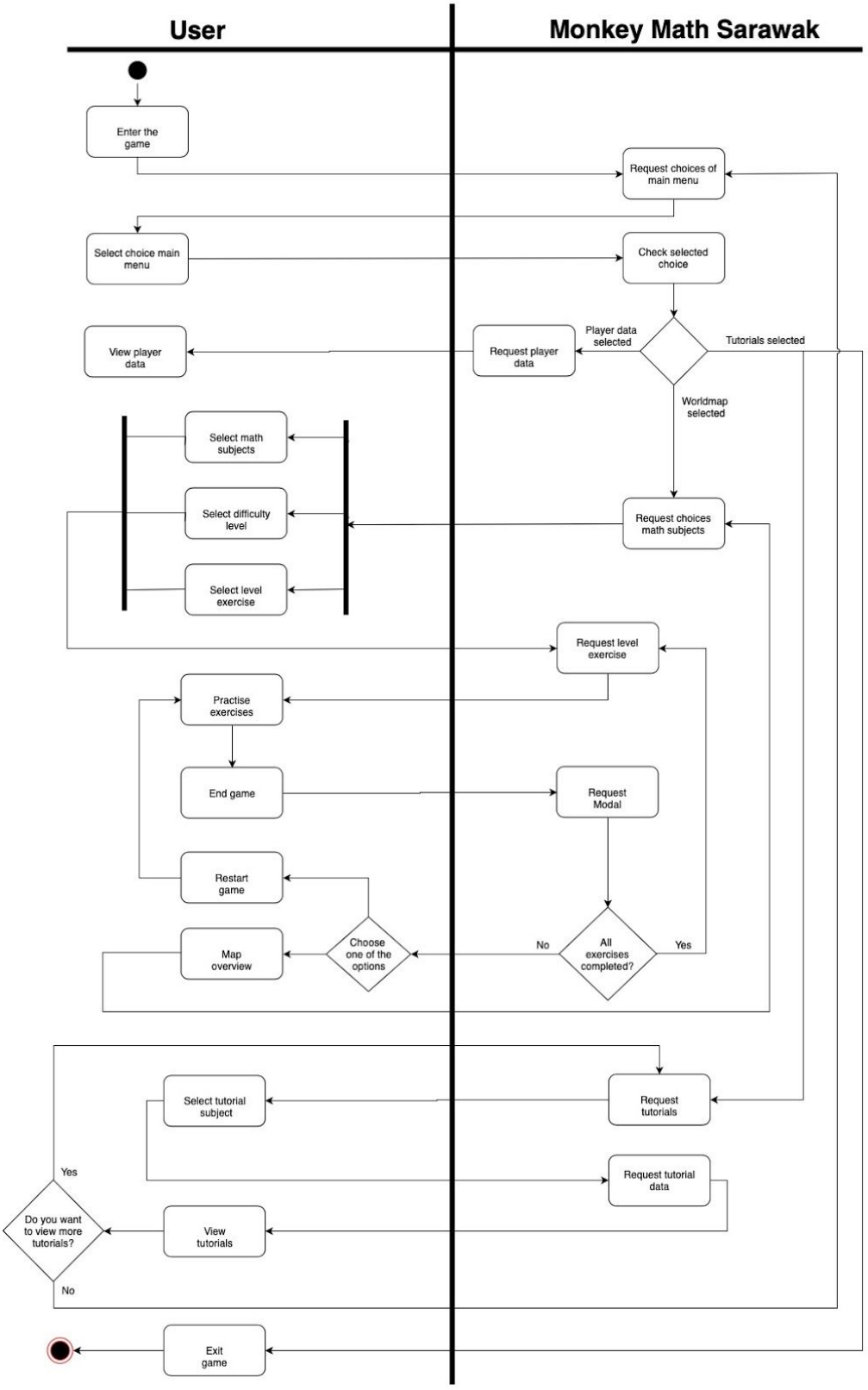




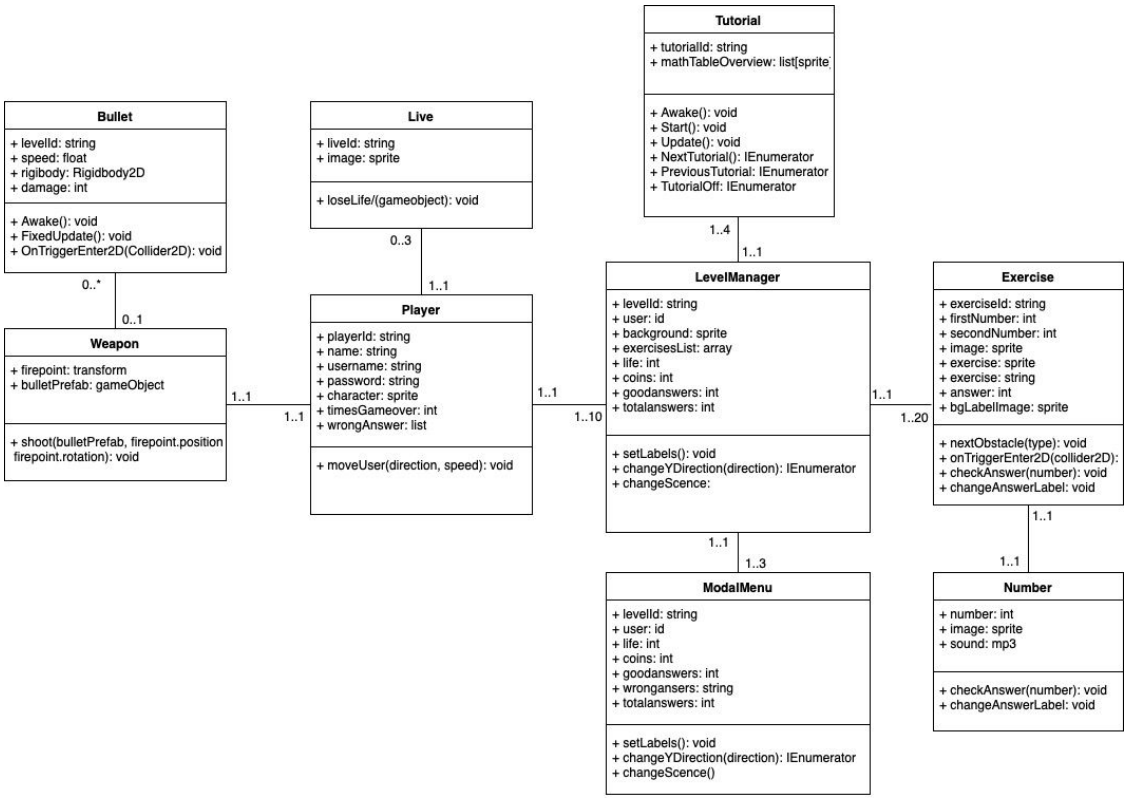
Rewarding board

D. UML Diagrammen

D1 Activity Diagram



D2. Class Diagram



E. Questionnaire during the evaluation

E1. Answers overview questionnaire evaluation with the students

System Usability Scale	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I think that I would like to use this application to learn mathematics	2	2	0	3	8
2. I found the application difficult to use	1	3	2	4	5
3. I think that I would need assistance when playing the games	8	4	0	1	2
4. I found that tutorials were useful for my education	2	1	1	3	8
5. I will use the tutorials when if I make mistakes in playing the game	2	1	2	7	3
6. It was hard to understand navigation through the application	5	8	0	2	0
7. I would use the English translations of mathematical words	1	2	1	2	9
8. The tips who are provided in the application were useful for practicing	0	1	2	5	7

	OLPC	Smartphone
Prefer playing the game on a particular device	4	11
	Yes	**No**
Playing the game in your spare time	11	4

Level	Amount of student
Level 1	3
Level 2	2
Level 3	5
Level 4	2
Level 5	3
Level 6	0

E2. Questionnaire in English

Questionnaire Evaluation Monkey Math Sarawak Students – Pinggan Jaya

Name:

Age:

Level of primary school: ☐ level 1 ☐ level 2 ☐ level 3 ☐ level 4 ☐ level 5 ☐ level 6

Which device did you test the game?

☐ OLPC ☐ Android smartphone ☐ iPhone

Instructions for the following statements, mark one box that best describes your reaction to the application

	System Usability Scale	Strongly Disagree				Strongly Agree
1.	I think that I would like to use this application to learn mathematics	☐	☐	☐	☐	☐
2.	I found the application difficult to use	☐	☐	☐	☐	☐
3.	I think that I would need assistance when playing the games	☐	☐	☐	☐	☐
4.	I found that tutorials were useful for my education	☐	☐	☐	☐	☐
