Establishing requirements for a gamified digital math tool in a South African township primary school

A case study based on gamification and interaction design

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Abstract: This project is based on the desire to increase the understanding and knowledge of digital resource usage within the math education in South African townships. Digital education is considered to facilitate solutions for current shortcomings, yet knowledge and experience of the local circumstances are vital for successful implementation. Interviews, observations and analyses of existing games were used to define requirements regarding design and usability, which were implemented through prototypes and evaluated formatively. This study indicates that the requirements of an educational and stimulating digital tool are the most important and suggest consideration of feedback, gamification features, such as storytelling, as well as the balance of formal and informal settings. Furthermore, user characteristics heavily implies low complexity, few distractions and a logical structure. Requirements of appropriate level, in both language and content, also proved to be crucial. However, this demands further assessment before implementation. The developed tool was perceived as suitable and was accepted as a long-term solution to make better use of the current resources. Although the limited time and the difficulty to comprehend the users’ opinions bounded the conclusions, the established requirements are suggested to provide a solid foundation for further research.

I. INTRODUCTION

In sub-Saharan Africa, 9 out of 10 people do not reach minimum proficiency levels in math and reading [3]. Surprisingly, data reveals that most of the children who are not learning are not isolated from communities but are in fact sitting in classrooms. According to UNESCO, the problem is rooted in the difficulty of retaining the students in school and the education’s quality.

These problems are present in Vissershok Primary School, located in a township in Cape Town, South Africa. The principle expresses a struggle to find enough resources to meet every student’s need with too few teachers in the classrooms. This is in particular seen in the math department, where the students’ knowledge varies a lot which makes it a challenge for the teachers to provide a high-quality education. The SAVE Foundation cooperates with Vissershok Primary School among with a large amount of other schools in similar situations. The SAVE Foundation acknowledges this problem and introduced a collaboration in order investigate a possibility to improve the conditions for teachers and students.

The fundament of this thesis is to examine how education can be improved in order to help more students become motivated and appreciate math, using what’s already in the classrooms. The study aims to examine what requirements are important when a gamified digital math tool is developed in this context and examine if the tool contributes to a more resource effective education. The goal is to help fulfill students’ aspiration within the subject and the result is intended to both contribute with a customized math game for students at Vissershok Primary School and propose requirements, vital in this context, for similar projects in the future.

II. RESEARCH QUESTION

The research question of this thesis is: “What are the requirements when developing a gamified digital math tool in a South African township primary school?”. Additionally, to get a broader perspective of the effect of digital learning the question, “Does the implementation of a digital tool in a South...
African township primary school contribute to a more efficient resource distribution?”, will be examined.

A. Specifications & Limitations

The South African primary school curriculum will be taken into consideration, although this study will not focus on pedagogy. The evaluation process will consist of the exploration of what requirements regarding design and usability are important, not if the digital math tool improves the math results of the students in Vissershok Primary School. To limit the context and include the local characteristic, this project focuses solely on an unprivileged primary school in Cape Town, South Africa. The target group is defined as students attending grade four to six at Vissershok Primary School.

III. BACKGROUND

A. South Africa & Education

South Africa is located in the sub-Saharan Africa. The population is 57 million, where 29% is under the age of 15 [4]. This means 16.5 million children are, or soon going to, school. According to OECD rankings, which rates countries on the skills of math and science of 15-year-olds, South Africa came second last out of 76 countries [5]. This number is even lower in townships, where the education has even more shortcomings like a large gap in the student-teacher ratio and few education resources [6].

B. Digital Education

In today's high technological and global society numerous tools with the goal to educate math have been developed and a general idea that technology could help enhance learning have been established. One of the advocates, Dr. Lazar Stošić, states that implementation of educational technology could help students to thrive at their own pace, independently master teaching materials and test performance immediately [7].

Some research state that digitalization of education builds gaps in classes in the education sector in developing countries as it is only accessible to those who can afford it [8]. However, digital education is also considered to have potential to decrease the gap between urban and rural areas of developing countries [9]. Helen Zille, former Head of Government of Western Cape, explains the opportunities of this progress and why e-learning is important to the province, “E-learning will assist us to tackle some of the problems we face, including increasing access to quality education in disadvantaged communities, providing support for struggling learners. [...] It will also provide learners with the skills to participate in our increasingly technology-based economy in the future” [10].

C. Interaction Design

In recent years, the governance, numerous companies and organizations in South Africa have made investments in digitalization and innovative e-learning. A study, which examined digital services for education in Africa, found that the projects most likely to be adopted by the target public was the ones that fit within the existing practice [11]. Therefore, they suggest initiatives should aim to adapt the technologies and teaching content to specific local characteristics. “The Mobile Learning for Mathematics project” [12] highlighted that inequalities are still prevalent in South African schools. This underlines the importance to understand the context and the users of the tool. With the use of interaction design it is possible to design for a certain user experience, which is the motive for this project being based on interaction design.

Interaction design is the practice of designing interactive tools, where the designer’s focus goes beyond the tool itself [1]. The main goal is to increase positive aspects, like lust and engagement, and decrease negative aspects such as frustration and irritation. Interaction design aims to result in an efficient, intuitive and practical interface. The process consists of identification of needs, formulation of requirements, production of prototypes and evaluation. The determination of requirements is considered as a vital part of the user centered approach and acts as a foundation for the following design and development.

D. Gamification

In order to examine how to increase motivation through a digital math tool, this project is also based on gamification. Gamification is the collective name for when tools for game elements are used in non-ordinary game context. The purpose is to improve the user experience and increase the users’ effort. When gamification is incorporated in education, it is not equal to simply playing games or the addition of scores, medals and scoreboard as reward system, but it is about to understand how games create engagement and how it could make learning more efficient [2].

