Designing learning opportunities for the hardest to reach

Game–based mathematics learning for out–of–school children in Sudan

Hester Stubbé–Alberts

Members of the doctoral committee:
Prof. dr. P.H.M. Drijvers (Utrecht University)
Prof. dr. H.L. Hardman (Utrecht University)
Prof. dr. L. Kester (Utrecht University)
Prof. dr. van Luit (Utrecht University)
Prof. dr. J.M. Pieters (University of Twente)

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Ontwerpen van leeroplossingen voor kinderen
die het moeilijkst bereikt kunnen worden
Leren rekenen met een rekengame voor kinderen
in Soedan die niet naar school gaan
(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de rector magnificus, prof. dr. H.R.B.M. Kummeling, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op woensdag 29 augustus 2018 des middags te 4.15 uur

door

Hester Elisabeth Stubbé–Alberts

geboren op 10 maart 1966 te Venlo

Promotor: Prof. dr. W.R. van Joolingen
Copromotor: Dr. A.H. van der Hulst

Acknowledgements

Worldwide, 61 million primary age children have no access to primary education. The three major reasons for this are: the long distances to school, inequality, and conflict. At the same time, all children have a right to education; education provides children with hope, structure and real opportunities for a better future. It also builds the capacities of children, parents, teachers and community members to cope with conflict – and to help prevent conflict in the future. Education is vital to breaking cycles of poverty and instability, and empowers future parents and leaders.

The project described in this dissertation started a little over six years ago, when Dr Aiman Badri (Ahfad University for Women in Khartoum) came to Amsterdam to discuss the possibilities of digitalising the Sudanese curriculum for out–of–school children in Sudan. Since then, we have come a long way. What started as a small project about a mathematics game in Sudan, has developed into a programme in multiple countries (Can't Wait to Learn), covering games for several school subjects, and including many new partners and stakeholders. This shows in the awards and prizes the project has received over the years: Innovations in Education Award (UNICEF, 2014); a second place in the E–Learning Excellence Award at the European Conference on E–Learning (ECEL, 2015); a Dutch Game Award for best co–production (2015); the 2016 TNO award (Leo van Breda Award) for best application of Human Factors in practice; and a place in the Humanitarian Education Accelerator programme, led by UNICEF, UNHCR and DFID (2016).

I hope this thesis contributes to the external credibility needed to attract (new) donors and convince Ministries of Education to implement the educational games to support and supplement traditional education. At the same time, I hope this research will contribute to the design of new educational games, either within or outside of the Can't Wait to Learn programme.

This project would never have started without the vision of Dr Aiman Badri, who believed ICT solutions could help reach the 2.7 million out–of–school children in Sudan. At the same time, it could never have been carried out without War Child Holland, who embraced the adventure to try and design educational technology for developing countries. A special thanks to Rebecca Telford who, as a country director in Khartoum, informed us about cultural aspects and arranged cooperation with relevant stakeholders. Her background in psycho–social research has been of great value to the project. Also a special thanks to Kate Radford who, as a programme director, managed the delicate balance between game development, local buy–in, and donors, in all its complexity. Thanks to her strategic planning, dedication and hard work, the programme could develop into what it is now. The funding and support by the Ministry of Foreign Affairs of The Netherlands has made it possible to develop an educational game and test it; the participating children in Sudan and their parents allowed us to try out the game and find out if it could work. Finally, a thank you for the involvement of UNICEF Sudan, who believed in this project and supported it in many ways.

The project in Sudan has very much been a 'sandbox', in a gaming sense of the word. The Ministry of Education in Sudan gave us much freedom in the design and development of the game. In the end, the game should teach the Sudanese mathematics curriculum, but we were allowed to add to the curriculum, and to try out and improve in an iterative way.

The design and development of the game has been a multi–partner collaboration. A special thanks to Margot van Niekerken. You helped me understand all the small, but essential details of learning mathematics and never tired of discussing the project and this dissertation with me. Also many thanks to the Flavour team, the game developers, for the intense and enthusiastic cooperation and collaboration. Thanks to Emily Jacometti for your quiet support in the background, and to Jaïn van Nigtevegt for your creative enthusiasm. Many thanks to Marijn Rijken. You have supported me over the years, in project management as well as personally. I thank you for listening to me, over and over again, and trusting my judgements. I value your perspective on things. Also a thank you for Nicolet Theunissen, Anja Langefeld, Martin van Schaik, and Marloes van de Klauw, who supported me in the research aspects of the project. Thanks for discussing the research methodology with me and for helping out with some of the analyses.

I would never have written this dissertation without Anja van der Hulst. I remember the afternoon you walked into my office and told me that this project, and the research we had carried out, could serve as the basis for a dissertation. Thank you for that! Also many thanks for your support and clear & concise comments over the years. This has encouraged me to keep going and think about my assumptions and presumptions.

Many thanks to Wouter van Joolingen. I understand I presented you with a project that was well on its way, with a second pilot study that had already started when we first discussed it. Although you could not add to the design of the game or the research methodology, you have added considerably to the analyses, conclusions, and the way in which I wrote them down. From now on, I will structure my writing much more, and keep in mind I should not say things without substantiating them.

Last but not least, I thank all my 'boys': Theo, Jasper, Laurens, and Ruben. For believing that I could do this, for being proud of me and for allowing me to take time away from our family; to travel and to write.

Table of contents

1. Introduction

Worldwide, 61 million primary age children are out of school. Most of these, 32.6 million, live in Sub–Saharan Africa. Differences between countries are significant: where some countries have achieved a 90% enrolment, a small number of countries struggles with high percentages of out–of–school children (UNESCO, 2017). Figure 1, below, shows an overview of the primary out–of–school rates worldwide.

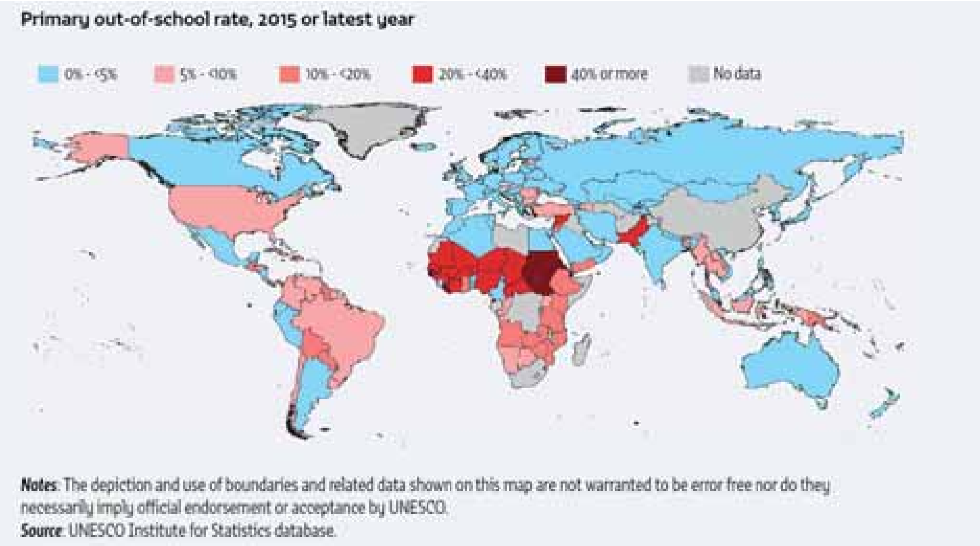


Figure 1. Overview of primary out–of–school rates worldwide, 2015 or latest year. From UNESCO, 2017.

United Nation's Millennium Development Goal 2 states that by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling (http://www.un.org/millenniumgoals/education.shtml). Although enrolment has increased considerably since the year 2000, this process faltered by 2009. Despite the many campaigns and initiatives, the number of out–of–school children has increased with 2.4 million in the period 2010–2013 (UNESCO, 2015). Not all out–of–school children are permanently excluded from education. Some have attended school in the past, but have dropped out. Others may attend in the future, and therefore enter school at a later moment in time, with late entry to school by overage children being strongly associated with dropout (UNESCO, 2017). Still, a third group will never set foot in a classroom. Although the gender gap is getting smaller (from 5% in 2000 to 2% in 2015), girls are still more likely to be out of school than boys.

The single most important determinant of access to education is the proximity of a school (Cremin & Nakabugo, 2012; Novelli & Lopes Cardozo, 2008; Kallaway, 2001; Burnett, 1996). Children in urban areas are more likely to be enrolled in school because there are schools at a walking distance. In rural regions, the distance to the closest primary school is often too far for children to attend. If transportation to school is a possibility, this may incur costs that parents may not be able to bear. Even when children walk to school, this brings about indirect costs: the time children spend on walking to and from school cannot be spent on household chores; moreover, children will be tired after walking long distances (Lockheed & Verspoor, 1991). In addition to direct and indirect costs, the road to school may not be safe enough, especially for girls (The World Bank, 2012). Constructing schools in rural areas does not solve this issue as teachers prefer to teach in the urban areas (The World Bank, 2012; Lockheed & Verspoor, 1991). As a result, even when school buildings are constructed in rural areas, there are not enough qualified teachers to provide education (UNESCO, 2015).

In addition, equity still remains a major issue, not only involving girls, but also the poor, including linguistic and ethnic minorities, and other disadvantaged groups (Novelli & Lopes Cardozo, 2008; Kallaway, 2001; Burnett, 1996). Although the gender gap is considerably smaller than in 2000, in 2013 1 out of every 10 girls was out of school, worldwide, compared to 1 out of every 12 boys (UNESCO, 2015). Once in school, girls do better than boys and are more likely to pursue their education (UNESCO, 2015; The World Bank, 2012). Equity is influenced by implicit messaging in textbooks; girls and minorities are not depicted as often as boys or majorities, and the way in which they are depicted reinforces existing differences (Kobia, 2009; Blumberg, 2007; Evans & Davies, 2000). For example, girls are shown in gender–stereotype ways (Blumberg, 2008). As teachers are taught with similar books, this influences their attitudes as well (Blumberg, 2007). Moreover, household survey data show that in Sub Saharan Africa in the poorest quintile, 48% of the children is not enrolled in school. In the richest quintile this is 15%. Children from low income backgrounds run a higher risk of being out of school (UNESCO, 2015). Also, when education is not provided in the language(s) children speak at home, it is almost impossible for them to learn.

Finally, conflict is an important indicator of school enrolment. In conflict situations, schools may cease to function, and families may move to safer areas or countries.

An estimated 50 per cent of out–of–school children of primary school age live in conflict–affected areas (UNESCO, 2015). This comes down to 28 million children (War Child, 2018). The Syrian Arab republic, for example, had achieved universal enrolment in 2000. As the civil war spread, the number of out–of–school children and adolescents jumped from 0.3 million in 2012 to 1.75 million by February 2016, with an additional 1.35 million children and youth at risk of dropping out (UNESCO, 2017). As a result, 1 out of 3 primary age children are out of school.

The push to achieve the goal of educating every child at least to primary level (enshrined in the Millennium Development Goals) put pressure on educational systems which already struggled to cope with demand. Class sizes, student–teacher ratios and student–textbook ratios all increased because of increased enrolment. Calculations showed that four million new teachers would have been needed to staff new classrooms and replace teachers who retire, to achieve universal primary education by 2015 (UNESCO, 2015). In addition, extra budget is needed for textbooks, desks and chairs.

Independent of demand issues, the quality of education is low at all levels in most low and middle income countries (Power, Gater, Grant & Winters, 2014; UNESCO, 2012; Lavy, 2012; Mtika & Gates, 2010; Sripakash, 2010; Vavrus, 2009; Moloi, Morobe & Urwick, 2008; Dembéle & Lefoka, 2007; Boissiere, 2004; Burnett, 1996), leading to high drop out after the initial increase in enrolment. In general, this is caused by a shortage of qualified teachers, inadequate instructional times caused by teacher absenteeism, large class sizes, lack of resources, and teacher centred pedagogies (Hardman, Abd–Kadir & Smith, 2008; Moloi et al., 2008; Dembélé & Lefoka, 2007). This quality of education can be negatively influenced because teachers resort to even more teacher–centred pedagogies when faced with increased class sizes. An increase in enrolment, therefore, does not automatically lead to more children finishing primary education. As a result of a lower quality of education, children may drop out. The most important reason mentioned for drop out is the perception of parents that additional schooling is not worth the investment in terms of time and money (The World Bank, 2012).

Where initially the focus of the Millennium Development Goal was very much on access to education, this focus has shifted towards access & quality of education in the Sustainable Development Goals (Power et al., 2014; Petrosino, Morgan, Fronius, Tanner–Smith & Boruch, 2012; Hanushek, Jamison, Jamison, & Woessmann, 2011; Moloi et al., 2008; Boissiere, 2004). For instance, Sustainable Development Goal 4 states: 'Ensure inclusive and quality education for all and promote lifelong learning' (http://www.un.org/sustainabledevelopment/education/). Looking at all the efforts made, and the stagnation of progress in achieving universal primary education, 'It is clear that business–as–usual approaches based on more teachers, more classrooms and more textbooks are not enough to keep the promise of a quality primary education for the most disadvantaged children.' (UNESCO, 2015). The focus should be on strengthening education systems, inclusion, and quality of education, for those children who are hardest to reach.

1.1. Education in Sudan

As other Sub Saharan countries, Sudan struggles with these issues. Sudan is one of the countries worldwide with the highest out–of–school rates (45%) meaning 2.7 million children in Sudan are not in school (UNESCO, 2017). The percentages of out–of–school children differ per region; in urban areas enrolment is better than in rural areas. Boys are more often enrolled in school than girls; in rural areas, the chance for boys to ever enter, but not necessarily finish, primary education is 82%, compared to 70% for girls (The world Bank, 2012). Socio–economic status seems to be an important determinant of enrolment as well: In Sudan, 45% of the children in the poorest quintile are out of school; for the richest quintile this is only 3% (UNESCO, 2015). A girl in a rural village from a poor family, therefore, has a much lower chance to be enrolled in school than a boy in a city from a rich family. The quality of education is low (The World Bank, 2012): school buildings and teaching aids are in need of repair and the average student–textbook ratio for mathematics can be as high as 9 to 1 in rural schools in North Kordofan, while the official policy is 2 to 1. Class sizes are quite large with an average of 48 students per teacher; in urban areas this is closer to 30 students per teacher (official policy), while in rural areas this can be as high as 90 students per teacher. In rural areas, it is also more common to have multiple grade classes. Lessons are not always taught as a result of teachers absenteeism or weather conditions. For an impression of a rural village in Sudan, see Figure 2.

Figure 2. Impression of a remote village in Sudan, White Nile state.

Following the three principles recommended by UNESCO (2015), any educational intervention in Sudan should first of all work with the Ministry of Education, strengthening and expanding the educational system from within. In addition, the intervention should at the same time improve access to and quality of education. There should be focus on inclusion, meaning that children who are now disadvantaged because of gender, language or ethnical background have access to quality education. Finally, the intervention should be aimed at those children who are hardest to reach, which is in rural and remote areas in the country.

1.2. Can't Wait to Learn Programme

This thesis reports on research carried out within the Can't Wait To Learn programme that has the goal to increase access to quality education for children who are disadvantaged by their location, irrespective of their backgrounds or gender. The project is conceived through a collaboration between the Ministry of Education of Sudan, the Ahfad University for Women in Khartoum and War Child Holland. Curriculum and game design is provided by TNO. The game was produced by Flavour with support from creative partners in Sudan.

1.3. Educational game

To reach children in rural and remote areas of the country, learning opportunities should be created close to their homes (UNICEF, 2009). This automatically implies learning will have to take place outside of schools, and without teachers. For this reason, the decision was made to design and develop an educational game that can be used by children autonomously, outside of school and without the presence of a teacher, integrating the roles a teacher would take as much as possible into the learning materials. This decision is supported by a meta–analysis of 77 randomised experiments of school–based interventions on learning in primary schools in developing country by McEwan (2014). He found that interventions with computers or instructional technology showed the largest mean effect size (0.15) with respect to learning outcomes compared to teacher training, smaller class sizes, contract teachers, performance incentives, and instructional materials. The educational game should provide quality education for all; specific attention should be given to language and equal presentation for gender and ethnical background. The methodological guide 'Promoting gender equality for textbooks' (UNESCO, 2009) provides many guidelines and recommendations for this.