5.	I will use the tutorials when if I make mistakes in playing the game	☐	☐	☐	☐	☐
6.	It was hard to understand navigation through the application	☐	☐	☐	☐	☐
7.	I would use the English translations of mathematical words	☐	☐	☐	☐	☐
8.	The tips who are provided in the application were useful for practicing	☐	☐	☐	☐	☐

Will you use this application in your spare time?

☐ Yes ☐ No

If answered "Yes" or "No" to above question, kindly state why?

_____

_____

_____

Do you have any suggestions for the application?

_____

_____

_____

_____

_____

_____

E3. Questionnaire in Malay

Penilaian Penilaian Kuesioner Monyet Matematik Pelajar Sarawak - Pinggan Jaya

Nama:

Umur:

Tahap sekolah rendah: ☐ tahap 1 ☐ tahap 2 ☐ tahap 3
☐ tahap 4 ☐ tahap 5 ☐ tahap 6

Peranti mana yang anda menguji permainan?

☐ OLPC ☐ Telefon pintar Android ☐ iPhone

Arahan untuk pernyataan berikut, tandakan satu kotak yang paling menggambarkan tindak balas anda terhadap permohonan itu

	Skala kegunaan sistem	Sangat Tidak Setuju				Sangat Setuju
1.	Saya fikir saya ingin menggunakan aplikasi ini untuk belajar matematik	☐	☐	☐	☐	☐
2.	Saya mendapati aplikasi itu sukar digunakan	☐	☐	☐	☐	☐
3.	Saya fikir saya memerlukan bantuan semasa bermain permainan	☐	☐	☐	☐	☐
4.	Saya mendapati bahawa tutorial berguna untuk pendidikan saya	☐	☐	☐	☐	☐
5.	Saya akan menggunakan tutorial apabila saya membuat kesilapan dalam bermain permainan ini	☐	☐	☐	☐	☐
6.	Sukar untuk memahami navigasi melalui aplikasi	☐	☐	☐	☐	☐
7.	Saya akan menggunakan terjemahan bahasa Inggeris dari perkataan matematik	☐	☐	☐	☐	☐
8.	Petua yang disediakan dalam permohonan itu berguna untuk berlatih	☐	☐	☐	☐	☐

Adakah anda akan menggunakan aplikasi ini dalam masa lapang anda?
☐ Ya ☐ Tidak

Jika menjawab "Ya" atau "Tidak" kepada soalan di atas, sila nyatakan mengapa?

_____
_____
_____

Adakah anda mempunyai cadangan untuk permohonan itu?

_____
_____
_____
_____
_____
_____