Gamification is proven to be effective to motivate people to do assignments which are considerate to be complex, complicated or unengaging. Palmaquist state that the clear goals, rules and visible progress used in gamification are elements that schools could learn from. Research shows that students with more insight of their learning process become more engaged and get better results [25].

E. Resource Distribution

The development of a digital math tool may also change the distribution of resources and possibly make better use of the school’s assets. The findings of a project examining introduction of digital tools in South African education indicated that a digital tool made students less dependent on a teacher [12]. By increasing the use of existing technology, human resources could be more focused to where it’s needed the most. A study [13] examining the cost effectiveness and efficiency in digital learning declares that quite few reports have been focusing on this matter, but instead narrowed it down to the user, the provider or the society. This is described to lead to a potential problem when implemented, since it might imply a solution which is in the long run not favorable for any part involved.
IV. METHOD

A. Data Collection

Fig. 1. Summary of the data collection.

Semi-structured interviews were conducted at Vissershok Primary School with three math teachers of the target group. The interviews consisted of exploratory open questions to give a vast qualitative understanding of the math education, technology usage and current resources at the school. As a complement, direct observation of the users was also conducted by assisting teachers and volunteers by tutoring the students. Direct observation is important as it is considered to provide an in-depth understanding of the context of the user activity [1].

Next, a state-of-the-art analysis and a think aloud on existing games was made. This was performed to get a better understanding of existing solutions and how the students interact with them. A state of the arts-analysis was made on eight computer-based math games; Treasure Quest, Far out Functions, Number bonds to 20, Meteor Multiplication, Candy stacker, Toon Ballonz and Super Math Buffet. The think aloud was made on eight students. The students were asked to explain what they experienced and their thoughts. Although, the think aloud method is a useful way to understand on what goes on the user’s mind, it can also be challenging to make the user feel comfortable and speak [1].

To get further input from the main users, a workshop was held where the students acted as game designers. This was inspired by the method used in the paper “Gamification of Elementary Math Learning: A Game-Designer Role Playing Experience with The Kids.” [14]. The study found that the method of involving the students in the development process leads to an increase in usability and creates a game designed for use in the specific context.

Before defining the requirements, personas and pain points were identified. User personas are detailed descriptions of the intended typical users, which represent a summary of real users who participated in data collection [1]. Based on the data collection and the personas, six pain points were defined, which lay the groundwork for the requirements. Both functional and nonfunctional requirements were defined, as suggested by the method of interaction design. Establishing requirements has two main purposes. The first is to understand the users, their activities and the context in an adequate way in order to support them achieving their goals. The second is to form a solid foundation for development and design [1]. The requirements were rated on importance based on the primary and secondary user personas and further evaluated by formative evaluation.

B. Formative Evaluation of Requirements

Fig. 2. Summary of the formative evaluation of the requirements.

Formative evaluation is defined as “Evaluation performed during the design process to ensure that the product fulfills the established requirements and continuously meet the user’s needs” [1]. To assess the requirements in a lower abstraction level a questionnaire with closed questions was used. As no quantitative evaluations were performed before, and it is preferable to combine different data collection methods to cover contrasting perspectives [1], the goal was to quantitatively measure preferences connected to each requirement. The questions were answered by the students, volunteers and teachers, accompanied with explanatory photos and were formulated as a choice between two alternatives (see Appendix D).

To further investigate the implementation of the requirements two hi-fi prototypes were developed and evaluated by user testing combined with informal interviews. The two different prototypes assisted in comparing and contrasting conceptual and concrete designs. However, after this evaluation one superior design was chosen to be developed.

The chosen prototype was developed into a complete math game and the goal of the iterative testing was to evaluate the relevance and details of the requirements in the user’s natural setting; a tutoring session with students and volunteers (see Appendix E). The student’s reactions, feelings and opinions were observed and semi structured interviews with open questions were conducted with the students, volunteers and a teacher. The findings from each session were considered and improvements applied.

At last, a final design was proposed and tested by the users through qualitative and quantitative evaluation. The students played the game with volunteers from start to end. The students’ reactions and opinions were observed. After the final test session, the volunteers, together with the students, filled out a questionnaire. All math teachers involved in the project played the math game and through qualitative interviews the relevance and details of the requirements were acquired.

A key aspect of user testing is the number of involved users. As comfort selection was applied throughout the study, due to the circumstances and obligation to the school, this number varied. However, it was kept within the range of five to fourteen, which is advised as acceptable numbers [1]. Compared to evaluation in controlled environments, testing a specific hypothesis and assemble in depth knowledge of why the users react and interact a certain way is more challenging in a natural environment. However, evaluation in natural settings reveal valuable insights of the opinions, interaction and integration in the intended environment in order to understand how successful the tool will be. Therefore, it is particularly useful when evaluating new products and prototypes [1].
C. Resource Distribution

After the implementation of the math game, interviews were held with the same three math teachers as in the beginning of the field study. Open questions explored if the implemented game will be used considering technical hurdles, educational structures and the low collective understanding of technology are present. Additionally, it was examined if the math game is a long-term solution and whether it can be adopted with minimal requirements for external support.

V. THEORY & EARLIER STUDIES

A. Interaction Design & South Africa

South Africa is called “The Rainbow Nation” as it is a mix of several cultures and religions like Zulu, Xhosa, Hindu, Muslims, Pedi and Afrikan [16]. The user population is diverse when it comes to education and technological expertise and this, together with the fact that South Africa has more official languages than any other country, form a unique environment and sets the tone for the interaction design researchers and practitioners in South Africa [17].

According to research [18], culture is a factor that needs to be taken into consideration when developing a digital tool as culture influences people’s perception and decision making. An article [17] examining interaction design in developing countries suggests that, “Instead of redeploying technologies developed for industrialized countries in developing regions, Human Computer Interaction methods can be employed to design technologies that address local contexts more closely”. However, the numbers of software engineers in South Africa with education within the field of interaction design is notably low. The knowledge of standards for usability and user centered design is considered absent in the industry [19].