1.4. Why mathematics?

Out–of–school children will need to learn how to read and write (literacy) and do mathematics. Although both subjects are equally important, it was decided to start with one subject: the effectiveness of autonomous, game–based learning had to be demonstrated first. There are several reasons to start with mathematics, instead of literacy. Research into school readiness shows that mathematics achievements at the end of kindergarten are the strongest predictors of achievement by the end of grade 2 (Duncan et al., 2007; Pagani, Fitzpatrick, Archambault & Janosz, 2010). There are differences for gender: girls with less kindergarten cognitive skills were more vulnerable than boys with similar deficits when predicting grade 2 mathematics achievement (Pagani et al., 2010). As mathematics achievement is the strongest predictor in the lower grades of primary education, stronger than reading achievement and attention skills, it was assumed to be the best subject to start with. Apart from this, there were pragmatic reasons for choosing mathematics to start with. As a subject, mathematics is easier to translate into digital learning materials than literacy: the underlying algorithms of mathematical concepts can easily be programmed. Literacy does not have such underlying algorithms, thus requiring a more detailed preparation. Literacy is also much more interconnected with culture, making it a more sensitive subject to develop. The choice to start with mathematics means children will not learn to read and write. Therefore, it cannot be assumed they are able to read written instructions.

To create a mathematics game and ensure its adoption, technology is an important, but only enabling element. Without multi–stakeholder partnerships and community involvement, the educational game itself would never be as relevant and engaging, and implementation would not be supported. This thesis focuses on the design of the educational game itself and the way it will function in its direct context of application in rural areas in Sudan.

1.5. Research Questions

A search has not yielded any curriculum–based digital mathematics interventions in Arabic, aimed at autonomous learning by young children. Therefore, a new mathematics game needs to be developed and evaluated. This means the overall question that needs to be answered is:

How can children in remote villages in Sudan learn mathematics from playing a mathematics game without additional instruction from teachers?

To answer this question, a number of sub–questions need to be answered. First of all, as there is no available mathematics game that is appropriate for the situation, a new game needs to be designed. The first step of game design is to define the requirements for the game; what specific characteristics (target population, learning objectives and context) and challenges need to be addressed in the game.

Research question 1:

> What are requirements for an educational mathematics game for out–of–school children in remote villages in Sudan?

Once the game requirements have been defined, a translation of those requirements into a game design can be made. The game design describes how the requirements are addressed in the game. As requirements consist of both general requirements and quite specific mathematical requirements, this is addressed in two research questions:

Research question 2:

> How do the general game requirements translate into a working game design?

Research question 3:

> How do the specific requirements for learning mathematics translate into a working game design?

Based on the game design, the game can be developed. Game development is a complex and iterative process, including feedback from partners and stakeholders and testing. Once part of the game has been developed, it can be tried out with children in a first evaluation. This first evaluation aims to study whether children can learn at all from playing the game.

Research question 4:

> Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?

Following a successful first evaluation, a larger part of the game can be developed. This can then be used in a second evaluation, researching whether sustained learning takes place, including more and more diverse learning objectives.

Research question 5:

> Can out–of–school children in remote villages in Sudan learn mathematics autonomously for a longer period of time, covering a diversity of mathematics learning objectives, by playing the game autonomously?

To establish whether some children benefited more from playing the game than others, the influence of child–related and contextual factors needs to be studied. Results can be used to improve the current mathematics game, but also inform future developments. As the programme aims to develop a scalable technological education intervention, information on factors that influence the learning outcomes can be used to analyse the new context for the presence or absence of such factors. Therefore, the final research question relates to such factors.

Research question 6:

> What child–related and contextual factors influence learning effects?

1.6. Outline of this thesis

In chapter 2, research question 1: What are requirements for an educational mathematics game for out–of–school children in remote villages in Sudan? is answered. The general requirements for the game are identified, based on the specific characteristics of the target population and the context, and a literature study on how to address these specific characteristics. Research question 2: How do the general game requirements translate into a working game design? is addressed in chapter 3. For each requirement, the relevant game elements are described. In chapter 4, research question 3 is answered: How do the specific requirements for learning mathematics translate into a working game design? Chapter 5 addresses research question 4: Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?. It describes the first evaluation of the game, Pilot I, answering the question whether children can learn at all from playing the game. Chapter 6 addresses the question of sustained learning and answers research question 5: Can out–of–school children in remote villages in Sudan learn mathematics autonomously for a longer period of time, covering a diversity of mathematics learning objectives, by playing the game autonomously? Chapter 7 answers research question 6: What child–related and contextual factors influence learning effects? This provides insights in whether the game is more effective for some learners than others and which elements of the game need to be adapted when taking it to a new context. In the final chapter, the findings on the research questions are discussed, in relation to scaling. Also, future work, based on this research, is introduced briefly.

2. Game requirements[1]

As described in the introduction, the decision has been made to create and evaluate a mathematics game to provide access to education for children in remote villages in Sudan. As a search did not yield any existing mathematics games that were appropriate, covering a full curriculum, supporting autonomous learning for young children and in Arabic, a new game needed to be designed. In this chapter, the following research question is answered: *What are requirements for educational mathematics games for out–of–school children in remote villages in Sudan?*

An instructional design approach was used to analyse the target population, the learning objectives and the context in which the target population will learn.

The context in which the game will be used is quite specific: the target population are young children, aged 7–9, who have never used technology before. Moreover, they have never been to school before. The game will have to be used in their own villages, which means it will be used outside of school, without teachers. As most parents have not finished primary education themselves (Stubbé–Alberts, Van der Klauw, & Langefeld, 2014), it cannot be assumed that they can help their children to learn. In addition, the game has to be in Arabic; apart from the language itself, this has consequences for the writing direction. In this chapter, the context will be analysed in detail and requirements for the game, needed to address this context, will be identified.

2.1. Method

The method used to create the instructional design is a combination of a literature study, interviews with local and subject matter experts, and input from children of the target population.

[1] *A previous version of this chapter was published as: Stubbé, H., Badri, A., Telford, R., Oosterbeek, S., & Hulst, A. van der (2016). Formative Evaluation of a Mathematics Game for Out–of–School Children in Sudan. In Cai, Y., Goei, S.L., & Trooster, W. (eds.) Simulation and Serious Games for Education. Springer Science+Business Media, Singapore. ISBN 978–981–10–0860–3.*

The literature studied focuses on:
1. Education in developing countries
2. Education in Sudan
3. Learning with technology
4. Learning with technology in developing countries
5. Autonomous learning
6. Pedagogical design
   6.1. Learning with technology
   6.2. Autonomous learning

Interviews were carried out with the following experts:
[1] Aiman Badri, associate professor Ahfad University for Women, Khartoum, Sudan; initiator of the project in Sudan
[2] Frank Velthuizen, War Child Holland, Kosti, Sudan; specialist on inclusive education and psychosocial support in developing countries
[3] Hala Elrofai, scientist TNO, Helmond, Netherlands; Sudanese by birth and former teacher of mathematics, Khartoum university, Sudan
[4] Jedidja Slagter, Programme Development Advisor War Child Holland, Khartoum, Sudan
[5] Kimaru Wa Karuru, coordinator psychosocial programme War Child Holland, Khartoum, Sudan
[6] Margot van Niekerken, 'internal advisor' primary education, Amersfoort, Netherlands; focus on mathematics
[7] Rebecca Telford, Country Director War Child Holland, Khartoum, Sudan
[8] Shahla Eltayeb, associate Professor Health & Counselling Psychology, Ahfad University for Women, Khartoum, Sudan

2.2. Results

2.2.1. Analysis of target population: who needs to learn?

As described before, children in rural regions are more likely to be out–of–school than children in urban regions, which is why the focus is on rural regions in Sudan. The National Council for Literacy and Adult Education (NCLAE) is responsible for the education of all children in the age–group 7–9 who are out–of–school, boys as well as girls. The designated target population, therefore, comprises children from seven to nine years old, boys and girls (see Figure 3).

Figure 3. Children in the target population.

These children live in remote villages in rural areas and have never been to school before. It can, therefore, not be assumed they will be able to read and understand written text. Based on interviews with local experts [1], [2], [4], and [7] it can be concluded that they are not familiar with technology, and hardly travel outside their villages. There are no roads, street names or house numbers in the villages. Some adults have mobile phones, but these cannot always be charged as there is no electricity in the villages. Water is available in a water hole, a large hole in the ground that fills during the rainy season.

A baseline study, carried out at the start of Pilot II (Stubbé–Alberts, van der Klauw & Langefeld, 2014), provides more detailed information on the characteristics of the target population in rural regions in Sudan.

- The target population includes girls as well as boys, in almost equal proportions (51% girls; 49% boys).
- Most parents and caregivers (80%) have not finished primary education themselves. Therefore, it cannot be assumed that they can help their children to learn mathematics.

- 85% of the children has one older sibling. As the distance to the nearest primary school is at least 3 kilometres and can be as much as 14 kilometres, it cannot be assumed that siblings have been to school before.
- 10% of the children do not have both their parents. Less than 1% of the children does not have any parents at all.

In Pilot I one state was involved: White Nile. In Pilot II, three states were involved: White Nile, Gedaref and North Kordofan. While all three states are rural, North Kordofan is also a conflict–affected state: families fleeing the conflict in South Kordofan settle in North Kordofan. These people are called Internally Displaced People (IDP): they move to a different region in their country.

Motivation

For the game to be effective, it should first of all be attractive and motivating for the target population. This means the target population should be able to recognise and relate to the narrative and graphics in the game. Furthermore, they should feel challenged and rewarded by the interactions in the game. In remote villages in Sudan, access to education is an issue for girls as well as boys. The game should, therefore, be attractive and motivating for girls as well as boys. The NCLAE is responsible for all out–of–school children in the age–group 7–9. This means the game has to be attractive and motivating for children in the age–group 7–9. Finally, the children in the target population grow up in rural and remote areas of Sudan. This influences how they see the world. Therefore, the game should be attractive and motivating for children growing up in rural and conflict–affected regions in Sudan.

Game requirement 1

1. The game should be attractive and motivating for the target population
    1.1. The narrative, graphics and interactions in the game should be similarly attractive and motivating for girls and boys.
    1.2. The narrative, graphics and interactions in the game should be similarly attractive for children aged 7, 8 and 9.
    1.3. The narrative, graphics and interactions in the game should be attractive and motivating for children growing up in rural and conflict–affected regions in Sudan.

Flexibility

Interviews with local experts show that from an early age, children are expected to help out with household tasks [1], [2], [5] and [7]. Learning, therefore, always has to take place alongside other responsibilities. The game should be flexible enough to fit in with those household tasks. Examples of household tasks are shown in Figures 4 and 5. Figure 4 shows a boy herding cattle, Figure 5 shows a girls cleaning dishes. In addition, interviews with local experts [1] and [7] made clear that families travel, moving away from conflict (IDP) or to find water or work (nomadic people). Families usually travel from one remote village to another. The game should, therefore, enable learning for children on the move.

Figure 4. Example of household task: herding cattle. *Figure 5.* Example of household task: cleaning dishes.

Game requirement 2

2. The game should enable learning for the target population
    2.1. The use of the game should be flexible enough to fit in with household tasks.
    2.2. The game should be flexible enough to support populations on the move such as nomadic groups, but also Internally Displaced People (IDP).

2.2.2. Analysis of learning objectives: what needs to be learned?

Parents are likely to assess whether additional schooling for their children is worth the investment in terms of time and budget. In emergency contexts, such as during natural disasters but also in conflict situations, education programmes are generally developed as transitional programmes. Transitional programmes have the objective to 'get children back into the formal school system'. In general, these programmes do not aim for recognition of their curricula, teachers and learners, because of the administrative issues involved. Consequently, learning is often not recognised, and children are not allowed to take formal tests; as a result they cannot progress to formal education.

Enable progress into regular education

For learning to be worthwhile, it should enable children to progress to formal education (UNICEF, 2009). Although the NCLAE aims to stream out–of–school children back to the formal education system, the reality is that almost 3 million children in Sudan are not in school. This requires a foundational approach, designed to be part of the rebuilding as well as of the formal education process. Therefore, the curriculum in the game should be aligned with the national mathematics curriculum, and it should be recognised and endorsed by the NCLAE and the Ministry of Education in Sudan.

In their overview of the education sector in Sudan, The World Bank (2012) describe the education system in Sudan as follows. In Sudan, general education is 13 years, including two years of preschool, eight years of primary school and three years of secondary school. Basic education is compulsory and free. The national curriculum for basic and secondary education is developed by the National Centre for Curriculum and Education Research. Curriculum development for preschools and IDP schools is the responsibility of the state ministries of education. Nomadic schools use the same curriculum as that used in regular schools. The federal Ministry of General Education in Khartoum is in charge of planning, coordinating, and monitoring preschool, basic and secondary education. The delivery of education is decentralised, the states and the localities are responsible for that. Although this decentralised system can address the regional and social disparities better, it poses a challenge in terms of the varying capacities at the local level to raise the necessary budgets, and to design and implement policies.

Game requirement 3

3. The game should enable progress to formal education in Sudan
    3.1. The curriculum should be aligned with the mathematics curriculum in Sudan.
    3.2. The game and the curriculum should be endorsed by the Ministry of Education in Sudan.
    3.3. The game and the curriculum should be endorsed by the National Council of Literacy and Adult Education.

Mathematics curriculum

A study by Yelland and Kilderry (2010) shows that the process of becoming numerate is continuous and begins in early childhood years when parents and caregivers interact with their children in informal contexts as they go about their daily activities. Depending on the opportunities to learn in this informal context, children develop mathematical skills at different levels before beginning formal schooling (USAID, 2009; Aunio, Hautamäki, Sajaniemi & van Luit, 2009). Once children begin formal education, they use this informal knowledge when completing new tasks (Baroody, 1999; Ginsberg & Russel, 1981). Across cultures, children seem to bring similar types of skills to school, but do so at different levels (Guberman, 1996). In general, children from low–income backgrounds begin school with a more limited skill–set than those from middle–income backgrounds. This is related to the environment in which children grow up that enables them to understand the world, master language and get insight in the basic knowledge needed for mathematics (Greenman, Bodovski, & Reed, 2011). One of the interviews very much focused on the importance of informal mathematics knowledge as the basis for further learning [6]. Children need a strong basis of basic mathematical skills to be able to master more difficult ones (Pellegrino & Goldman, 1987). With additional support children can still be successful (Chard et al., 2008); providing at–risk children with optimal opportunities to improve their knowledge and skills might prevent them from falling further behind (Praet & Desoete, 2014). Where in developed countries this support is usually given as extra support to individual children, in developing countries early interventions should be aimed at all children. The official curriculum for out–of–school children in Sudan should be included in the game. This has already been addressed in sub requirement 3.1 *The curriculum should be aligned with the mathematics curriculum in Sudan*. In addition, based on the characteristics of the target population, kindergarten learning objectives should be included; children are not expected to have mastered those learning objectives and they are quite important for further learning (interview [1], [4], and [7]. To further ensure the quality of the game in terms of learning objectives included, a check against internationally recognised learning objectives for early grade mathematics was made. A more detailed description of this check and an overview of the learning objectives included in the game are described in chapter 4.

Game requirement 4

4. The mathematics curriculum in the game should be of good quality
   4.1. The curriculum should include the kindergarten learning objectives.
   4.2. The curriculum should include internationally recognised learning goals for grades 1–3.

2.2.3. Context: what is the context of learning?

The context of learning is influenced by two factors: the physical and the cultural context. The interviews [1], [2], [4], [5], [7] and [8] revealed that most remote villages have no electricity, running water and internet connectivity at all (Figure 6). Furthermore, Sudan has a desert climate: dry with high temperatures (35–45 degrees).

Figure 6. A water hole serves as the primary source of water in the villages.

This physical context requires specific choices for hardware and software. The game cannot be web–based because there is no reliable internet connection. At the same time, it should be possible to keep track of progress and analyse data at a group level. This means the game should have an online–offline system with children always being able to play, and a possibility to synchronise data to a central server when possible. As the temperatures are high and there is much dust, hardware should be chosen with this in mind. The software of the game should be designed to run on this hardware. Finally, there needs to be electricity in villages, to be able to use the hardware and the game. As all hardware will probably have to be charged from one power outlet, hardware needs to charge quickly, and not need power while being used.

Game requirement 5

5. The game should be accessible in rural and conflict–affected regions
    5.1. The game should be based on an online–offline system, with students always being able to play.
    5.2. The game should be designed to be played on rather simple hardware.