A similar study to this, which examine gamification and mathematics for primary students in rural Sri Lanka, also confirms the shortage of studies of interaction design focused on educational technology in developing countries [20]. The writers developed a customized math game for the students as no such games were found. It was identified that even though the learning concept remained the same, the complexity of the tasks confused them and obstructed the interaction. These findings highlight the importance of including user characteristics and adjusting for the user’s previous experience and knowledge. In general, beginner-users require step by step instructions and limited interaction whereas expert users demand flexible interaction and more extensive control powers. An interaction based on conversation is suggested to fit inexperienced users as it resembles familiar situations [1].

B. Gamification & Motivation Sources

When designing to increase the motivation in the classroom, it is important to understand that people are driven by different sources of motivation. Intrinsic motivation often represents self-fulfillment, happiness or self-respect, in contrast to extrinsic motivators which often appears like social reputation, money or peoples’ appreciation [2]. Extrinsic motivators, such as scoreboards, points and medals, are commonly used in gamification to encourage the player. However, gamification should also strive to increase the players interest to achieve a skill and strive for self-fulfillment. This suggest the need of intrinsic motivators. Additionally, in the school environment extrinsic motivated students tend to seek the specific knowledge that is premiered on tests, whereas students with goals in the intrinsic sphere often strive for more all-around knowledge, which leads to deeper knowledge [26].

A concept of gamification, which improves the students’ focus ability, is storytelling and the use of characters, challenges and conflicts. Storytelling is in human nature and makes it easier for the mind to comprehend and remember information, especially as the story has a start, several defined parts and an ending [2]. Games, which let the player be a part of the story, give the student a bigger meaning and enhance learning.

C. Stimulating Learning Experience

Feelings are engaging and gamification strive to benefit the positive feelings to create motivation and commitment [2]. Particularly individuals with intrinsic motivation are often emotionally driven. Feelings of success, creativity, lust, curiosity and pride can be activated through elements as competitions, roles, praise and feedback. Furthermore, when students feel joy, meaningfulness and safety, the learning progress increases, which in long term also increase the student’s health and wellbeing. In contrast, all form of negative feedback has proven to undermine the students feeling of competence, which in long terms prevent their learning [2]. This suggest that gamification should always encourage effort, no matter how big or small it may be, instead of enlighten failure or using punishment.

The report “Motivational strategies to enhance effective learning in teaching struggling students” shows that many students experience a strong fear to fail and highlights the aspect of the allowed number of tries for a task [28]. There is however a chance of the players taking advantage of the trial and error element and guess, without much effort in terms of problem solving, which was observed in a case study of computer games for math [21]. The research [21] did nevertheless found that participants tended to invest more when the task was considered to be within their regime of competence or a high-stake for accomplishing the goal. This suggest that the element of levels may be useful to encourage learning engagement as well as the need for appropriate math level.

Feelings are also central when examining the user experience in interaction design. The style of shapes, colors, balance and their combination may affect emotions [1]. Bad design may result in the user feeling stupid or insulted, whereas attractive design tends to result in more patience users. Moreover, Palmqvist found that excitement tend to increase when the interaction allows the users to make choices by themselves. The choices should not be too many either as it could lead to uncertainty, stress and dissatisfaction [27].

D. Feedback & Rewards

Humans like to follow their progress and not being able to orientate strain the human orientation ability and increases the risk of lost interest [2]. The cognition and education researcher Mikael Jensen [2] found that when giving valuable feedback, it
is important to be descriptive and specific rather than evaluative and general. The feedback given in school is often text based, given long intervals apart, extensive and mainly focuses on performance. Gamification provides tools that could present visual feedback given with shorter intervals. The feedback of games often contains less information at a time and could be given for just starting or finishing a task regardless of the performance. It is important to keep in mind that games and education have different tasks and goals. The main goal for games is to motivate the players and get them to like the game, whereas education strive to give the student’s knowledge [2].

E. Formal & Informal Learning

The different characteristics of education and games also lead to a challenge of how to develop gamification that seamlessly interact with education. A study examining how students interact with computer math games and a game-based learning environment, found that among some participants the excitement of playing games turned into disappointment when they realized that they were learning games. This was due to an experienced separation between playing games and learning [21]. The study suggest that learning can only be engaging when it is concealed within games and thus unconscious to the learners. Although the way informal learning is associated with positive coded aspects is also recognized by Viberg, Andersson and Wiklund that some representations of informal learning can gain the idea of designing or specifying the learning process [22]. This suggest that the student’s perception of formal and informal settings must be taken into consideration and may affect their interaction with the digital tool.

F. Challenges in Resource Distribution Efficiency

When developing digital technologies in South Africa for teaching and learning purposes technical hurdles, educational structures, and the lack of collective understanding of technology, are considered to be the largest obstacles [11]. A study [11], which analyzed the reactions of teachers that encountered arrival of computers in numerous African schools, revealed that a considerable number of teachers struggled to adopt teaching methods. An aspect to prevent this, which is found to foster the development and success of digital tools, is the involvement of the principal and other members of the educational system [23]. Another challenge is to develop replicable, low cost approaches and programs to be adopted with minimal requirements for external support [24]. However, the expenditures do not necessarily involve extra spending and by offering an improved service cost could decrease in the long term. Furthermore, positive externalities, as user behavior may impact the wellbeing or behavior of others, and long-term collaborations with universities, companies and organizations can be mutually beneficial.

VI. DATA COLLECTION

This section presents the results gathered in the data collection of the field study.

A. Interviews

All three math teachers expressed that most of the students wrestle with basic math skills and that they do not understand how math connects to real life. Teacher 1 said, “A lot of my kids ask; why math? I try to teach them why it is important, why we need math. It is about the application.” Additionally, they stressed that their students are on different levels in math and computer skills, even though they attend the same class. Hence, their job becomes difficult and time consuming. They also experience the curriculum as overwhelming and since some students need a lot of repetition and reinforcement, the task of covering it all is considered to be impossible.

When it comes to digital tools and gamification all three teachers are optimistic and trust it would make their job easier. Teacher 1 believes they has the potential to explain another dimension of the concepts he teaches in class and that the kids would enjoy it. Teacher 2 express similar thoughts and highlights the visual aspects. Although teacher 1 mentions that he does not know a lot of appropriate games himself and that some teachers struggle with technology, he argues that technology is worth investing in and says, "We are in this age. If you cannot do it, you are gonna have to learn how to do it". It was also highlighted that the students are seldom users of technology like computers and smart phones, and that the internet at the school not always works. Teacher 3 is hopeful and believes that there are no cons to introducing math games in her class, as long as the games are interactive.

Another challenge mentioned in the interviews are the language barrier as Vissershok Primary School is an Afrikaans speaking primary school. Teacher 2 also highlights the potential risk of the kids not being able to separate informal and formal settings and consequently not take the game seriously. Teacher 2 suggested the game including content similar to what the students are used to, whereas teacher 1 proposed problem-solving exercises. Teacher 3 stressed the significance of this school’s students being from the township Dunoon. "In the townships survival is the priority - education is not. Some students understand that education is important, some need to focus on how do get food today, or where they will sleep tonight". Furthermore, teacher 3 suggested the game should include rewards as the students need praise and positivity, as they are used to be put down.

B. Observation

Two hours a day, four days a week, a group of volunteers help the teachers by offering one to one assistance in math, English and computer skills. The volunteers did not receive prepared material but had to examine the students’ knowledge level and then suggest suitable exercises themselves. The students’ difference in math levels was confirmed and an uncertainty using computers was also detected. The majority hesitated the take own initiative and struggled to use the mouse and keyboard correctly. Furthermore, all information around the application, like pop-ups from other programs, seemed to create great distraction and made it difficult for the students to navigate. See appendix A for photos of the school and computer room.
C. State-of-the-Arts Analysis

In almost all games, extrinsic motivators like score, prized and high score lists were present yet represented differently. Some games presented the score at the end of each level, whereas other games gave instant feedback. The majority of the feedback was text based, displaying “Correct”, or “Wrong, try again” after each solved question, but feedback in the form of stars and thumbs up occurred in Super Math Buffet. Most games included general feedback, not descriptive.

Feedback, rewards and appealing colorful interfaces contributed to a more stimulating experience. Meteor Multiplication did include vague elements of storytelling, although no characters nor conversations were used, and the story did not influence the game. All games were solely about solving non-complex problems with basic interaction and therefore was no game considered to strive for deeper knowledge nor purpose. Some games enforced waiting between answering math problems and contained misleading icons and instructions. Therefore, they were experienced frustrating to play. Additionally, the game Number Bonds to 20 was perceived to be monotonous as it included repetition of the same exercises for an excessive amount of time.

D. Think Aloud on Existing games

1) Meteor Multiplication

The students struggled in understanding what to do in the game, which made them frustrated. However, that changed when the volunteers explained the game to them. It was implied by the students that the game was too formal and tedious as the tasks of the game were similar to the ones in class, even though the game had a story; saving the space center from meteors. The game had a time limit, which made some students, suggestively those with strong intrinsic motivation, stressed and unfocused. Meteor Multiplication was too hard for most of the students, even though an easy difficulty level was chosen. This led to the students making effortless guesses and they did not care about their score nor the descriptive feedback given at the end of each level.

2) Far Out Function

Most students did not enjoy playing the game as it was too difficult for them, mainly because the game required the students to perform several tasks to finish a round. However, some students, perhaps those with extrinsic motivation, kept playing the game without asking for help. The colorful and playful interface, and the game being a mix between informal and formal learning was appreciated by the students. Additionally, the game did not include text-based feedback, which confused the students on knowing when they did something right or wrong.

3) More or Less

Most students did not struggle to play the game as it had low complexity, both design and math content wise. Although it was noticed that some students had a difficult time to grasp the meaning of icons and buttons, which created discomfort. The game included both positive and negative feedback in form of score and stars, which motivated some students to perform better, whereas some students did not notice it. Some students wanted to play the game again as it was easy and fun. Additionally, as nine alternatives were given as answers the volunteers noticed that some students guessed, instead of solving the problems. See appendix B for photos of the games.

E. Brainstorming Workshop with the Students

Three out of four students prototyped a car racing game that used money as the math feature (see Appendix C). Money was received when winning a race and was supposed to be used to sell, buy and upgrade cars. A storyline, characters and interactive conversations with the player signified that the students are stimulated by storytelling as a game feature. Furthermore, when a game was won the player would get a gold medal as a reward, which shows the students wish of extrinsic motivators. The fourth game that was presented included fruits where the player had a certain amount of time to complete exercises similar to the ones from class. The student expressed that this game would help in understanding math better as it had 100 levels and would cover everything in math class.

F. User Personas

1) Primary Persona – Student

Niebe is 12 years old and attends grade six. Niebe is not comfortable in using computers and only use them at the school together with volunteers, maximum once every second week. At the tutoring sessions with the volunteers he always proposes to look at photos of dogs instead of doing the exercises suggested by the volunteers. He struggles with math and does not understand when he would ever use it in real life. He failed the last test, but it does not bother him because so did his best friend. His parents have a food store, but when Niebe grows up he wants to become a doctor.

2) Secondary Persona – Teacher

Mrs. Nkosi has been a teacher at Vissershok Primary School for five years and teaches grade five math. 54 students attend her largest class and she finds it difficult to give enough attention to each student and keep everyone’s focus. She is comfortable in using computers and believes that technology would improve the students’ ability in math and make the learning better customized for each individual. The problem is that Mrs. Nkosi cannot find a suitable program to use, since most of the games would be too difficult to understand for her students.