Language in the game

Arabic is the official language in Sudan. However, many distinct native languages can be identified (Mugaddam & Dimmendaal, 2006; Miller, 2006; Jernudd, 1979). These native languages are spoken in the various regions of the country. Several studies (Miller, 2006; Jernudd, 1979) report that 50% of the population speaks Arabic as a first language. Up to 80% of the population can speak Arabic as a first, second or third language. The reason for this is that Arabic is used as a *lingua franca*, a common language people use when they do not understand each other's native languages. Still, a small but significant percentage of the population does not speak Arabic. These are mostly old people, young children, and people in remote regions of the country (Miller, 1989). The use of Arabic in education and the urban movement–people moving towards the larger cities–will increase the number of people speaking Arabic to the point that the second generation, with parents who have moved to the cities, only speak Arabic (Mugaddam & Dimmendaal, 2006). As Arabic is the official language in Sudan, the language used in the game should be Arabic (Modern Standard Arabic). However, as the game is going to be used by young children, in remote regions, we cannot assume all of them to speak Arabic (well). This was supported by three of the interviews [3], [4] and [7]. The Arabic that is used in the game should, therefore, be simple; avoiding difficult words and long sentences.

Although learning objectives for mathematics in the early grades are more or less the same across countries (USAID, 2009), it is too often assumed that mathematics is a universal language and that mathematics curricula are easily adapted (Gerdes, 1988). The differences between western European curricula and the Arabic mathematics curriculum are large enough to warrant special caution, because, like language, it may contain sensitive issues imbued with symbolic, political and cultural values. In the interviews [3], [4], [5], and [7] it was stressed that the various elements of the game should not offend the Sudanese culture. For example, a graphic showing the sole of a shoe is offending and should not be used. In addition, the various elements of the game should not reinforce existing symbolical, cultural or political issues. For example, girls and boys should be portrayed as equal in the game, engaging in similar activities.

Game requirement 6

6. The game should be culturally appropriate
   6.1. The language in the game should be simple Modern Standard Arabic.
   6.2. The various elements of the game should not offend the Sudanese culture.
   6.3. The various elements of the game should stay away from sensitive symbolical, cultural, and political issues.

2.2.4. Instructional design

Teaching is arguably the strongest school–level determinant of student achievement (Hattie, 2009; Dembéle & Lefoka, 2007; Lockheed & Verspoor, 1991). In Sub–Saharan Africa this effect is reportedly higher, as school is the primary source for learning basic cognitive skills (Dembéle & Lefoka, 2007; Boissiere, 2004). Therefore, learning without a teacher is a challenge that needs to be addressed in the game–design.

Easy to use

Before going into the specific roles of teachers, it is obvious that for children to use the game without the support of a teacher, the game itself and the hardware should be easy to use. Children should be able to understand the technical aspects of the game and the hardware intuitively, with little instruction.

To identify the specific challenges for the game design, an analysis of the roles of a teacher was made. Overall, teachers provide instruction, learning activities and feedback, motivate children to learn, and are responsible for classroom management. It is not realistic to believe parents can replace teachers: 80% of them have not finished primary education themselves and must be assumed to be illiterate (Stubbé–Alberts, van der Klauw & Langefeld, 2014). Some of the roles of teachers can be integrated in the game–design, for other roles this is harder to do. In the current situation, teachers travel to villages from time to time. They teach a few lessons in an ad hoc setting, for instance in the shade of a hut (Figure 7).

Figure 7. Sometimes teachers travel to villages to teach a few lessons.

Guided learning

Teachers guide children through a curriculum, providing timely instruction, setting activities, assessing them, and providing feedback. When necessary, they revisit earlier learning objectives and explain again. Without teachers to support the learning process, the game–design should enable guidance of learning. This was confirmed in two of the interviews [3] and [6]. Children should be guided through the curriculum and only be allowed to move to the next learning objective once they have mastered the previous one. This is in line with a mastery learning approach (Bloom, 1985). Using the mastery learning approach ensures a strong basis to build on; children will be able to understand instruction of consequent mathematical concepts, because they have sufficient knowledge of the previous and underlying mathematical concepts.

Instruction

When using educational technology, instruction needs to be designed beforehand. While teachers can be more flexible and adapt their instruction based on children's needs, instruction in the game cannot be changed easily. As there is no interaction between a teacher and children, it is not possible to have children start from their own assumptions about a mathematical concept, and then guide them to a correct understanding of the concept. Pre–designed instruction needs to be *explicit instruction*; explaining the mathematical concept and showing through worked examples how to solve mathematical problems relating to this concept. This is in line with the approach for struggling learners (Timmermans, 2005; Milo, 2003), learners who have difficulty understanding instruction the first time, or do not master previous mathematical concepts. Looking at the characteristics of the target population, it is to be expected that children start playing the game with little informal mathematical knowledge and will have to get used to learning in an organised setting as well. Explicit instruction would, therefore, suit this target population well. Instruction should fit in with children's experiences and interests with an emphasis on supporting the development of mathematical activity. Through real life examples, taken from the children's own environment, mathematical concepts can be explained. A study by Bodovski and Farkas (2007) shows that struggling learners show less engagement during instruction. However, if children's engagement during instruction is increased, their performance increases as well. The instruction in the game should, therefore, be interesting and motivating for the target population.

Feedback

For learning to be effective, children should receive feedback to understand whether their answers are correct. This will help them to check assumptions and build knowledge. Also, it helps them to know how much progress they have made. Two of the interviews, [3] and [6], supported the inclusion of feedback. Educational technology is, by its very nature, suitable to provide feedback on progress and results. Where teachers might not have the time or the patience to correct a child for the tenth time, a digital system can provide feedback in a positive way, as many times as necessary (Kegel, Bus, & IJzendoorn, 2011). The game should, therefore, include feedback on progress and results to children.

Management system

In addition to direct feedback to children, it should be possible for officials to keep track of progress of individual children or groups of children. This was a specific request from the ministry as well, discussed in one of the interviews [1]. Therefore, the game should have a management system that provides information on the progress of individual children and groups of children.

Game requirement 7

7. The game should enable self–paced, autonomous learning
    7.1. The game should be easy to use by the target population.
    7.2. The game should provide guided learning.
    7.3. The game should provide motivating, explicit instruction.
    7.4. The game should provide feedback on progress and results to children.

7.5. The game should include a management system that provides information on progress of individual children and groups of children.

Active learning

In their meta–analysis of 225 studies that reported data on examination scores and failure rates, Freeman et al. (2014) conclude active learning increases student performance in science, engineering and mathematics. Active learning implies that students are actively engaged with the learning materials, instead of passively listening to instruction or lectures. Active learning interventions included approaches as diverse as occasional group problem–solving, worksheets or tutorials completed during class, use of personal response systems with or without peer instruction, and studio or workshop course design. Although the effect size of active learning in primary education seems to be smaller than in undergraduate courses (Lipsey et al., 2012, p. 36), it still is an interesting positive effect. As active learning decreases the risk of dropping out significantly, this is probably a very positive finding for struggling learners: struggling learners are more likely to drop out than high–achieving learners (Freeman et al., 2014). Sarama & Clements (2004) approach to learning mathematics is in line with active learning: they suggest the basic design of the learning intervention should be based on 'Finding the mathematics in, and developing mathematics from, children's activity.' (Sarama & Clements, 2002 p. 99). Meaningful activities should be designed with a clear focus on learning goals or objectives (Kalloo, Mohan, & Kinshuk, 2015; Praet & Desoete, 2014; Clements & Sarama, 2007; Sarama & Clements, 2004; Sarama & Clements, 2002) and start in the real world, with real life examples (Sarama & Clements, 2002; Freudenthal, 2002). Later, students are expected to develop an understanding that goes beyond this physical situation. Finally, interactivity, the active participation of the child with the learning materials, is seen as one of the important characteristics of learning with technology for young children (Kegel et al., 2011; Saine, Lerkkanen, & Ahonen, 2011). This was supported by two of the interviews [3] and [6]. The mathematics game should, therefore, be based on an active learning approach.

Game requirement 8

8. The game should be based on an active learning approach
   - 8.1. The game should include meaningful activities.
   - 8.2. The game should support active engagement with the learning materials.

Learning sessions & facilitators

Although the game requirements identified in this chapter can, and should, lead to a game that can be used by children autonomously, children can still benefit from face–to–face contact, with other children and with adults. This was suggested in three interviews [2], [5], and [8]. It is recommended to organise learning sessions in which a number of children learn in the same place, at the same time. These learning sessions can be supervised by a facilitator who provides additional motivation for children to learn and takes responsibility for 'classroom management' tasks such as starting learning sessions on time, checking for attendance, keeping track of children's progress, and taking care of the hardware. Any responsible adult could fulfil this role, once trained in child–friendly approaches and some technical details on the hardware and the game. A training can also guarantee similar facilitation across villages.

2.2.5. Learner centred approach

Together, the game requirements described in this paragraph suggest a learner–centred approach. The idea is that people learn best when engaged in the subject and motivated to understand new knowledge and skills because they need them in order to solve the problem at hand. Learning materials should invite active engagement and allow learners to explore in order to construct their own knowledge.

Learner–centred education is often seen as a western construct, perhaps not suitable for developing countries because it does not take the cultural context into account. However, several studies have shown that it is possible to introduce learner–centred elements to education in developing countries in a successful way (Thompson, 2013; Sripakash, 2010; Vavrus, 2009). According to a meta–review of 72 studies about the implementation of a learner–centred pedagogy in the development context (Schweisfurth, 2011), there are four recurring implementation barriers, relating to (1) educational reform and change, (2) resources, (3) culture, and (4) the national educational system. These barriers are very much related to a situation in which the focus is on transforming the existing educational system towards a more learner–centred pedagogy. (1) Teachers would need to change their teaching methods, implying that also teacher colleges will have to change their approach. (2) Resources are scarce as it is, and learning materials that support a learner–centred approach would need to be developed. (3) A learner–centred approach may not fit in with the local culture, with respect to identity orientation. Last but not least, (4) it is quite difficult to change a national educational system. When, however, learner–centred learning is not the goal, but a means to an end, these barriers can be viewed from a different perspective. The choice for educational technology in this programme originates in the Ministry of Education of Sudan and is aimed at those situations where there are no schools and teachers. Within the programme, it is possible to provide the necessary resources relating to the design and development of the mathematics game, the procurement of hardware and the installation of solar power panels in the participating villages. That leaves the barrier related to culture. As described in requirement 6, the game should be culturally appropriate. Consequently, choices made in the game design should be aligned with the local culture and endorsed by the Sudanese Ministry of Education.

2.2.6. Educational technology design

The choice for an educational game has been made at the start, based on the target population and the context in which children will need to learn. Still, it is worthwhile to review the literature on the effectiveness of applied gaming and the use of educational technology in developing countries to understand whether this provides any additional requirements for the game–design.

Over the past decade, several meta–analyses and meta–reviews have been performed on the effectiveness of serious gaming in general. All of these follow the media comparison approach, investigating whether students learn more or better using serious gaming compared to learning with more conventional media. Although all meta–studies report that the descriptions of the research methods in the original studies were not always clear or thorough, the overall conclusions are that across people and situations the learning effect is larger for applied gaming than for more traditional ways of teaching (Wouters, van Nimwegen, van Oostendorp, & van der Spek 2013; Connolly, Boyle, & MacArthur, 2012; Sitzmann, 2011; Wouters, van der Spek, & van Oostendorp, 2009; Vogel et al., 2006). In addition to the research on effectiveness of serious gaming in general, there has been specific attention to the use of computers in relation to mathematics education as well. The overall conclusion is that using educational technology leads to a better mastery of mathematics for children in kindergarten and primary education than classroom teaching (Praet & Desoete, 2014; Steenbergen–Hu & Cooper 2013; Li & Ma, 2010; Räsänen, Salminen, & Wilson, 2009; Clements & Sarama, 2007). The research on digital mathematics interventions showed that they were specifically effective for low achieving or at–risk children (Steenbergen–Hu & Cooper, 2013; Li & Ma, 2010). Furthermore, they increased motivation (Rosas et al., 2003), and more positive attitudes towards mathematics (Ke, 2008). Recently, Pitchford (2015) evaluated the effectiveness of a tablet intervention for mathematics in a school in Malawi. She concluded that children using the tablet technology for mathematics learned more than children who received classroom education in mathematics or children who played a general tablet game.

Control over order and pace

Although the general findings for the use of technology and gaming in education are positive, there are elements in the game design that are more effective than others. When children can influence the order and pace of the learning process, games are more effective than when teachers or the computer controls the programme (Kegel et al, 2011; Saine et al., 2011; Vogel et al., 2006). The game should, therefore, give children control over order and pace. This is partly in contradiction with the sub–requirement 7.2: *The game should provide guided learning* that suggests the order of learning should be pre–determined and children should not progress to a next level until they have mastered the previous one. Therefore, this requirement should be that game should give children some control over order and pace, within a level.

Instruction

The design of instruction delivered by games is of crucial importance as the variation in learning outcomes is amongst other factors determined by clear and concise instruction (Clark, Yates, Early, & Moulton 2008; Rosas et al., 2003). This is in line with O'Neill, Wainess, & Baker (2005) who conclude that adding instructional support might help to reduce cognitive load. De Jong, van Joolingen, & Swaak (1998) mention a similar influence in relation to discovery learning. Examples for instructional support mentioned are: scaffolding, worked examples, organising, and pre–training (Mayer & Moreno, 2002; Sweller, 2008). This is addressed in sub–requirement 7.3: *The game should provide motivating and explicit instruction.*

Active engagement

Children learn more when the learning materials are conveyed actively instead of passively (Sitzmann, 2011; Clark et al., 2008). This in line with literature on active learning (Freeman et al., 2014), and has been addressed in sub–requirements 8.1:

The game should include meaningful activities and 8.2: *The game should support active engagement with the learning materials.*

Embedded in the educational system

Although research into the effect of games on learning supports the choice for an educational game and provides insight into the game elements that add to effectiveness, the existing evidence is mostly from developed countries; it is not clear whether these findings also apply in the developing country context. Whilst the use of ICT in education is mentioned as a key area of opportunity to increase access to learning (UNESCO Institute for Statistics, 2009), the evidence for this advocacy is less clear than the optimism it expresses. There is material which heralds ICT as a relatively simple way of giving children in the developing world access to education (Bender, Kane, Cornish, & Donahue, 2012), but there is also scepticism that this enthusiasm may relate specifically to marketing of ICT or distance learning products (Daniel, 2010; Krstic, 2008). Overall, although the possible impact of ICT is seen as being significant, many authors (Selinger, 2009; Latchem, 2012) agree with Daniel's (2010) caution: 'while computers do enrich children's lives and encourage self–directed learning, they need to be embedded within a wider framework if they are to make a systematic contribution to achieving Education For All' (p. 43). This embedding in a wider framework is addressed in requirement 3: *The game should enable progress to formal education in Sudan.*

In her evaluation of a tablet intervention for mathematics in a school in Malawi, Pitchford (2015) concluded that tablet technology can effectively support early year mathematical skills in developing countries if the software is carefully designed to engage the child in the learning process and the content is grounded in a solid well–constructed curriculum appropriate for the child's development stage. The careful design of the game is reflected in this chapter: all the requirements for the game are based on a thorough analysis of the context – target population, learning objectives, and context in which the game will be used – and grounded in the theory on learning with technology, learning mathematics and education in developing countries.

Balanced presentation

Finally, *functionality* of the game should be considered: the right balance between content and presentation–neither too dull because of the abundance of content, nor too playful or with an overly flashy presentation (Kegel et al., 2011; Saine et al., 2011). Two interviews focused on the specific balanced presentation needed for children without any experience with technology, [4] and [8].

Requirement 9

9. The game should include characteristics that increase effectiveness
    9.1. The game should allow children some control over order and pace.
    9.2. The game should have the right balance between content and presentation.

2.3. Overview of game requirements

1. The game should be attractive and motivating for the target population
    1.1. The narrative, graphics and interactions in the game should be similarly attractive and motivating for girls and boys.
    1.2. The narrative, graphics and interactions in the game should be similarly attractive for children aged 7, 8 and 9.
    1.3. The narrative, graphics and interactions in the game should be attractive and motivating for children growing up in rural and conflict–affected regions in Sudan.

2. The game should enable learning for the target population
    2.1. The game should be flexible enough to fit in with household tasks.
    2.2. The game should be flexible enough to support populations on the move such as nomadic groups, but also Internally Displaced People (IDP).

3. The game should enable progress to formal education in Sudan
    3.1. The curriculum should be aligned with the mathematics curriculum in Sudan.
    3.2. The game and the curriculum should be endorsed by the Ministry of Education in Sudan.
    3.3. The game and the curriculum should be endorsed by the National Council of Literacy and Adult Education.

4. The mathematics curriculum in the game should be of good quality.
    4.1. The curriculum should include the kindergarten learning objectives.
    4.2. The curriculum should include internationally recognised learning goals for grades 1–3.

5. The game should be accessible in rural and conflict–affected regions
    5.1. The game should be based on an online–offline system, with students always being able to play.
    5.2. The game should be designed to be played on a rather simple hardware.