G. Pain Points

- Most student lack basic math knowledge.
- Most students do not understand why math is important in real life.
- Most students are not comfortable using computers.
• The teacher to student ratio is very low.
• The teachers’ workload is too big.

VII. REQUIREMENTS

A. Functional

Functional requirements are those which state what the system should be able to do [1]. The main goal of the digital math tool is to be educational and corresponds to what is taught in class presented in an easier and more visual way, as highlighted by teacher 1 and 2. As discovered in the interviews and state-of-the-arts analysis it is important that the game is interactive with the students. Furthermore, as seen in the brainstorming workshop the students are driven by different motivational sources. Additionally, the game must be stimulating enough for the students to use the tool without losing concentration in order to decrease the teachers’ workload.

As discovered in the state-of-the-art analysis, all games include positive, negative or general feedback, as well as known research stating descriptive feedback is important in education. Additionally, during the think aloud it was noticed that feedback is important for the students to understand if they are doing something right or wrong. Hence, feedback is a crucial requirement. Based on the theory of gamification in an educational environment and teacher 3’s insight of the students’ demand for positive feedback, the requirement is limited to positive feedback.

Moreover, it was identified during the think aloud session that the students struggle in understanding instructions and how to navigate the game using icons and buttons. Furthermore, as the students are beginner-users a requirement must be clear guidance throughout the game, with intuitive instructions and an appropriate language and language level. Additionally, it was observed that the students battle to understand how to use the computers and do not take own initiative. Therefore, a logical structure is essential.

B. Non-functional

The non-functional requirements traditionally define the limitations of the system and its development [1].

1) Data

Content wise, the difficulty level must be adjusted to fit the students’ knowledge in math. As discovered in the interviews and observation the students’ knowledge does not corresponds to the curriculum. Choice of difficulty level encourages the students’ confidence and avoids frustration, disappointment and effortless guessing, as seen in the think aloud workshop. Additionally, the students’ knowledge varies widely within the classes and consequently a requirement to use tasks on different difficulty levels is needed.

2) Environmental

A crucial requirement is that the tool can be used at the computers of the school, and therefore it must be compatible with Windows 10, the computer’s processor and memory allocation. As the internet connection is inadequate, the tool is required to function offline.

3) User Characteristics

As discovered through observation and the think aloud workshop, the students feel insecure when using computers and the majority have little experience with digital education. The tool must be adjusted for the users’ background and therefore contain low complexity with step by step instructions. The students are considered as beginners and the computer interaction must be easy to understand even if it is used less than once per week. Furthermore, it is vital that the digital tool has few distraction events, like pop-ups and texts in the math game, as the students get distracted while they play the game, which was observed in the think aloud workshop.

4) Priority for the Users

VIII. FORMATIVE EVALUATION OF REQUIREMENTS

A. Low-fi Prototype

Fig. 3. Priority level for each user, where 1 represent a requirement which is crucial, and 5 less so.

B. Hi-fi Prototypes

One of the two prototypes was a basic math game programmed in Java. It focused on repetition of multiplication and problem solving, were the user were asked to answer one question at a time and became rewarded with score if answered correctly. The other prototype was an adventure math game.
with challenges and storytelling made using RPG Maker MV (see Appendix E). The programs were tested on students, volunteers and one teacher.

1) Conceptual Design
A conceptual model explains what the user could do with the tool and what concept is needed for the users to understand how to interact with it [1]. During the testing it was quickly noticed that the students favored the adventure game over the basic math game. This was as they thought the game was more entertaining, interesting and not like "a normal math class". The volunteers agreed whereas a math teacher had objections. Teacher 1 believed that the adventure game needs to be more formal and include repetitive exercises like the basic Java game to be able to complement his teaching.

2) Concrete Design
Additionally, the Java math game was made in six versions to examine concrete design solutions. Concrete design cover questions related to user characteristics and context [1] and the ambition was to further examine aspects like language, type of feedback and type of math problems preferred, which were not agreed upon in the low-fi questionnaire.

During the testing of the different versions of the Java math game the preferred language was identified as Afrikaans, although not all students agreed. The volunteers, on the other hand, favoured English as they thought it might be difficult to help the students if the game was in Afrikaans. Regarding feedback, no significant difference was perceived between general and descriptive feedback. Although, it was discovered that the students preferred receiving instant feedback instead of feedback after each session. The question of how to formulate math problems was not clarified. Most students wanted normal calculation problems, as that was what they are used to, whereas teacher 1 and the volunteers desire problem solving exercises, as the students need to practice that.

Moreover, it was observed that the usage of mouse or mouse and keyboard did not have an impact on the complexity of the game as long as the remaining computer interaction was kept basic. It was suggested by teacher 1 to restrict the player’s movement even more, by making the walking in the game automatic, to make the complexity of the game more appropriate for the students.

Moreover, it was observed that the student what the story in the game was about. It was suggested that the story in the game be able to complement his teaching.

3) Summary of Prototyping
Conclusively, based on the hi-fi prototype testing it was decided to solely focus on developing the adventure game using the RPG Maker MV yet taking the pros of the basic Java game, like formal exercises, a clear interface and low complexity, into consideration. Furthermore, it was decided to remove the requirement “clear icons and buttons” as it not longer as relevant as the adventure game guides the player through the game with interaction through conversation instead of buttons and icons. It was determined that the game should be able to be played in Afrikaans and in English.

Moreover, to assess the math skills of the students two math tests was designed with the exercises proposed to be in the math game. Each test was taken by 30 students and the result was used as the base for the difficulty level of the game. It was discovered that the math level was much slower than expected, so all difficulty levels were made easier.