6. The game should be culturally appropriate
    6.1. The language in the game should be simple Modern Standard Arabic.
    6.2. The various elements of the game should not offend the Sudanese culture.
    6.3. The various elements of the game should stay away from sensitive symbolical, cultural, and political issues.

7. The game should enable self–paced, autonomous learning
    7.1. The game should be easy to use by the target population.
    7.2. The game should provide guided learning.
    7.3. The game should provide motivating, explicit instruction.
    7.4. The game should provide feedback on progress and results to children.
    7.5. The game should include a management system that provides information on progress of individual children and groups of children.

8. The game should be based on an active learning approach
    8.1. The game should include meaningful activities.
    8.2. The game should support active engagement with the learning materials.

9. The game should include characteristics that increase effectiveness
    9.1. The game should allow children some control over order and pace.
    9.2. The game should have the right balance between content and presentation.

3. Developing a working game design, based on the requirements

In chapter 2, the requirements for the game have been identified, based on context, local expertise and literature. These requirements inform the design of the game. In this chapter, the following research question will be answered: *How do the general game requirements translate into a working game design?*

First, the game design is described in a general way, followed by a more detailed description of the game design elements per requirement. The choice for game design elements is made based on literature and input from local experts, representatives from the Ministry of Education and children in the target population. Following an iterative process, proposed game design elements were shared for feedback with the same people.

3.1. General description of game design

The educational game for mathematics was developed in three phases. The first version allowed for six weeks of learning and was tested in a small pilot during December 2012 – February 2013. Based on the findings in this pilot, the second version was developed that allowed for six months of learning. This version was tested in a scaled pilot between October 2014 – March 2015. Based on the results of this pilot, the final version of the game was delivered mid 2016, covering three years of learning.

The resulting game incorporates two distinct levels, each with a different pedagogy. The first level is that of game worlds which provide the connecting narratives for the second level, that of separate mini–games (44 different mini–games, 160 variations of mini–games in the three–year curriculum game). This can be described as a *games within games* game design pattern (Bjork & Holopainen, 2004). In addition, instruction videos and a management system are included in the game.

3.1.1. First level of the game: game worlds

The top level of the game environment, that of the game worlds, uses a predominantly experiential learning approach. Learners have a certain level of control (agency) over their exploration of the game world. For example, they decide whether they watch an instruction video (when and how often they watch the videos is without limits), check the progress they have made, do a mini–game or just try out the funny elements in the game world. Narratives are used to create meaningfulness which allows children to understand the characters in the game and feel empathy (Marsh, Ma, Oliveira, Hauge, & Göbel, 2016). The narrative in game world 1 is about helping other children to achieve goals in their lives (visions) (Figure 8); by doing mini–games, children help other children to become e.g. a goat herder or doctor, and build their village. Half of the jobs are familiar within the target communities, such as a goat herder, cooking lady, tractor owner or brick maker. The other half are known to the children, but belong to the city, such as a teacher, nurse, doctor and engineer. In a playful way, this helps the children to broaden their future perspective.

Figure 8. Game world 1: Goat herder vision.

Figure 9. Game world 2: The shop.

Game world 2 is a shop where children can buy and sell products (Figure 9). By playing the mini–games, children can increase the number of products they can sell and enhance their shop. In the shop narrative, children can also decide themselves which products to buy and sell. The implicit message in this game world is that you can succeed in life if you try your best. The two game worlds are interconnected: from game world 2, the shop, children go back to game world 1, the village, to collect products to sell in the shop. In this way, earlier mathematical concepts are repeated as well.

Where the first narrative, achieving goals in your life, is very much related to children's everyday lives, the second narrative, the shop, is more connected to mathematics. The correct number of objects need to be sold, and money has to be paid.

There are *inaccessible areas* in the game that children can see but cannot enter from the beginning: the locations of new visions are visible, but can only be played after reaching a certain mastery level (Figure 10). This presents children with a challenge and motivation to keep on playing (Bjork & Holopainen, 2004).

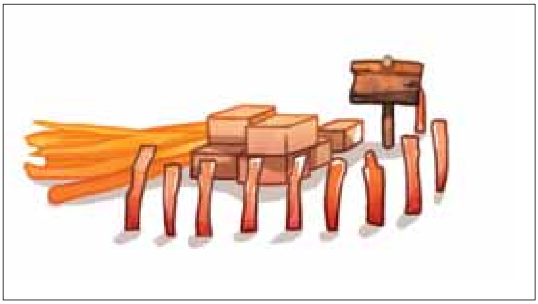


Figure 10. Inaccessible area in the game: the location of a new vision.

3.1.2. Second level of the game: mini–games

The lower level of the game, with the mini–games, has a different pedagogy: mastery learning with direct feedback on performance, and consequently less control over the learning environment. Each mini–game (for example, see Figure 11) addresses a specific mathematical concept. Some mini–games have variations that can be used for several mathematical concepts and all mathematic concepts can be practised by several mini–games. Progress through the game is structured and based on performance: the number of correct answers within a certain time–frame decides whether children can continue to a more difficult mathematical concept.

Figure 11. Screen shot of mini–game: ordering; the child has to drag the correct number into the empty space in the yellow box.

For reasons of tracking individual progress of children and to ensure that children can progress at the right difficulty level, the mathematics game is a single–player game (Bjork & Holopainen, 2004).

3.2. Detailed description of game design

While the general description provides a global overview of the game design, this paragraph describes in detail how the various characteristics of the game reflect the game requirements. Each paragraph addresses one requirement and all its sub requirements.

3.2.1. Requirement 1: The game should be attractive and motivating for the target population

For the game to be attractive and motivating for the target population, the following sub requirements should be addressed:

1.1. The narrative, graphics and interactions in the game should be similarly attractive and motivating for girls and boys.

1.2. The narrative, graphics and interactions in the game should be similarly attractive for children aged 7, 8 and 9.

1.3. The narrative, graphics and interactions in the game should be attractive and motivating for children growing up in rural and conflict–affected regions in Sudan.

Requirement 1.1. The narrative, graphics and interactions in the game should be similarly attractive and motivating for girls and boys.

To ensure the narrative, graphics and interactions in the game are attractive and motivating for boys and girls, the following choices were made:

1. a co–creation process was followed that involved local experts and girls as well as boys.
2. the game design focused on gender neutrality.
3. a mixed set of motivational aspects was used, appealing to both boys and girls.

(1) Three possible game narratives (building a village, achieving goals with jobs, and a shop) were discussed with local experts. Based on the results of those discussions, two narratives were chosen (achieving goals with jobs and the shop). One of the important criteria for the narrative was that it should depict girls in the same way as boys, engaging in similar activities.

Boys as well as girls from the target population were involved in a co–creation process with respect to the graphics and colours in the game. They were asked to make drawings of their own environment, drawing familiar food, animals, clothing, trees and vegetables, and transport (Figure 12).

Figure 12. Girls and boys drawing their environment.

The most important reason to ask children to draw their own environment is to ensure the game environment resembles the children's own environment. For instance, the children's drawings made clear they knew tomatoes, carrots, eggplant and onions. Those vegetables were, therefore, used in the minigames. Furthermore, the drawings were interpretations of how children in the target population see their environment. In general, children in the target population do not have access to drawing materials. Therefore, they are not experienced in drawing.

The graphics used in the game were based on these drawings. The first set of graphics was sent to Sudan to be checked by the children. Per object, children were asked by a local researcher whether they knew what the object was and to name it. Then they were asked if they liked the graphic of this object. Sometimes, the graphics looked very much alike. An example of this is the graphics of the olive and the grape; children could not tell these apart. Graphics that children did not like or recognise were not used in the game. Figure 13 shows a drawing of a cow and a tomato. Figure 14 shows two examples of graphics based on drawings.

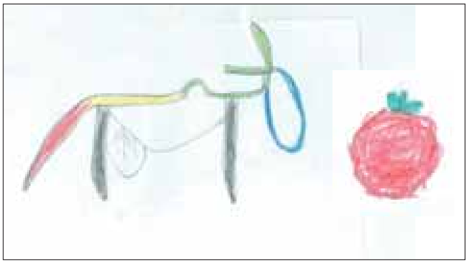


Figure 13. Children's drawing: a cow and a tomato.

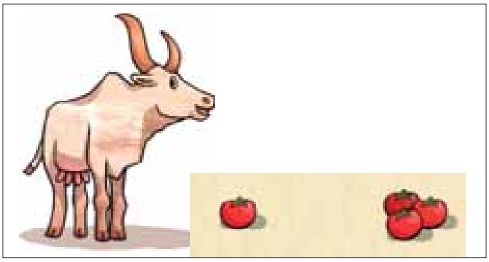


Figure 14. Graphics for the game: a cow and tomatoes.

(2) Besides involving the children in the design of the game, much attention was given to a gender neutral presentation of the game. In the instruction videos, boys and girls explain mathematical concepts. The visions in game world 1 are based on jobs that are 'female' and 'male', for example a cooking lady and a brick maker. In addition, a more gender neutral job such as doctor, have a female character. The characters in the visions are half girls and the other half boys (Figure 15). In game world 2, a girl and a boy together are the shopkeepers.

Figure 15. Characters in the game, girls and boys.

The only element of the game that is not gender neutral, is the 'teacher' in the game. Audio instruction in the game is given by a female voice, and the pictogram to ask for help shows a female adult (Figure 16). The reason behind this is that female teachers are perceived to be more friendly than male teachers by children in the target population (interviews with local experts [1], [2], and [7]). As the game should be a safe learning environment in which children feel free to learn and are not afraid to make mistakes, a female teacher was chosen.

Figure 16. Pictogram of the 'teacher' in the game.

(3) In addition to a co–creation process with girls and boys and a focus on gender neutrality, motivational aspects were specifically chosen to appeal to girls as well as boys. In general, there are four categories of motivational aspects in applied games: competition, creation, competence and connection. Most games include motivational aspects that stimulate competition. Competition is generally more liked by boys than by girls and might implicitly make the game more attractive to boys (Sherry, Lucas, Greenberg, & Holmstrom, 2010). Therefore, in the game design, elements of all four categories are included. Examples of competition are the progress bar with stars and the levels in the game. Children playing in the same learning session can compare their progress which stimulates competition. Examples of creation are the many different mini–games in the game. Finishing the mini–games is intended to make children feel successful in solving challenges. An example of competence is the unlocking of levels, once a previous level has been finished. The fourth motivational category, connection, is not included in the game itself. Children play the game in learning sessions, supervised by a facilitator (Figure 17). As children are playing the game at the same time, and in the same room as other children, they will talk to each other; about the game but probably also about other things. This diversity in motivational elements ensures girls and boys will be motivated to play the game.

Figure 17. Learning session in one of the villages. Children play the game at the same time in the same place, but can be playing different mini–games, due to the mastery learning approach.

In addition to these motivational elements, a few funny elements are added to the game with no other purpose than to motivate children (Figure 18). First of all, there is a football. Each time the child starts the game, the football will be in a different place in the game world. Children can find it. When they tap the football, it will bounce. If the child taps carefully, it can keep the football in the air; at the same time the number of bounces are counted in audio and with digits. Although a football might appeal more to boys than to girls, the interaction with the football in the game is not related to playing football: children can look for the football and try to bounce it a number of times. This relates more to competence than to competition. Then, there are children walking around in the background of the game. When the child taps them, they will either cheer with their hands in the air, or clap their hands. Finally, some chicken walk around in the game world. When the child taps them, they will startle and lose some feathers.

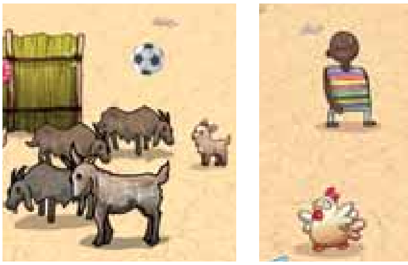


Figure 18. Motivational elements in the game world: the illustration on the left shows the football, the illustration on the right shows the child and the chicken.

Requirement 1.2. Similarly attractive and motivating for children age 7–9.
The co–creation process described above involved children of all ages in the age group. In addition, the game worlds were chosen to be appropriate for this age group: the narrative is not specifically aimed at younger or older children, making it suitable for all ages.

Requirement 1.3. Growing up in rural and conflict–affected regions in Sudan.
To ensure children will recognise the environment and objects used in the game, their own drawings were used. In addition, graphics were based on many photographs, taken locally (Figure 19). For example, the brand of milk sold in the shop has a label on it that resembles the label of the most sold brand of milk in Sudan.

Figure 19. Graphics based on photographs: example of sheep herder, on the left side a photograph of a young goat herder, on the right side the graphic in the game.

The game worlds and narratives are based on rural Sudan as well, and should be familiar to the children (Figure 20).

Figure 20. Graphics based on photographs: example of the 'vision' of the Brick maker, on the left side a photograph of brick making in the villages, on the right side the graphics in the game.

3.2.2. Requirement 2: The game should enable learning for the target population

To enable learning for the specific target population of children in remote villages, the game should be flexible in two different ways:

2.1. The game should be flexible enough to fit in with household tasks.
2.2. The game should be flexible enough to support children on the move.

Requirement 2.1. The game should be flexible enough to fit in with household tasks.
Children in remote villages are used to help their parents. Household tasks include fetching water, looking after siblings, growing vegetables, herding goats or helping with the harvest. Based on these household tasks, flexibility should take two different forms: (1) every day, children should have time to do (small) household tasks, and (2) from time to time children are busy for days or even weeks on end, for example, helping with the harvest. The first type of flexibility does not have any implications for the game design itself and is addressed in learning sessions: children attend

one learning session of 45 minutes on weekdays (five sessions a week). The rest of the day can be used to do household tasks. Two learning sessions a day are provided, parents can choose which sessions fits best in their family. The second type of flexibility is addressed by the fact that instruction is included in the game and children always work at their own pace, at their own level. Every time they log in, they start exactly at the point where they left off the last time they played. This means children do not miss out on instruction when they have to skip a number of learning sessions.

Requirement 2.2. The game should be flexible enough to support children on the move.

Nomadic groups move around with their cattle, staying in one place for a number of weeks to months, then travelling to a new place. Internally Displaced People (IDP) are people who have moved away from their own communities, or who are on the move, because of conflict. Sometimes, they stay in the communities they have moved to, on the other hand they might move again or return to their own communities. There are two different ways in which the game caters for this type of flexibility. All actions children take in the game are logged on the hardware they use and thus always available. (1) Children can take their hardware with them to the new location, and keep on playing the game. The new location needs to have power to make this work. (2) If the new location has hardware, the child can access his or her own account on new hardware. If there is internet connectivity, logging on to the child's account is enough. If there is no internet connectivity, the logged data of the child's account should be brought on a USB stick.

3.2.3. Requirement 3: The game should enable progress to formal education in Sudan

For learning to be meaningful, it must be recognised by the formal educational system in Sudan. To enable progress to formal education in Sudan:

- 3.1. The mathematics curriculum should be aligned with the mathematics curriculum in Sudan.
- 3.2. The game and the curriculum should be endorsed by the Ministry of Education, and specifically by the National Council of Literacy and Adult Education.

Requirement 3.1. The curriculum should be aligned with the mathematics curriculum in Sudan.

The curriculum in the game is based on the official mathematics curriculum for out–of–school children in Sudan. All the learning objectives of the Sudanese curriculum are included.

Requirement 3.2. The game and the curriculum should be endorsed by the Ministry of Education in Sudan, and specifically by the NCLAE.

In a three–day workshop with representatives of the Sudanese Ministry of Education– the NCLAE, the National Council of Mathematics and the National Council of Curriculum Development – the curriculum and the possible ways in which it could be gamified were discussed (Figure 21). Then, a didactic framework for the game was designed which was endorsed by the Ministry of Education and the NCLAE.

Figure 21. Discussing the mathematics curriculum with representatives of the Ministry of Education in Khartoum.

3.2.4. Requirement 4: The mathematics curriculum in the game should be of good quality

First of all, the curriculum in the game should be aligned with the Sudanese mathematics curriculum for out–of–school children. This has already been mentioned in sub requirement 3.1. In addition, the NCLAE stressed the point that the curriculum should include all learning objectives children need to learn mathematics. There are two types of learning objectives that should be addressed:

4.1. The game should include the kindergarten learning objectives.

4.2. The game should include internationally recognised learning objectives for grades 1–3.

Requirement 4.1. The game should include the kindergarten learning objectives.
The kindergarten learning objectives were identified and discussed with the NCLAE. They were endorsed by the ministry and are included in the game.

Requirement 4.2. The game should include internationally recognised learning objectives for grades 1–3.
A detailed description of the internationally recognised learning objectives up to grade 3, the comparison of these learning objectives with the ones in the Sudanese curriculum, and the way in which these are addressed in the game are described in chapter 4. Again, any differences between the Sudanese curriculum and internationally recognised learning objectives were discussed with the NCLAE. They agreed to include a few additional learning objectives.

3.2.5. Requirement 5: The game should be accessible in rural and conflict–affected regions

For children to be able to access the game in their own rural and conflict–affected regions, hardware, connectivity and power issues must be solved. The following sub requirements that impact the game design should be addressed:

5.1. The game should allow students to play the game anytime, even without connectivity.
5.2. The game should be designed to be played on rather simple hardware.

Requirement 5.1. The game should allow children to play the game anytime, even without connectivity.
The game is based on an offline–online system. The offline system allows children to play anytime, with or without internet connection. Their progress is logged on the hardware, enabling them to continue where they left off, the next time they play. Data can be synchronised to a server whenever there is internet connectivity, or downloaded by hand.

Requirement 5.2. The game should be designed to be played on rather simple hardware.
As the game needs to operate offline, all files needed to play the game should be downloaded on the hardware itself (including audio and video files). This means that the memory space needed to download the game should not be too large. If too much memory space is needed, the game will not play at all, or badly. The

instruction videos proved to be of very good quality, and as a consequence the file size was very large. To ensure the game would not crash, the quality of the instruction videos was decreased to a point that they were still good enough to watch, but did not take up so much memory space.

Obviously, hardware needs power to play the game. Remote, rural villages usually do not have power, which meant that solar panels had to be installed in the villages that participated in the pilots (Figure 22). The solar panels were placed about a meter from the ground to create an additional value: shade. They stayed in the villages after the pilots.

Figure 22. Solar power panels in a community.

3.2.6. Requirement 6: The game should be culturally appropriate

For the game to be culturally appropriate, children should be able to recognise the language, graphics and narratives used. At the same time, the graphics and narratives should not offend the Sudanese culture. This means the following sub requirements need to be addressed:

- 6.1. The language in the game should be simple Modern Standard Arabic.
- 6.2. The various elements of the game should stay away from sensitive symbolical, cultural, and political issues.
- 6.3. The various elements in the game should be specifically designed for the typical rural situation in Sudan.

Requirement 6.1. The language in the game should be simple Modern Standard Arabic.
Although Modern Standard Arabic is the formal language in education in Sudan, the language in the game is simple Modern Standard Arabic. As the children in the target population may speak a local variation of Arabic or have a limited vocabulary, simple words and sentences are used. This will help children to understand the instruction.

Each Arabic–speaking country has a slightly different pronunciation of Arabic. Because of this, all audio and video was scripted by the project team, but taped in Sudan, with local people. The actual audio and video tapes were consequently checked by an Arabic speaking member of the project team to ensure they matched the original scripts. In this way, pronunciation as well as word choice are aligned with the Sudanese culture with respect to language.

Requirement 6.2. The various elements of the game should stay away from sensitive symbolical, cultural, and political issues.
The narratives for the two game worlds were developed in cooperation with local experts. The narrative for game world 1, helping others to achieve their goals, is very much part of the Sudanese culture: it is an honour to help others. The implicit message in this narrative, 'if you do well, you can progress in life', was discussed and approved. The specific jobs used for the visions were chosen together. They were based on jobs the children know in their communities and jobs from 'the city'. The narrative in game world 2 is about having a shop and helping customers. This is a rather neutral concept and is deemed to be appropriate for the Sudanese context. Again, the implicit message is that you will get further in life if you do your best. The graphics in the game were based on the Sudanese context. Clothes and dress code follow the Sudanese traditions, for example, not showing the soles of shoes or cleavage. Food, trees and transport resemble the local situation. At the same time neutral objects were chosen; children learn their numbers and addition using fruits and vegetables. Specific care was given to gender neutrality.

Requirement 6.3. The various elements in the game should be specifically designed for the typical rural situation in Sudan.
The setting of game world 1 is a remote, rural village. The narrative as well as the graphics are completely based on this rural setting (Figure 23). Children should be

able to recognise their own way of living and their living environment. The setting of game world 2 is more in a town or city; remote communities do not have shops. On the other hand, children will probably recognise the idea of trading or buying and selling food.

Figure 23. Environment in game world 1 resembles the local situation, on the left a photograph of a hut in a village, on the right a graphic of a hut in the game.

3.2.7. Requirement 7: The game should enable self–paced, autonomous learning

To achieve self–paced, autonomous learning, the following sub–requirements should be incorporated into the game design:

- 7.1. The game should be easy to use by the target population.
- 7.2. The game should provide guided learning.
- 7.3. The game should provide motivating, explicit instruction.
- 7.4. The game should provide feedback on progress and performance.
- 7.5. The game should include a management system that provides information on progress of individual children and groups of children.

Requirement 7.1. The game should be easy to use by the target population.

The game design explicitly addresses the usability aspect of the game in four different ways. In addition, children are introduced to the hardware and software in a face–to–face session.

First of all, as it cannot be assumed that children can read and understand written text, all instruction is provided in audio and video. This will help them to understand instruction. Secondly, user accounts are based on the photograph of the child as the user name, and a combination of pictures with coloured backgrounds as the password. This helps children to log in themselves; a username or password with letters and numbers would be too difficult for them. Children can choose their password themselves; remembering the password is facilitated by the colours in the background of the pictures (Figure 24).

Figure 24. Pictures that can be used for the password; a password consists of three pictures, children tap the correct pictures in the correct order.

Thirdly, in the game design, much attention has been given to the systematic and consistent use of colours and pictograms. For example, the colour green is used for everything positive. A green smiley means your answer was correct. Tapping the pictogram that has a green background, means your answer is 'Yes'. The colour red is used to indicate the answer 'No' (Figure 25). Because children indicated that they felt the colour red was too negative to indicate that an answer is not correct, the colour orange was used for that (Figure 26).

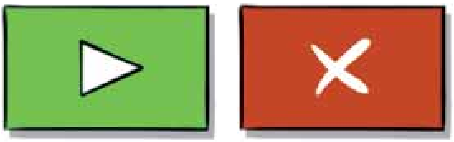


Figure 25. Yes' and 'No' button.

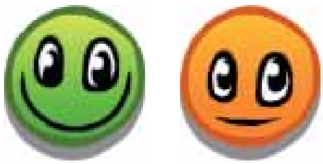


Figure 26. Feedback on answer: a green smiley for correct, an orange smiley for incorrect.

A specific pictogram has the same meaning throughout the game. For example, smileys are used to provide feedback on answers. A smiling (green) smiley indicates the answer is correct, a more neutral (orange) smiley indicates the answer was wrong. Discussions with local experts [1] and [5] revealed that a sad smiley is not culturally acceptable, because being sad is perceived as negative. Pictograms such as smileys and a 'thumbs up', were checked for cultural appropriateness with local experts. They have the same meaning in Sudan.

When playing the game for the first time, children follow a short tutorial. First of all, they are told what the overall goal of the game is. Then, the possible actions in the game are explained, and children are asked to perform those actions, helped by audio instruction and a green arrow on the screen. Every time a new action is introduced, this is explained in audio.

Finally, children are introduced to the hardware in a face–to–face session. In a formal setting, the hardware is handed out to the children (Figure 27). The formal session, with representatives from the ministry, the head of the village and the Sudanese initiator of the programme, stresses the fact that this is something special, and that children really need to be careful when using the hardware.

Figure 27. Handing out the tablets: the tablet is handed out to each child separately. A photograph is taken with representatives from the ministry, the head of the village and the Sudanese initiator of the programme.

Then, the working of the hardware is explained (Figure 28): how do you turn it on and off? How do you access the game? What types of actions work with this hardware?

Figure 28. Introducing the tablets: after the children have been given a tablet, the working of the tablet is explained to them.

Requirement 7.2. The game should provide guided learning.
Children are guided through the game based on their own mastery level. The management system in the game continuously assesses progress. Children can

progress to a next level, based on the number of correct answers given in a certain timeframe. If they make too many mistakes, or need too much time, they will practise the same mathematical concept a little longer. To ensure that children always progress, even when they are starting to learn a new mathematical concept, the number of correct answers needed, varies. When a new mathematical concept is introduced, the child only needs to give three answers before moving to the next activity. One of these can be a mistake, so two correct answers are enough to progress. There is no time limit at this stage, and children can use hints. The number of answers per mini–game increases with practice of the mathematical concept, until, finally, 20 answers of which 19 should be correct, need to be given within a certain timeframe, to progress to the next level.

This means children are always learning at their own mastery level, and are assumed to build a strong basis. As a result, children will progress through the game at different paces.

Working at their own mastery level, will give children a feeling of accomplishment. This should motivate them to keep on learning. The aim for the game is to be challenging, without being too hard (Csikszentmihalyi, 1990).

Requirement 7.3. The game should provide motivating, explicit instruction.
Instruction is given in short, clear videos; one video for every mathematical concept. In these videos, children aged 12–15 explain the mathematical concept, starting from an example in everyday life, then relating this to the more abstract mathematical concept (Figure 29).

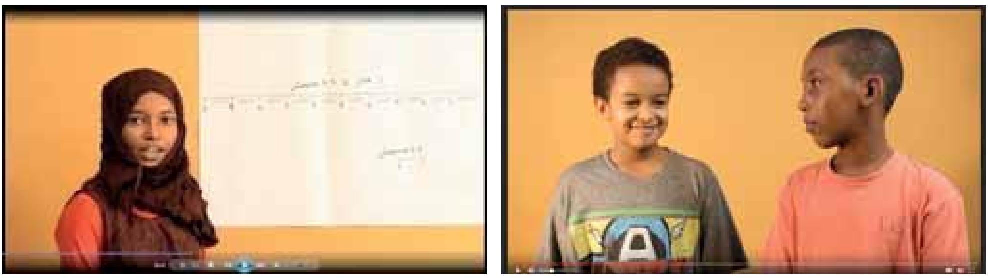


Figure 29. Screen shots instruction videos: girls and boys, slightly older than the target population explain mathematical concepts following a script.

For more advanced mathematical concepts, instructions start with a recapitulation of earlier concepts. In this way, previous knowledge is activated to help children understand the new concept better. The 'actors' are both boys and girls to implicitly emphasise gender neutrality and provide 'role–models' for boys as well as girls. The videos were scripted based on best practices in mathematics instruction, and taped in Sudan. For example, counting is introduced using everyday objects (Sarama & Clements, 2004; Freudenthal, 2002). Showing how objects can be manipulated in various ways – whether real or digitally – helps students to understand the concept of addition. In this way students do not only learn to 'do mathematics' but also build their mathematical knowledge and mathematise everyday life situations. By taping the videos in Sudan, the environment and language – choice of words and pronunciation – should be in line with the local culture as much as possible.

As the actors in the instruction videos are children, only slightly older than the children playing the game, they can be seen as role models. The purpose of this is to motivate the children to see that other children understand the mathematical concepts '*If they can if do it, I can do it as well*'. As both boys and girls explain the mathematical concepts, role models for boys as well as girls are provided.

Videos pop up when children reach the point where a new mathematical concept is introduced. They have to watch the instruction videos at least once, then they can decide whether they want to watch them again. They can watch the videos as many times as they like, see Figure 30 for an overview of instruction videos that have been watched.

Figure 30. Overview of instruction videos that have been watched. The child can tap one to watch it again.

In several mini–games, hints are available. For example, when children start learning the numbers, they can get help when counting a number of objects. Touching a small, blue button below the objects will have the objects 'count themselves' (Figure 31). Each object moves slightly upwards while it is counted aloud. When all the objects have been counted, the child has the answer to the question. However, at the same time, the child has repeated the numbers and counting objects.

Figure 31. Hints in mini–game: touching the blue button beneath the objects starts them counting themselves aloud.

The hints can be used when learning a new mathematical concept. In this way, children are supported when learning new things (scaffolding). One of the characteristics of scaffolding is fading: scaffolding is withdrawn gradually (van de Pol, Volman, & Beishuizen, 2010). Support should match the student's performance level, and therefore change when the student's performance level increases. In the game this support remains available in this mini–game. Fading is implemented by adding a time limit: the time allowed to answer a streak of items will be limited when the child's performance level increases. As a result, it is still possible to use the hints, but there is no time to use the hints for each item.

Requirement 7.4. The game should provide feedback on progress and performance.
Two types of feedback are provided: (1) feedback on performance and (2) feedback on progress.

(1) Feedback on performance is a combination of audio and visual feedback. A correct answer is praised in audio. At the same time a green smiley appears in the progress bar. When the child does not give a correct answer, this is mentioned in a friendly way in audio ('Too bad'). At the same time an orange smiley appears in the progress bar. Children are allowed to make one mistake per mini–game; sometimes

they just accidentally give a wrong answer. When two mistakes are made in one mini–game, the child has to start again.

(2) The game uses several elements to create a feedback loop for the player to measure their game progress. In the game progress within a mini–game is shown by the coloured smileys. At the start of a mini–game there is a number of empty circles at the top of the screen (3, 5, 10, 15 or 20). With every answer one of these circles is filled with a smiley. When all circles are filled, the mini–game is finished. Progress after every mini–game is provided by stars that are filled a little after each successful mini–game. When a star is completely filled it is coloured in the 'star banner' (Figure 32). From the beginning, the star banner shows the number of stars that can be achieved; the stars are not coloured. With each new star, the game environment becomes more beautiful as well (Figure 33).

Figure 32. Star banner: every time a number of mini–games have been finished successfully, a star filled in the star banner. The number of stars shows progress.

Figure 33. Building visions: Growing vegetables, every time a number of mini–games have been finished successfully, assets are added to the vision, until it is complete.

Requirement 7.5. The game should include a management system that provides information on progress of individual children and groups of children.
To keep track of children's progress in the game, individually as well as at group level, a management system was designed. The management system comprises four levels: (1) facilitators, (2) supervisors, (3) state, and (4) national. Each level has access to all levels below: for example, facilitators can see the result of the children in their group. Supervisors can see the data of all the facilitators they supervise, and the children in their groups. At group level, it is possible to compare progress between groups based on gender, age or location.

Progress is initially logged on the hardware itself. When there is internet connectivity, data can be synchronised with a server. In situations where there is no internet, logged data can be downloaded onto a USB stick and uploaded to a server by hand (Figure 34).

Figure 34. 'Milking the tablets': the data from the tablets are downloaded to a laptop to be transferred to a USB stick.

3.2.8. Requirement 8: The game should enable active learning

To support active learning in the game, the following sub requirements need to be addressed.

8.1. The game should include meaningful activities.

8.2. the game should support active engagement with the learning materials.

Requirement 8.1. The game should include meaningful activities.

The game has two levels, a game world and mini–games. In the game world, most activities contribute to the feeling of control: children can choose between activities (watch an instruction video, play a mini–game or check on progress). Some activities in the game world (football, child, and chicken) are just for fun, they do not have any additional meaning. In the mini–game level, the mini–games are designed to support the learning of mathematical concepts in an effective way; the activities in the mini–games help the child to understand and practise mathematics.

Requirement 8.2. The game should support active engagement with the learning materials.

Active learning engages students in two aspects: doing things and thinking about the things they are doing. The use of mini–games enables the child to do things: after a short and explicit instruction video, children start practicing straight away. The three–year mathematics game contains a total of 44 different mini–games that allow children to actively engage with the mathematical concepts. Each mini–game has a number of variations, leading to 160 different mini–games in the three–year game. Questions within a mini–game are based on algorithms and randomly chosen. For example, see the functional design of the mini–game for additions (Figure 35). The boxes with squares inside represent a random number. The small circle represents the answer to the problem. Answers can be chosen from three multiple choice options, shown in boxes below the addition problem. The operation, in this case addition, stays the same, while numbers can vary according to the range that is related to a specific mastery level.

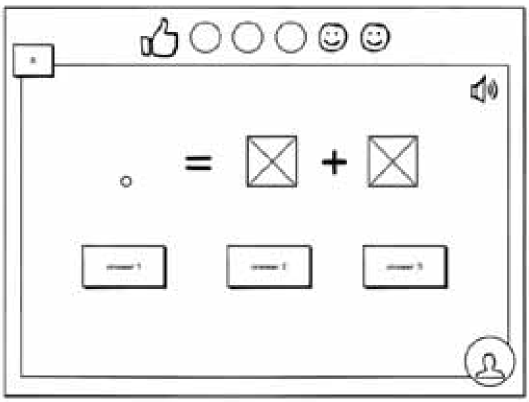
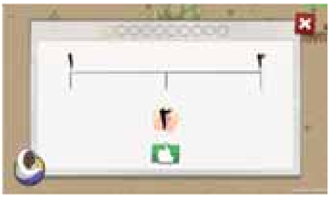
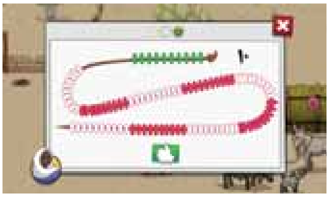


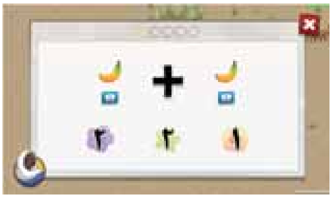
Figure 35. Functional design of mini–game for addition problems. The squares with a cross inside represent random numbers, the small circle represents the answer to the addition problem. The three answer boxes below the problem show the possible multiple choice answers for this problem.