C. First Testing of Complete Game

1) Functional
According to teacher 1 the game is educational and corresponds to what he teaches in class and is therefore a suitable complement to his teaching. Additionally, he thought that the game encouraged creativity and showed the students a different visual representation of math. Although, during the evaluation with the students it was not always clear to the student what the story in the game was about. It was suggested by the volunteers that the story, together with the player’s progress information was repeated more frequently to the player.

Some of the students did not consider the consequences of getting questions wrong negatively, as they were too excited to play the game and did not mind replaying parts of the game. However, one student did get more motivated to answer the questions right when mistakes implied consequences. Furthermore, one student thought that the time limit and score requirement was good and similar to situations in class, which the student wanted to practice. Another student pointed out that it did not feel as bad to do something wrong in the game compared to in class, although he though he tried as much in both situations.

It was discovered that a different division and multiplication symbol is used in class than in the math game. Furthermore, did teacher 1 suggest to short down the texts in the game, as the students are not used to read a lot. This was also observed during the testing. Moreover, everyone did state that they believed that the game had a logical structure, especially because of the four crises that needed to be solved, the guidance and the usage of conversation interaction throughout the story.

2) Data
The teacher concluded that the three difficulty levels are appropriate, as they are based on material used in the grades which will play the math game. Two students got frustrated while they played the game as they thought it was too difficult to meet the time limit, however after using pen and paper it went better for them and the frustration withdrew. A volunteer suggested that the characters in the game should encourage the student to use pen and paper.

3) Environmental
The game worked perfectly on the school’s computers and the volunteers highlighted that it was great that the game was not internet based, as there always is a problem with the internet connection.

4) User Characteristics
Some students struggled to navigate the game in the beginning. However, they found out by simply trying or had a volunteer or classmate to help them. Teacher 1 found the math game stimulating as he thought it was imaginative and exciting. All students thought the game was fun and all of them would play the game again, which implies it is not only based on extrinsic motivation. The game took around one hour to finish.
The students did not get distracted by anything in the game as all the features like a menu and player information were removed. This was done since it was noticed that the students did not know what to do when accidentally opened extra features in the game.

D. Second Testing

During this iteration an Afrikaans game version was played, and the story appeared to be clearer to the students than when played in English. The added progress reminders may also have contributed to that result. Before the second testing the text was worked through an additional time to achieve an even more vigorous and clear text. Because of that and the fact that the game could be played in the students’ mother tongue fewer comprehending problems were identified. More students seemed to consider consequences in the game, compared to the first testing and when a student was asked if he knew what would happen if he answers incorrectly, he answered: “The people in the village will starve”. Additionally, after the operation symbols were changed, the students were not struggling as much with understanding the math problems.

Furthermore, it was proposed by the volunteers and teacher 1 to include pedagogic photos to the math problems, to make the problems clearer and more educational, especially by the problem-solving exercises. It was also noted by one of the volunteers that one of their students managed to stay focused for 1.5 hour, which otherwise never happens. This indicates that the game includes appropriate motivators.

After the second testing, the school received new computers. Unfortunately, it turned out that these had less processor capability and not all parts of the game worked properly anymore. For instance, the timer had to be removed and the back-end logic of some events had to be simplified.

E. Final Design

1) Qualitative Evaluation

Photos were added to the game, as requested by the volunteers and teacher 1. This implementation was appreciated by the students, as some of them used the photos to solve the math exercises. It was nonetheless still observed that some students struggled to understand what to do in the game, as they did not read the instructions. One student said that the game had too much text and that the best parts of the game are the ones with basic math exercises, like simple multiplication problems. Another student noted that the problem-solving exercises are difficult, like the math riddles, as it is not similar to the exercises they do in class. Although, teacher 1 stressed that it is important for the students to practice reading math comprehension and do exercises different from the math book to be able to pass the regional examinations.

Furthermore, it was noted by one of the teachers that the game seems user friendly and adapted to the students’ computer knowledge. One student was asked what he thought of the fact that the player has to do more exercises if they to something wrong and answered: “I think that is fair. If you do not try you should get punished”. Teacher 1 concluded the final design evaluation with pointing out, “It [the math game] speaks to the students. It speaks to the basic math, and that’s all I want. You see they want to play the math game instead of listening to me or writing in their books. That is really good”. See appendix F of photos of the students playing the game.

2) Quantitative Evaluation

![Fig. 5. Volunteer’s answers to the questionnaire, where 1 is “do not agree at all” and 5 is “fully agree”.](image)

A video of the game can be found in appendix G. For a summarized explanation of how each requirement was implemented, see appendix H.

F. Resource Distribution

Teacher 1 stated that the game has appropriate computer interaction, both for students and other math teachers, which he believed will lead to the game being used at Vissershok Primary School. Furthermore, teacher 1 noted that even though he does not believe that the game will make his teaching easier in terms of work to do, the game will explain math concepts to the students in a different way, which may lead to them learning better. Teacher 1 suggested that this might eventually lead to him being able to walk away from revising basic concepts, and instead focus on working through the curriculum. This was acknowledged by all the teachers although Teacher 2 added, “I will definitely use this game as a complement to my teaching by letting the volunteers play the game with the students”. Teacher 2 also suggested that the game can be played collectively in class, as the school does not have enough computers for each student in one class to play the game alone. Teacher 1 proposed that he might let the more struggling students revise the basics concepts with the math tool while he goes through more challenging theories on the board.

Teacher 1 was certain that the management and regional chief will support the use of the math game and has a goal for the game to be implemented in the school’s policy. He had a vision of the game being part of their math program and a building block in what the volunteers use when helping out at the school. Hence, he stated that the implementation of the math game at the school is a long-term solution, especially helpful for the most struggling students. Although, the teachers wished
there would be a way to see the students’ progress in the game because now volunteers record students’ score on paper. This is not resource efficient; however, an implementation of an administrator view of the game was not a possibility in the RPG Maker MV. Lastly, all three teachers did not see a problem in installing or using the game after developer support is no longer present.

IX. DISCUSSION

A. Evaluation of Final Design

The qualitative evaluation of the final design indicated that the story, together with the interactive conversations and characters, are considered valuable and the tool is suggested to trigger both extrinsic and intrinsic motivators. Even though some of the students and teachers did not always agree in every aspect, for instance regarding the use of problem solving and text, the priority levels of the requirements acted as a guideline.

The results of the quantitative evaluation of the final design were not surprising as being a logical consequence of the previous testing, which proves the process of assessing the requirements to be fruitful. Even so, one question that received a lower score than predicted was whether the student cared for the story or not. This could be explained by the struggle of reading and comprehending the story or the fact that other elements of gamification were more appealing. Yet the story is fundamental in the tool and considered to contribute to a high average score of the requirements stimulating and logical structure. Therefore, the use of storytelling in this context is acknowledged to be useful.

B. Fulfillment of Aim

The project aimed to fulfil students’ aspiration within the subject and the final design is expected to reach the expectations of being educational. As explained in the theory, gamification and education have different goals and this make education as a requirement both vital and challenging. The math content is based on the South African curriculum CAPS and approved by the math teachers, which is crucial as the tool must have the same purpose and framework as the teachers. To implement this requirement the math problems cover basic concepts, which encourage repetition and reinforcement of the teachers lectures. Digital education could also have been used to introduced and explained new concepts, but the teachers suggested it was more important to help the students understand the basics in a different way. Furthermore, considering the students previous experience, the use of a digital tool meant many new intricacies as it was making the option to introduce additional topics overwhelming.

The requirements educational and stimulation was also discovered to be affected by the balance of formal and informal learning. Conceptually, the informal approach is preferred for the tool to be entertaining and attracts the students’ attention for a longer time. In contrast, the formal approach implies a familiar situation and, in many cases, encourage the students to avoid effortless guessing. An interesting note is that since the students were not used to play computer games, they found the introduction of digital gamification interesting enough. Hence, many of the tasks in the game were designed to be formal without losing the students’ interest. The requirement of feedback does also help the students to follow their progress and keep focus. In particular, the implementation where the problems are simplified and explained are perceived as helpful.

C. User customization

The requirements are all dependent of the users and their context. The users’ experience with technology enforced the requirements low complexity, clear guidance and few distractions. A tradeoff between these requirements and a stimulating game was found and the latter was given a lower priority. It was discovered that if these requirements were not met, the tool did not fulfill its purpose. Limited control power, views and interaction combined with simple instructions given in a familiar and consistent way proved to adjust the tool to be appropriate for the users. A logical structure, with only one task for the students to solve at the time, is also important. The implementation of a timer simulates the situation of a test and was found to have a positive effect of the students’ concentration. Unfortunately, the change of computers in the school influenced this element and as the screen froze, it had to be removed. This highlights the importance of examining the environment and current resources. The requirement to function offline is crucial as an online tool is not an option at Vissershok Primary School at this time.

In order to achieve an appropriate math level, incorporating the curriculum is not enough. The analysis of the math test results provided more accurate content. In addition, it confirmed both the need for different levels and indicated the range it must cover. The requirement of appropriate language is not as simple, and the complexity originates from the user multilingual background and the volunteer’s presence at the school. The help from volunteers is relatively unique for this school and therefore their opinions should not be prioritized if this study is intended to provide guidelines for schools in similar contexts. Despite this, English is an official language and some students did prefer to play the game in English. Implementation of additional languages may also have been welcomed, but time and language knowledge limited this possibility. Furthermore, Afrikaans and English are the most used languages by the users and implementing a version in Afrikaans is already a great contribution to already existing games, like the ones tested in the think aloud.

D. Resource Efficiency

The teachers seem confident that the game is appropriate for the students as it is tailored to their technology knowledge and want to incorporate the game into their education. Therefore, the time spent establishing requirements and implementing the math game, by students and teachers, will not be wasted. However, the tool could have contributed to more resource effective teaching if an administrator view could have been implemented in the RPG Maker MV.

Additionally, as the game fits within the educational structure of the school and curriculum it is expected to be a sustainable long-term solution for revising basic math concepts. The methods of interaction design and the involvement of the user might also have contributed to the long-term usage as the users and teachers have contributed to the final tool. Even though the
E. Criticism & Limitation

This study was bounded to fit within the ordinary activities of the volunteers, teachers and students. This caused comfort selection to be the only option for data collection and limited the number of participants and the control of their characteristics. As a consequence, the opinions were difficult to quantify, and some individuals may have disproportionately influenced the identified needs. This was in particular significant in the analyze of the teachers’ perspective, as only one teacher was available throughout most of the iterative testing. The volunteers’ opinions were taken into consideration as a complement, since they were considered to have a similar mission as the teachers. However, their insights and local knowledge varied, and some volunteers switched throughout the project. Therefore, more extensive inclusion of the teachers would have been desirable.

As discussed in the method section, it can be difficult to assess what the users think during testing. This was challenging and many students had to be asked many questions in order to say anything at all. As the open questions, such as “Why?” or “What made you do that?”, almost never were answered in a way that conveyed reason, the follow up questions might have been perceived as leading. The reason for their taciturnity could be explained by shyness, especially as the researchers possibly were seen as superior authorities, or by the language barrier [1]. For this reason, observations played an important, yet not fully comprehensive, part. Furthermore, the observations and perceptions might have been affected by prior stereotypes and expectations as a common mistake is that the researchers’ beliefs and prejudice influence the analyze of the result. [1] This is difficult to avoid, but the close collaboration and recurrent visits helped strengthen the relationships. Furthermore, the lack of interaction design researcher in this region limited the access to previous work. However, the study involves the local characteristic and is expected to result in different requirements if it was performed in a different context.