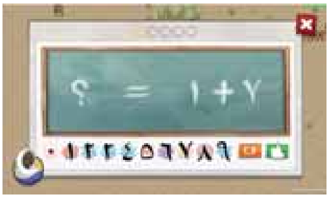
Repeating a mini–game, therefore, means repeated practice of the mathematical concept, not repeating the same questions. Also, mathematical concepts can be practised with various mini–games which should stimulate children to keep on practicing. In game design patterns this is referred to as varied gameplay, which is used to keep the game interesting, allow for different outcomes and increase replayability (Bjork & Holopainen, 2004). For example, addition under 10 can be practised by six different mini–games as shown in Figure 36.


Number line


Bead game


Bus game


Object addition


Addition problems

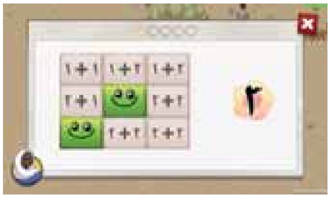

Three in a row

Figure 36. Six mini–games for addition under 10.

Number line: first, the child places a number on the number line. Then, the child is asked to add a specific number to the first number and state which number on the number line represents the answer to the addition.

Bead game: first the child separates a number of beads by moving them to the knot of the string. Then the child is asked to add a specific number of beads to the beads selected previously. The child has to state how many beads are selected in total.

Bus game: The child has to answer how many people are on the bus. Then a specific number of people get on the bus. The child has to state how many people are on the bus now.

Object addition: two sets of objects are presented. The child has to answer how many objects there are in total.

Addition problems: an addition problem is presented. The child has to give the answer to this addition.

Three in a row: an answer to an addition problem is presented. In a grid, nine possible additions are shown. The child has to select an addition problem that has the given answer as an answer. The aim is to select three addition problems in a row (horizontal, vertical or diagonal)

The first three mini–games (Number line, Bead game and Bus game) can be characterised as 'word problems'. Children are, for example, presented with the following problem: '*You have got 2 (on the number line, beads, people). Now you add 1 (on the number line, bead, person). How many have you got in all?*' These word problems have a low linguistic complexity, low arithmetic complexity (direct route) and low to medium solution strategies (single and double digit numbers) (Daroczy, Wolska, Meureres, & Nuerk, 2014). Although the Bead game and the Bus game are actually quite similar, children feel these are two completely different games. During feedback discussions they mentioned playing the 'Bead game' and the 'Bus game', indicating they saw them as two different games. The mini–game Object addition introduces the symbol '+'. In the Addition problems, the symbol '=' is introduced. In this mini–game, children can practise abstract additions, one problem at the time. The three in a row mini–game is different: the answer of a problem is given, children have to select the problems that can lead to this answer. The goal of this mini–game is to identify three possible answers (green cells) that together form a line (horizontal, vertical or diagonal). Having six different mini–games to practise one learning objective should stimulate active engagement with the learning materials because children feel they are doing many different mini–games and are not so easily bored (Jonker & Wijers, 2008).

In the game design, it is more difficult to address the second aspect of active learning, relating to children thinking about what they are doing. It is not possible to provide specific feedback to each individual child to make it think about what it is doing. Instruction and feedback is not adaptive, but designed in a more general way. In the instruction videos, however, previous mathematical concepts are related to present concepts, and the relation to everyday examples is explained.

3.2.9. Requirement 9: The game should include characteristics that increase effectivity

Although educational games in general have shown to benefit motivation (Rosas et al., 2003) and to be effective with respect to knowledge acquisition (Connolly et al., 2012), some characteristics of educational games seem to add more to effectiveness than others. To increase the effectiveness of the game, the following sub requirement should be addressed:

9.1. The game should allow children some control over order and pace.
9.2. The game should have the right balance between content and presentation.

Requirement 9.1. The game should allow children some control over order and pace.
The guided learning approach is the basis for self–paced autonomous learning. However, it does not allow children much control over order and pace in the game. The issue of learner control (agency) was addressed in the two–level game design. In the top level, the game world and narrative, children can choose themselves what they want to do first, and how much time they spend on the various elements of the game. This should give children a feeling of control. In the lower level of the game, learning is guided and children follow a specific learning path. Learning objectives, and therefore instruction videos and mini–games, appear in a specific order. Progress through the game only varies in pace, based on the number of mini–games completed successfully. Children can work at their own pace in the sense that fast learners can go through the curriculum rather quickly, whilst slow learners can take the time they need to understand the mathematical concepts, repeating and going back to instruction videos and mini–games.

Requirement 9.2. The game should have the right balance between content and presentation.
In the game design, much attention has been given to presentation to make the game attractive and motivating for the target population. This is visible in the game worlds, the narratives, graphics, and instruction videos. At the same time, these are carefully designed in such a way that they are not overly flashy: objects do not move by themselves and there is no music in the game. Where the game world includes an environment and characters that resemble the real environment, the mini–games use simple objects against a white background. Successfully finishing a mini–game is followed by small fireworks and applause.
The instruction videos are recorded in a studio that was specifically decorated; all objects that appear in the video are needed to explain the mathematical concept. Although the wall behind the actor is coloured, there are no additional decorations that could distract from the explanation.

3.3. Dilemmas in game design

Although all game requirements have been incorporated into the game design, there are four areas that required careful consideration.

(1) There seems to be a contradiction between learner control and guided learning. Motivation is increased by allowing the children to have more control. At the same time, struggling learners benefit from guided learning approach. In the game, this was solved by the two–level design. In the game world level children have a high level of control, the mini–game level is designed according to guided learning.
This means children have some control over pace, and they can go back to earlier materials, but they cannot decide what they want to learn first. Children will follow a specific learning path through the game, but can do so at their own pace.

(2) The use of tablets and self–paced learning software enables children to learn 'anytime and anywhere'. The advantage of this is that children can spend more time on learning, and show the tablet and the game to their siblings and caregivers. The disadvantage of giving tablets to children is that the social interaction between children and between child and adult can disappear completely; learning might become an isolated, individual activity. Furthermore, tablets cannot be shared between children, which is less cost–effective. They are also more likely to break or get stolen. In this programme, the tablets are, therefore, only used in learning sessions.

(3) Adaptive feedback supports children to learn from their mistakes. Although the game does provide feedback on the correctness of the answers, no feedback is given in relation to learning strategies. The most important reason for this is that it is quite difficult to do this digitally. It would either require an extensive effort to digitally identify answering patterns and link them to learning strategies, or a narrowing down of problems, with specific, scripted feedback per problem.

(4) Although social interaction between children and between child and adult is quite motivating, it was not incorporated into the game itself. The most important reason for this is that there is no reliable internet connectivity. Digital social interaction might be impossible most of the time.
Collaborative learning, with two children using the same tablet and playing together is effective, but it makes it very hard to track individual progress. As the game is based on mastery learning and relies on self–paced learning, tracking individual progress is quite important. To enable social interaction, children learn in learning sessions, with a facilitator. In this way they meet others, see how others are learning and can compare progress.

4. Developing a game design that supports learning mathematics, based on requirements

In chapter two, the requirements for the mathematics game have been identified. One of these requirements is that the game should allow children to progress to formal education in Sudan. This requirement was described in terms of curriculum and learning objectives: the curriculum in the game should be aligned with the mathematics curriculum in Sudan and it should be endorsed by the Ministry of Education in Sudan. To ensure quality, the Sudanese curriculum should be checked against internationally recognised learning objectives for grades 1, 2, and 3 of primary education. It is, however, not enough to just include the correct learning objectives. For children to master these objectives, they should be taught in an effective way and allow them to practise the learning objectives in multiple, effective ways. To address these issues, in this chapter the following research question will be answered: *How do the specific requirements for learning mathematics translate in a working game design?*

First, the Sudanese learning objectives for out–of–school children are described and checked against international standards. Then, the selection of learning objectives that will be used in the proof of concept (duration: 6 months) will be described in more detail. As the game design follows accepted ways of teaching mathematics and of sequencing of learning objectives, a short summary of both is included. After a brief overview of the game components, a number of challenges, relating to the Arabic context and to pragmatic choices, are mentioned. Then, the translation of learning objectives into the game design is discussed. The most important conclusions are summarised at the end of this chapter.

Proof of concept

Before developing the proof of concept, the complete design for a game that covers all three years of the curriculum was developed. This means that, on paper, all the mini–games and instruction videos needed were described and matched to the learning objectives. The reason for this is scalability: although at first only six months of the game was developed, it should be possible to teach the complete curriculum for grades 1, 2, and 3 in this way, when the first six months prove to be effective. There were ethical, methodological and pragmatic reasons for choosing a period of six months for the proof of concept. The most important ethical dilemmas were: Is it ethical to spend much time on a thorough design and development of the game, when so many children do not have access to education? On the other hand, is it ethical to spend a large budget on the development of a game that has not yet proved to be effective? The methodological and pragmatic reasons are listed below:

- It is long enough for children to show progress on a mathematics test. This increases the chance of finding an effect when the game is effective.
- It is long enough to allow for the testing of various learning objectives and various interaction types, increasing the possibility to generalise the results to other learning objectives and interaction types.
- It is not too long; within six months it is clear whether children in this context can learn from the game at all.
- It is not too long: development costs for a part of the curriculum are lower than for the complete curriculum. If the game is not effective, not too much of the budget will have been spent on it.
- It is not too long: during the proof of concept, research is carried out. Logistically, this is a challenge in Sudan. Keeping the proof of concept to six months makes it possible to carry it out.

4.1. Learning objectives Sudanese curriculum grades 1–3

The Sudanese curriculum for out–of–school children consists of eight 'books' for grades 1, 2, and 3. Learning objectives are not described in a separate document, as teaching follows the books. Therefore, learning objectives are implicitly included in the teaching materials. Through the study of an English translation of these books and a three–day workshop with representatives of the National Council of Mathematics and the National Council of Curriculum Development in Sudan, both departments of the Ministry of Education in Sudan, the following learning objectives could be identified (Table 1).

Table 1.

Learning objectives of the Sudanese curriculum, as identified from the books.

Sudan – books	Sudan, identified learning objectives
Numbers	Numbers up to 1,000 (recognise verbal and written numbers, and write numerals)
	Place numbers on number line, identify given number on number line
	Sequence: place numbers in the correct order, identify missing number
	More & less (incl. symbols < and >)
	Components of numbers up to 14
	Successor and predecessor
Addition	Addition up to 1,000, horizontal
	Vertical addition up to 1,000
	Addition word problems up to 100
Subtraction	Subtraction up to 1,000, horizontal
	Vertical subtraction up to 1,000
	Subtraction word problems up to 100
Multiplication	Tables 1–10, in order of tables as well as random multiplication problems, memorised, but also automated
	Vertical multiplication, 2–digit number by 1–digit number and 2–digit number by 2–digit number
Division	Tables 1–10, in order of tables as well as random multiplication problems, memorised, but also automated
Geometry	Shapes (square, rectangle, triangle, circle): passive recognition of names of the shapes and characteristics of shapes
Fractions	Recognize 1/2, 1/3, 1/4, in illustrations of objects and as a mathematical notation
Measurements	Time: read & set the clock, analogue & digital, hours, half hours and quarters
	Time: read calendar western and Islamic (days & months)
	Length: metre, decimetre, centimetre & yard, foot, inch, incl. conversion
	Weight: kilogram, gram & pound, ounce, incl. conversion

4.2. Comparing to international standards

The identified learning objectives in the Sudanese curriculum for grades 1–3, as described in the table above, were compared to international standards. For this comparison, the internationally accepted tests TIMMS and EGMA were used. The Trends in International Mathematics and Science Study (TIMMS) comprises the core cycle of mathematics up to fourth grade for the International Association for the Evaluation of Educational Achievement (https://timssandpirls.bc.edu/index.html). TIMMS has been used since 1995 in more than 60 countries. TIMMS has two tests that could be used for comparison: TIMMS mathematics–Fourth Grade and TIMMS Numeracy, a less difficult version of TIMSS Mathematics— Fourth Grade that is newly developed for TIMMS 2015 (Martin & Mullis, 2013). Both tests assess the fundamental mathematical knowledge, procedures, and problem–solving strategies that are prerequisites for success in mathematics. As both tests were developed for Grade 4, they will include learning objectives that are too difficult for the curriculum for grades 1–3.

The Early Grade Mathematics Assessment (EGMA) was developed in 2009, funded by the United States Agency for International Development and has since mostly been used in developing countries. 'The focus of EGMA is on the early years of mathematics learning; that is, mathematics learning with an emphasis on numbers and operations and on geometry through second grade or, in developing countries, perhaps through third grade.' (USAID, 2009, p. 1). Apart from differences in learning objectives due to the different grade levels that are assessed, the most important difference between these two tests is that TIMMS is a written test, and EGMA is an oral test. For a detailed comparison between these tests and the Sudanese mathematics curriculum for out–of–school children, see Appendix A. Although all three tests used for comparison do not match the grade level of the Sudanese curriculum–both TIMMS tests are meant for grade 4 and EGMA for grade 2–EGMA should cover similar learning objectives. It is intended to be used at the end of grade 2, but in the description of the test the developers indicate that in developing countries the test should probably be taken in grade 3 (USAID, 2009). Overall, six main differences between the tests and the Sudanese curriculum can be observed.

(1) The TIMMS tests do not include kindergarten learning objectives such as counting, one–to–one correspondence and quantity discrimination explicitly, as these

are taught in kindergarten. The Sudanese curriculum does not explicitly mention them either. In EGMA, these learning objectives are included. Children with insufficient knowledge of numbers and related skills such as counting, recognising quantity patterns, comparing and estimating quantities are at risk of developing mathematical learning difficulties at a later stage (Toll & van Luit, 2014). It is, therefore, important that children master these learning objectives. Children in remote villages in Sudan do not have access to kindergarten. Furthermore, opportunities to learn from everyday situations in the villages are scarce: remote villages do not have streets with street names, house numbers, shops, or newspapers. Therefore, kindergarten learning objectives should in the curriculum of the game.

(2) The TIMMS tests include learning objectives about fractions, decimals, angles, expressions and data display, that are not included in EGMA or in the Sudanese curriculum. This is because TIMMS is taken in grade 4; these learning objectives are too difficult for grade 3 children in Sudan. Also, in many Western countries these objectives are presented from grade 4 and further in a more detailed way. Although these learning objectives will not be included in the curriculum of the game, the Sudanese curriculum does give a first introduction to fractions. This will be addressed in the game as well.

(3) The Sudanese curriculum comprises more learning objectives than TIMMS and EGMA. They include weight and time; the calendar as well as the clock. These learning objectives are usually included in national curricula (e.g. see www.slo.nl), but not in these tests as they do not have the same predictive value for mathematical knowledge as number knowledge and knowledge of basic operations. As these learning objectives are included in the Sudanese curriculum, and in other curricula throughout the world for these grades, we will include these learning objectives in the curriculum of the game.

(4) There are more learning objectives for length and weight in the Sudanese curriculum as it includes the metric as well as the imperial system and conversion between the two. The reason for this can be found in Sudan's history; since Sudan used to be formally a part of the British empire, knowledge of the imperial system was added to the curriculum. As this is part of Sudan's culture these learning objectives will be included in the curriculum of the game.

(5) The order of the curriculum differs from the order used in Western countries (Resnick, Wang, & Kaplan, 1973; Raveh, Koichu, Peled, & Zaslavsky, 2016). In Sudan, children first learn all the numbers, up to 1,000, and then proceed with addition, up to 1,000, etc., instead of starting to learn addition up to 10 when they have mastered the numbers up to 10. Apart from a less optimal match to the child's natural order of learning mathematical skills, the Sudanese order will have a lower variety of activities. Mathematics games can have a positive effect on both achievement and engagement, if designed well (Girard, Ecalle, & Magnant, 2013), less variety of activities and interaction types can become boring more easily and thus less engaging. One of the other requirements of this game is that it should be motivating for children to play for a longer period of time, without additional encouragement from teachers. Following the Sudanese order of the curriculum would not support this as well as a curriculum with more variety of interaction types. An official request to change the order of the curriculum was granted by the ministry. The curriculum in the game will, therefore, teach some of the basic arithmetic operations (addition, subtraction, multiplication, and division) simultaneously instead of teaching them one after the other.

(6) Finally, although most of the internationally recognised learning objectives are included in the Sudanese curriculum, they seem to be addressed in a less detailed way. In TIMMS and EGMA components and sub–steps of learning objectives are made explicit, which facilitates the design of learning materials. The curriculum in the game will include components and sub–steps of the learning objectives to ensure children master earlier steps before moving to more difficult ones.

4.3. Learning objectives in the proof of concept

The previous paragraph describes which learning objectives will be included in the three–year curriculum of the game. As the proof of concept only lasts for six months, only a part of the curriculum will be developed into a game. The decision on the learning objectives that will be included in the proof of concept is based on the natural sequence of acquisition of mathematical skills and concepts: starting with kindergarten learning objectives, the learning objectives that are included cover more or less the first six months of this sequence.

The game uses a mastery learning approach, in which previous learning objectives have to be mastered before moving on to a more difficult learning objective. The two most important reasons for this are (1) children need a strong basis to build on, without this, they may not understand later mathematical concepts and (2) the game uses a linear, guided learning approach as there are no teacher available. This means the learning objectives need to be presented in a specific order that supports the natural sequence of acquisition of mathematical skills and concepts. Resnick et al. (1973) tested a task analytical hierarchical sequence of introductory mathematical units, and the individual objectives per unit. They concluded that counting and one–to–one correspondence for numbers should be introduced before the numerals of those numbers, especially for the lower numbers. In addition, they suggest to teach comparisons of sets after mastering the numerals up to 10. Then addition and subtraction can be introduced as concepts, followed by addition and subtraction equations. The numbers to 20 (counting and numerals) were placed after addition and subtraction. They found, however, that children had much difficulty mastering the addition and subtraction of units, while the numbers and numerals up to 20 did not create many problems. Therefore, they concluded these topics could also be rearranged, introducing the numbers up to 20 before addition and subtraction have been mastered. Based on this, a hierarchical sequence of learning objectives in the game for the first 6 months was developed (Figure 37).

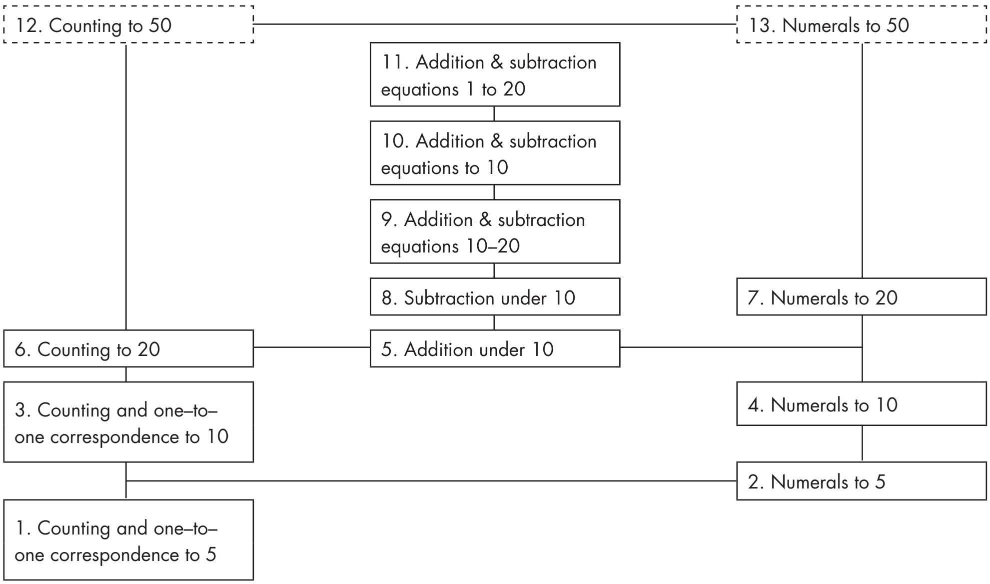


Figure 37. Hierarchical sequence of learning objectives in the game (Resnick, Wang, & Kaplan (1973), adapted).

In this sequence, addition as a concept is introduced before the concept of subtraction. This choice was made based on the characteristics of the target population: they probably do not have much mathematical knowledge before starting the game. By separating the two concepts, the pace of introducing new concepts is slightly reduced. Following the conclusions by Resnick et al. (1973) the numbers up to 20 are taught when addition and subtraction have not been mastered completely yet.

Following this sequence, learning objectives are taught in a specific order, but can be practised simultaneously. When more learning objectives show in a horizontal line, this means they are taught at the same time. This supports the child in understanding the interconnections between the concepts and increases the variety of mini–games, which is more motivating.

In addition to the learning objectives described in Figure 37, knowledge of shapes (square, rectangle, triangle, circle) was included in the curriculum of the 6 months proof of concept. Shapes are not an essential part of this phase of the curriculum, although many children know them before starting grade 1. The reason they are included is that children learn them easily, and the activities to practise them will add additional variety to the game.

The table below (Table 2) describes the sub goals per learning objective. Sub goals can be learned in sequence or parallel, depending on the sub goal. The right column in this table gives the ranges in which the children will practise the learning objectives. A smaller range needs to be mastered before moving to a larger range. Although the literature shows that the numbers up to five can be seen as one learning objective, this was divided into numbers up to three and then numbers up to five to facilitate learning for this target population.

Table 2.

Overview of learning objectives and sub goals in the game, including ranges.

Sub goal	Ranges
Numbers up to 20	
Count numbers up to 20 (1–20 in steps of 1 and in steps of 2; 20–1 in steps of 1 and in steps of 2)	1–3 1–5 1–10 1–20
One–to–one correspondence up to 20 (child is invited to pronounce numeral)	1–3 1–5 1–10 1–20
Match spoken number to numeral ('teacher' pronounces numeral)	1–3 1–5 1–10 1–20
Match numeral to set of objects	1–3 1–5 1–10 1–20
Match spoken number to set of objects	1–3 1–5 1–10 1–20
Place numerals in order	1–3 1–5 1–10 1–20
Place numerals on the number line	1–3 1–5 1–10 1–20
Identify numeral for place on the number line	1–3 1–5 1–10 1–20

Identify missing number in sequence	1–3 1–5 1–10 1–20
Addition up to 20	1–10
Components of numbers	1–10 11–20 1–20 (with carry–over)
Add two sets of objects	1–10 11–20 1–20 (with carry–over)
Use number line to add two numbers	1–10 11–20 1–20 (with carry–over)
Word problems addition (e.g. There are 3 people on the bus, two more get on. How many people are on the bus now?)	1–10 11–20 1–20 (with carry–over)
Abstract problems addition (2+3=; 14+5=; 9+4=)	1–10 11–20 1–20 (with carry–over)
Subtraction up to 20	
Components of numbers	1–10
Subtract two sets of objects	1–10 10–20 1–20
Use number line to subtract two numbers	1–10 10–20 1–20
Word problems subtraction (e.g. There are 5 people on the bus, 1 gets off. How many people are on the bus now?)	1–10 10–20 1–20
Abstract problems subtraction (7–3=; 16–4=; 12–5=)	1–10 10–20 1–20
Shapes	
Shape recognition (drawings of shapes)	Square, rectangle, triangle, circle

4.4. Design challenges

When designing the game, two main challenges had to be dealt with. One was related to time and budget, the other to the specific characteristics of Arabic.

(1) Writing numerals

Writing numerals is of great value to learning numbers. However, in this first proof of concept the writing of numerals was not included. The reason for this was that specific shape recognition software needed to be developed for the recognition of written Arabic numerals. This was time–consuming as well as costly. Moreover, it needed to be perfect: if the recognition was too strict, it would show an incorrect answer based on sloppy writing, not because the child gave the wrong answer. If the shape recognition was too permissive, it would not be able to distinguish between the different numerals; e.g. the number 2 and the number 3 look very much alike. Also, children may experience specific issues when learning to write the numbers: they may write a mirror–image of the number or switch the numbers in a two–digit number (12 becomes 21). As long as the game cannot also provide exercises to learn how to write the numbers, written answers should not be included. As a result, the choice was made to postpone this development until after the game had proven to be effective.

(2) Writing direction in Arabic

The language in the game is Arabic. The writing direction in Arabic is from right to left. A typical addition problem, therefore, looks like this:
12 = 9 + 3 or in Arabic: ١٢ = ٩ + ٣

Double digit numbers, however, do have the tens on the left side of the number and the units on the right side of the number. In the number 12, the 1 is on the left side, and the 2 on the right side: ١٢ .

There is, however, some inconsistency in the use of the writing direction in mathematics education. While children learn to place numbers in order from smaller to larger starting from the right side and going to the left, later in their learning process, this changes to left to right. This can probably be explained by the fact that more advanced mathematics is more internationally oriented, and follows the left–to–right direction. For example, the more formal number line has a left–to–right direction, while a more informal ordering of numbers is from right–to–left. The number line mini–games follow the left–to–right direction (Figure 38).

Figure 38. Mini–game Number line: Number line 1–3, the number 3 has to be dragged into the correct place on the number line.

The informal ordering of numbers is supported by the 'clothesline' mini–game; numbers need to be placed in order with the smallest number on the right and the largest number on the left (Figure 39). Audio instruction tells children to do it this way.

Figure 39. Mini–game Clothesline: The numbers 7, 8, and 6 have to be dragged into the correct order.

4.5. Translating learning objectives into game design

In his study of six cases, Drijvers (2013) concluded that three factors were decisive and crucial for success when using digital technology in mathematics education: the design, the role of the teacher and the educational context. In this research, the mathematics game will be used without a teacher in an out–of–school educational context. This means the design should include as many elements of the other two factors as possible, such as relating the experiences in the game to other mathematical activities, student motivation and engagement, and assessment.

When children start learning mathematics, there are two 'big ideas' they need to understand (Baroody, 2004): (1) counting can play several roles, involve numerous relations and can be represented in various ways. Counting can, for example, be used to find out how many objects there are in a set, or to make a set of a particular size. (2) Numbers can be operated on (computations) in various interrelated ways to model a variety of real–world transformations or situations. For example, a set of objects can be made larger by adding items to it, and smaller by taking some away from it. To achieve fluency, practice should be in a purposeful, meaningful manner, supporting reasoning and not the memorising of individual facts by rote.

Through discussions with primary school teachers (in Sudan and in the Netherlands) and an 'internal advisor' (a Dutch in–school specialist on didactics, who coaches teachers and can provide remedial teaching for children), classroom observation (in the Netherlands), and the study of mathematics books and tests, more knowledge and insights were gained for the didactic approach of the game. The two most important challenges being the translation of classroom activities to purposeful digital activities and ensuring that the actions and activities carried out by teachers are adequately addressed by the game and the facilitator.

The mathematics game consists of a game world with instruction videos and mini–games. The game worlds contain motivational elements and shows progress through the game. The instruction videos (1–3 minutes each) teach a mathematical concept, including worked examples to help children understand them. The mini–games allow children to actively practise the mathematical concepts. A more detailed description of the design of the mathematics game is given in the previous chapter. The mini–games themselves are described in Appendix B. The aim in this paragraph is to show how the elements of the game contribute to mastering the learning objectives.

Instruction videos and learning objectives

Instruction videos explain the numbers, addition and subtraction in an explicit and (one or more) correct way(s), in relation to each other. All examples used in the videos are performed correctly. To achieve this, all instruction videos, including the examples used, were scripted. The actors (children aged 12–15) were trained to explain the mathematical concepts following these scripts, even if this did not match the way they had learned them themselves. All videos were reviewed in relation to the scripts and re–taped when necessary.
In addition to an introduction of the numbers, addition and subtraction, carry–over and borrowing are explicitly addressed in separate instruction videos. As the numbers used in this phase range from 1–20, the choice was made not to explain vertical representations of addition and subtraction in an instruction video.

Mini–games and learning objectives

All mini–games generate random items according to the mathematical rules related to that mini–game, and therefore use underlying logic. This underlying logic, used to check children's answers, should be correct. When children answer correctly, their answer should be assessed as correct. At the same time, an incorrect answer should be recognised as incorrect. In addition, in multiple choice mini–games, there should always be only one correct answer. During the development of the game, much attention was given to a careful design of this logic. Once developed, the mini–games were tested thoroughly to check for any errors.

A number of mini–games address place value of digits in numbers: all mini–games using the number line and all mini–games using the string of beads. Number regrouping is introduced in the mini–games in which sets of objects have to be added to and subtracted from each other. It is also addressed in the mini–game in which beads have to be added to a set of beads that has been selected before. Moreover, the abstract addition and subtraction problems with a range of 1–20 practise regrouping of numbers.

As the learning objectives in the proof of concept stayed within a range of 1–20, the choice was made not to introduce mini–games using vertical representations of addition and subtraction.

Finally, to help children relate the concepts of addition and subtraction to each other, addition and subtraction are presented in mini–games using the same underlying concepts: counting on and counting back, using the components of numbers when regrouping them. The relevant mini–games all have variations for addition and subtraction; e.g. the bus mini–game (more and fewer people on the bus), the number line (+1 or +more, –1 or –more), the string of beads (+1 or +more, –1 or–more), addition and subtraction of sets of objects and abstract addition and subtraction problems. To help memorise simple addition and subtraction problems and their answers, the 3–in–a–row mini–games were added.

Per learning objective, the instruction videos and mini–games supporting that learning objective are described below.

Numbers up to 20
'Knowing' the numbers up to 20 means being able to count to 20, reciting the numerals as well as one–to–one correspondence when counting sets of objects. In addition, children should be able to state how many objects are in a set of objects or create a set of objects with the correct number of objects based on a numeral.

There are 27 instruction videos about numbers up to 20.
In the game, each number from 1–20 is introduced by a separate instruction video. In the video, the number is introduced in the following way:

1. The sound of the number is pronounced (a number of times)
2. The numeral is shown as a printed version
3. The correct number of objects for that number is shown (structured in rows of five objects) and counted, touching/slightly moving each object while counting (objects are recognisable everyday objects like stones or fruit/vegetables)
4. The numeral is traced with a finger to show how to write it

Then there are five videos introducing the following concepts:

- counting to 20 in steps of 1
- counting to 20 in steps of 2
- successor
- predecessor
- more & fewer

Finally, there are two playful instruction videos about counting to 10 or 20 and counting on from a given number.

- One video shows a group of 10 children. While running from one side of a playground to the other, they count themselves. Together they count from 1 to 10. While running back they again count themselves, thus counting back from 10 to 1.
- Another video shows three children playing a game in which one of them says a number, and another has to count on to 20 from that number. They take turns in saying the number and counting on.

There are eleven different mini–games that allow children to practise the numbers 1–20. All mini–games have an audio instruction that tells children what they need to do in this mini–game. All the objects presented in these mini–games are ordered in a five–structure. For each mini–game, the relevant sub goals they address are mentioned (Figure 40).

Some of these mini–games actually teach the same learning objectives, such as numbers 1 and 6. Both show a set of objects the child has to count and then select the matching numeral. Another such example is mini–games 2 and 3. In both mini–games children have to actively separate/drag the correct stated number of objects to a new place. The idea behind this is that children need as much practice as they can get. Using different illustrations makes them feel these are different games, which increases motivation.

To actively stimulate one–to–one correspondence and support counting when children are still learning the numbers, both mini–games that have a set of objects that needs to be counted (mini–games 5 and 6) have a small blue button. When pressing this button, the objects 'count themselves'. The objects move slightly up, one by one, while an audio is played in which the objects are counted (see Figure 41). This functionality is explained in the audio instruction of the mini–game.

1. How many eggs are there in the box?
   One–to–one correspondence and recognition of numerals
2. Drag the correct number of eggs into the box
   One–to–one correspondence and recognise stated numeral
3. Select the correct number of beads from the string
   One–to–one correspondence and recognise stated numeral
4. Select the stated numeral from three possible answers
   Recognition of numeral in relation to its sound when pronounced
5. Select the correct numeral for a set of objects. Choose from three possible answers
   One–to–one correspondence and recognition of numeral
6. Select the correct set of objects matching a stated numeral. Choose from three possible answers
   One–to–one correspondence and recognise stated numeral
7. How many fingers did you see? (flashcard, choose from three possible answers)
   One–to–one correspondence, recognition of numerals in combination with time limit and remembering when illustration is gone
8. How many dots on the dice did you see? (flashcard, choose from three possible answers)
   One–to–one correspondence, recognition of numerals in combination with time limit and remembering when illustration is gone
9. Place the numeral on the number line
   Place numerals in the correct order, drag a number to the correct place on the number line
10. Place the numerals in the correct order
    Place numerals in the correct order, drag a number to the correct place on the number line
11. Which number should be in the empty space (choose from three possible answers)
    Counting and place numerals in the correct order, choose one of three numbers and drag to the empty space

Figure 40. Description of mini–games that practise the numbers 1–20.