In addition, the quantitative evaluation of the low-fi prototype resulted in important information but was flawed. Some photos appeared to be misleading as they had a more appealing photo from games already played by the students. Additionally, it was noticed that some students could not explain why they preferred one alternative over the other. This limited the accuracy of the results and a qualitative evaluation might have been more suitable. At last, the limited time frame affected the project. Both the data collection and the formative evaluation could have been made more extensive and incorporated additional methods. Ho, Smyth, Kan and Dearden [24] state that typical usability evaluation tends to focus on “first time” experiences, causing the result to concern discoverability and learnability problems rather than long term usability problems. This is considered to be of even greater importance if development is added to the picture, which is why this is, if possible, highly suggested to take into consideration for future projects.

F. Further Work

In order to further evaluate the established requirement in this context, it would be interesting to examine a long-term perspective of usability and how well the tool incorporates in the school’s structure. It would also be appropriate to add a pedagogical aspect and examine how the tool and the requirements could be adjusted to improve educational results. Moreover, the context could be further analyzed by comparing the requirements for different subjects, ages or primary concentrating on the teachers’ perspective and needs.

X. Conclusion

This study proves the importance of the requirements of the tool being educational and stimulating, as well as the challenges to implement them. The tool must be designed to favor the ordinary education yet benefit from the motivational aspect of gamification. Examining the balance of informal and formal settings, including feedback like explanations and consequences, combined with gamification elements like storytelling and levels, were considered useful in this context. The requirements of appropriate math level and language are essential, however further assessment and tests are vital in order to implement correctly. The requirements of low complexity, clear guidance, few distractions, logical structure and different difficulty levels aimed to adjust the tool for the target group and are vital in order for the tool be used by the students. Without succeeding this, the tool is expected to cause frustration and fail fundamental aspects of interaction design. The context also required the tool to function offline and the choice of platform and the execution were limited to the current resources.

The implementation of the digital tool indicates a contribution to a more resource efficient distribution within the education. This as the tool was adjusted to fit the school structure, expected to be accepted by important actors of the school and is perceived as a long-term solution. However, the short period of evaluation makes it uncertain to draw any certain conclusions.

Conclusively, the established requirements give clear guidelines for development of future digital math tools in this specific context. The focus of this minor field study is unique, which hopefully leads to a decrease in the knowledge gap that exists in this research field. Therefore, this study hopefully evokes an interest in the globally important topic of digital education.
XI. AUTHORS

Aleks Durowicz is a student in Industrial Engineering and Management at KTH Royal Institute of Technology in Stockholm Sweden, specializing in computer science and communication. Both authors have been actively and equally contributing throughout the entirety of the study. Durowicz has been more involved in preparation and evaluation of testing.

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The SAVE Foundation is a non-profit organization in Cape Town that works to enrich, educate and empower various township communities. One of SAVE Foundation’s project is to assist in the education at a township school named Vissershoek Primary School.

XIII. REFERENCES

XIV. APPENDICIES

A. Appendix A

Vissershok Primary Schools’ computer room, Vissershok Primary School

B. Appendix B

Games played during the think aloud analysis. From top left: Meteor multiplication, Far out functions and More or Less.

C. Appendix C

Brainstorming session with the students

D. Appendix D

What is used while playing?

What type of game is it?

Low-fi prototypes questions

E. Appendix E

Hi-fi Java game prototype
Hi-fi RGP Maker MV prototype

F. Appendix F

Students playing the math game Wiskunde Village

G. Appendix G
https://drive.google.com/file/d/1OeqX0E8IMet_sgFCRzZDnK2T9CyQpbKW/view?usp=sharing

H. Appendix H
1) Educational
Math content based on the South African curriculum CAPS and approved by the math teachers. The math problems cover basic concepts, like multiplication, time and problem solving as that is what most students struggle with. Most problems include explanatory photos and when a problem is answered incorrectly it gets explained by being broken into parts.

2) Stimulating
Possible to play the game for approximately 1h. An adventure game with a clear story of saving a village after a wizard poisoned the water. The story is divided into four missions that must be completed in order to save the people from starving. The game is interactive with conversations and characters and is intended to trigger both extrinsic and intrinsic motivators.

3) Feedback
It is always shown if a math problem is done correctly or not. About half of the feedback is descriptive and if an exercise is wrong and explanation is given, and more similar exercises need to be done by the player. Only positive feedback is given.

4) Clear guidance
Instructions are based on conversation interaction is consistent throughout the game. The right answer to math problems are suggested with approximately three options, instead of the player writing them to ease interaction.

5) Appropriate language and language level
The game can be played in both English and Afrikaans. The instructions and math problem texts are formulated as elemental and short as possible. The math operation symbols are the same as used in class.

6) Logical structure
Only one task at a time must be done. There is a clear story to follow with four crises to solve, which are reminded to the player from time to time. The interaction and navigation in the game is kept constant throughout the game.

7) Appropriate math level
The math level is based on the curriculum and performed math tests. The concepts included was suggested by the teachers experience of what the students need to practice.

8) Offer different difficulty levels
The game offer three difficulty levels to cover the range of math skills of all students. The game can be played on three levels; easy, medium and hard. These levels are based on grade four, five and six math respectively and adjusted throughout test sessions.

9) Compatible with the school’s computers
The game function without remarks on the computers at the school’s computer room.

10) Offline
The math game function offline.

11) Low Complexity
Instructions of how to use the keyboard and mouse is provided at the beginning of the game, but the usage of the keyboard is voluntary. The user’s ability to move freely in the game is restricted. All excessive features were removed.

12) Few Distractions
The sound, buttons, icons and access to menu are removed. Additionally, the users view is limited to the current scene.