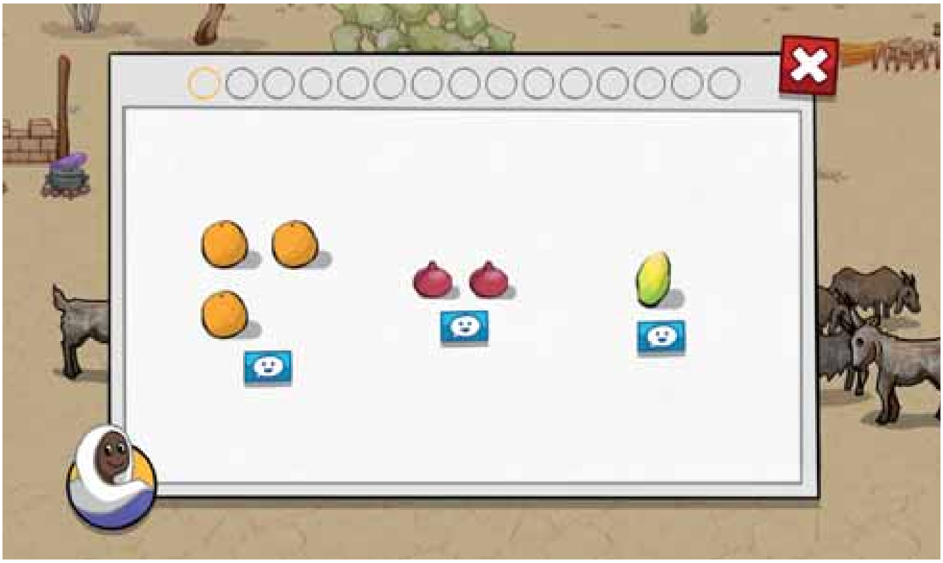


Figure 41. The blue button starts objects to count themselves.

A diverse set of interactions has been used. Some of the mini–games have a more passive interaction: the child can choose the answer from three possible answers. Others are more active: the child has to separate or drag objects or numerals actively to the correct place; active manipulation of objects will help children with one–to–one correspondence and the relation between numeral and number of objects. Finally, there are two flashcard games, with a time limit. The reason for this is that more variation should lead to more motivation. In addition, preferences may differ, in this way each child can find mini–games that are attractive.

Although a digital game is quite useful to support active learning – children are actively engaged with the learning materials, and get immediate feedback on how they have done – it is not possible to check spoken language. Reciting can, therefore, not be checked. However, the children are encouraged to recite the numbers along with the instruction videos or when they are using the blue 'count yourself' button.

Addition up to 20

Given two numbers stated, two sets of objects presented or two numerals, the child is able to add them and state the combined sum as the answer. There are two strategies for addition, the counting–based strategy and the reasoning–based strategy (Baroody, 2004). In the counting–based strategy, children count on from the first number to get to the answer. In the reasoning–based strategy, children can rewrite addition problems, regroup numbers and solve them (e.g. 8 + 4 = 8 + 2 + 2 = 10 + 2 = 12). To support reasoning–based strategies, children should be encouraged to look for patterns and relations. Finally, simple additions should be automated or memorised.

There are seven instruction videos about addition up to 20.
Addition is first introduced following a counting–based strategy, using the 'bus–concept: *There are 5 people on the bus when it stops in your village. In your village 2 more people get on the bus. How many people are on the bus now?* This concept was specifically checked before it was used. Children know the concept of a bus, and understand that people get on and off the bus to get somewhere.

The counting–based strategy is explained using a number line. This is explained in two steps: the first step is to find the place on the number line that matches the first number. The next step is to count the designated number of steps on, from that number. The point where you are on the number line then, is the answer to the addition.

There are two instruction videos introducing the symbols for '+' and '='. Using the bus concept, an addition is presented as a word problem. Then the symbol is introduced while saying that this is the way we write the word problem in a mathematical way.

Finally, three instruction videos are used to introduce regrouping and carry–over. The concept of regrouping is supported by two instruction videos, one showing that a set of objects can be divided into two sets in different ways, and another about the Friends of ten. The Friends of ten are the combinations of numbers that together make 10 (e.g. 2–8; 4–6). One instruction videos addresses carry–over.

There are nine mini–games that address addition to 20. All mini–games have an audio instruction that tells children what they need to do in this mini–game. The numbers used in these mini–games range from 1–10, 11–20 (without carry–over) to 1–20 (with carry–over). The number zero will be introduced later. For each mini–game the relevant sub goals they address are mentioned (Figure 42).

1. Bus game
   Counting–based strategy
2. Number line +1
   Counting–based strategy and successor
3. Number line + X
   Counting–based strategy
4. String of beads +1
   Counting–based strategy and successor
5. String of beads + X
   Counting–based strategy
6. Add two sets of objects
   Counting–based strategy
7. Divide objects into two groups
   Reasoning–based strategy
8. Abstract addition problems
   Counting–based and reasoning–based strategy
9. 3–in–a–row
   Counting–based and reasoning–based strategy, automation of simple additions

Figure 42. Description of mini–games that practise addition up to 20.

The bus game is actually a word problem using different combinations of numbers. The word problem is presented in audio, and supported by two illustrations which show the correct number of people on the bus before and after more people get on.

Mini–games 2 and 4 address the same concept (one more) in a different way. On the number line, children should take one step further. The answer can be found by counting on. This is a more passive interaction. With the string of beads, children should separate one more bead. This is a more active interaction. The answer can be found by either counting on or by counting the total number of beads selected. The same similarity applies for mini–games 3 and 5.

In addition, there is a similarity between mini–games 5 and 6. In both mini–games two sets of objects need to be added together. In mini–game 5, children actively separate the two sets, in mini–game 6 the two sets are presented, which is a more passive interaction.

The interaction in mini–game 7 deviates from the interaction in the other mini–games as there is no correct answer. The question is open–ended. In this mini–game children can explore how a set of objects can be divided into two sets by dragging them into two circles. Below each circle a numeral dynamically shows how many objects the child has dragged into that circle. Active manipulation of objects will help children with one–to–one correspondence and the relation between numeral and number of objects (see Figure 43).

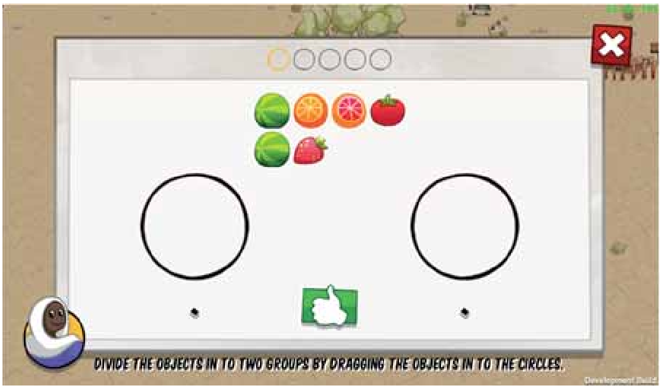


Figure 43. Screenshot mini–game: Divide objects over two circles. The English text was used for non–Arabic testers of the game and not included in the final game.

In mini–game 8, children can 'type' their answer to the addition problem using a number pad with the numbers 0–9. The number zero is included to type the number 10. Although there is a limited number of numerals to choose from, answers are 'free–input' as children can make any combination they want (see Figure 44).

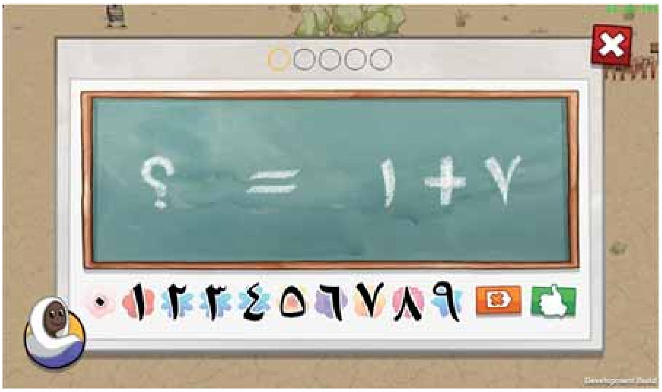


Figure 44. Abstract addition problems.

Finally, mini–game 9 shows a variation of addition problems, in a playful way (Figure 45). Instead of calculating the answer of the addition, the answer is given. In a 3x3 grid, nine addition problems are presented, in a structured way. The child has to select (one of the) additions that have this answer. The goal is to get three correct answers in a row, either horizontally, vertically or diagonally. When there are more correct addition problems, the child should choose the one that will get three correct answers in a row. This mini–game was developed in a 4x4 and 5x5 grid as well, for increased difficulty.

Figure 45. 3–in–a–row: the answer is 3, the child has to choose one of the problems that has this answer.

Subtraction up to 20

Given two numbers stated, two sets of objects or two numerals, the child is able to subtract the smaller from the larger and state the remainder as the answer. In subtraction, the same strategies as in addition apply: a counting–based strategy and a reasoning–based strategy. The counting–based strategy in subtraction uses counting back. The reasoning–based strategy uses rewriting of problems and regrouping of numbers before solving them (e.g. 12–6 = 12–2–4 = 10–4 = 6). There are four instruction videos introducing subtraction. In the videos, subtraction is introduced in a similar way as addition, using the bus–concept and the number line. The explanation starts by reminding children we have used these concepts for addition, but that we can also use them for subtraction, as addition and subtraction are related topics. Then, the symbol '–' is introduced, as the mathematical way of writing subtractions. The instruction videos referring to regrouping are not explicitly repeated, but children can always watch them again. The last video is about borrowing.

All mini–games that were described for addition, also have a variation for subtraction. There is one exception to this: the mini–game in which a set of objects is divided into two sets does not change for subtraction.

Shape recognition

The shapes (square, rectangle, triangle and circle) are introduced by one introduction video per shape with the following elements:

- The name of the shape is pronounced.
- A real–life example of the shape is shown
- Using the real–life example, the characteristics of the shape are described (number of corners and sides)
- A line–figure of the shape is shown, repeating the characteristics

There are two mini–games that allow children to practise the combination of name and characteristics per shape.

1. Select the correct shape
2. Find all illustrations for this shape

The first mini–game helps children to match characteristics to the name of the shape. The shapes have one illustration each, and these are shown in an organised way. The second mini–game is more playful. The child should tap all shapes that match the stated shape (Figure 46). The shapes are not organised–sometimes only part of a shape shows – and it is not immediately clear when an answer is complete (tap ALL shapes).

Figure 46. Screenshot Find all shapes.

4.6. Conclusion

The Sudanese curriculum for mathematics grades 1–3 shows much overlap with the learning objectives tested in EGMA (grade 2/3) and TIMMS (grade 4). There are some differences regarding fewer learning objectives in the Sudanese curriculum on some topics and more learning objectives on other topics. In addition, the order in which the learning objectives are taught is different, and the Sudanese curriculum contains less detail per learning objective. Based on the characteristics of the target population, the choice was made to include the kindergarten learning objectives and leave out the more difficult learning objectives mentioned in TIMMS (grade 4). The country specific learning objectives on length and weight – metric and imperial systems – were maintained in the curriculum of the game, as was time. The Sudanese Ministry of Education approved a change in the order of the curriculum to match the more accepted natural sequence of acquisition of mathematical skills and concepts. Last but not least, in the curriculum of the game, all learning objectives are addressed in a more detailed way, teaching components and sub–steps of the mathematical concepts.

The natural sequence of acquisition of mathematical skills and concepts (Resnick et al., 1973; Raveh et al., 2016) was used to determine which learning objectives to include in the six month proof of concept. Following the order in which mathematical concepts should be taught, an estimation was made of how many learning objectives to include for six months of learning.

The proof of concept includes four learning objectives and their sub goals: numbers up to 20, addition up to 20, subtraction up to 20 and shapes (rectangle, square, circle and triangle). For each of these learning objectives, a detailed description is provided on how they are supported by instruction videos and mini–games. Instruction videos are brief, explicit introductions to the mathematical concepts; one instruction video per concept, 1–3 minutes each. Mini–games provide active practice of learning objectives. To increase the diversity of interaction types, some mini–games have a more passive interaction, others are more active. Learning objectives are addressed by more instruction videos and more mini–games. Sometimes, only the graphic component of a mini–game is different, while the actual interaction is the same. The reason for this is to have enough repetition to learn, but still give children the feeling they are playing different games. This should be more motivating (Xiang, McBride, & Bruene, 2004). The instruction videos support the mini–games as the introductions and examples given in the videos are the same–or similar – as the interactions in the mini–games. This careful design should support mastery of the learning objectives.

5. Can children learn from playing the game?[2]

In Sudan, almost 3 million children do not have access to education. This research aims to contribute to solving this issue by providing quality education using an educational game. In this phase, the choice was made to start with mathematics. First, the requirements for an educational mathematics game for out–of–school children in remote villages in Sudan were identified. In addition, specific requirements related to learning mathematics were identified. Based on these requirements, the design of the game was developed. Much attention was given to the context – rural, remote villages in Sudan, without electricity, running water, internet connectivity or schools – and to the target population – girls and boys, 7–9 years old who have never been to school before and are not familiar with technology.

Although the resulting game is based on requirements and grounded in literature and context, this does not guarantee children can learn mathematics by playing the game. As game–based learning is completely different from the formal school system in Sudan, and the targeted children in remote, rural communities have never been to school before, a proof of concept was needed before the three–year curriculum could be gamified. The most important question that needs to be answered in this phase is: *Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?* Following the 'fastest route to failure', a small part of the game (approximately six weeks of the curriculum) was developed and tested in three remote communities in White Nile state in Sudan.

5.1. Method

This study used a pre–test–post–test control group quasi–experimental design. Participants were 67 children in three remote communities in White Nile state (Mona, Om Tifag, and Wad Almoshmer), aged between 6–11. The control group

[2] *A previous version of this chapter was published as: Stubbé, H., Badri, A., Telford, R., Hulst, A. van der, & Joolingen, W. van (2016). E–Learning Sudan, Formal Learning for Out–of–School Children. The Electronic Journal of e–learning, Vol. 14, issue 2, 2016 (pp. 136–149) And Stubbé, H., Badri, A., Telford, R., & Hulst, A. van der (2015). E–Learning Sudan, formal learning for out–of–school children. Proceedings of 9th European Conference on Game Based Learning, 8–9 October Steinkjer, Norway.*

consisted of 19 children in a fourth remote community (Om Okaz). None of these children had been to school before. The experimental group used the game for a period of six weeks, five days a week, 45 minutes a day, while supervised by a facilitator. The control group did not receive any education in the same period. In addition to the test results, the following data were collected: attendance & motivation (observed by facilitator) and the logged data in the mathematics game.

Participation

In the communities, all children between the ages 6 and 12 that had never been to school before were invited to participate in the experiment. Parents were informed about the goal and the method of the pilot. Moreover, the community was involved in setting up the 'learning centres' (huts where the children gathered to learn).

A total of 86 children participated in the pilot; 67 of them were in the experimental group, 19 were in the control group. There were more boys than girls, in the experimental condition (56%–44%) as well as in the control group (60%–40%). This reflected the situation in the communities; girls were not excluded from the pilot. There was no significant difference in participation of girls and boys between the experimental communities and the control group. The children's ages varied between 6 and 11, with most children at the age of 8 and 9. There was no significant difference between the average age of children in the experimental condition and the control group (8.3). In the experimental condition the percentage of 7 and 8–year–olds was higher, though. The average age in this group was influenced by three 10–year–olds and an 11–year old.

Table 3.

Number of participants, per village and per measurement.

	Mona	Om Tifag	Wad Almoshmer	Om–okaz	Total
Pre–test	20	24	23	19	67 + 19
Observations	20	22	18	–	60
Logged data	20	22	18	–	60
Post–test	19	20	15	19	54 + 19

In the experimental group, a total of 67 children participated in the pre–test. 54 of them did the post–test as well (Table 3). There were various reasons for this difference. In Om Tifag two boys achieved high scores on the pre–test. Further inquiry showed they had been to school before; because of this they were excluded from the pilot. In Wad Almoshmer, a six–year–old boy from another community became very homesick after a few days and was returned to his own community. He did not participate in the pilot any further. In Mona, one girl refused to answer on the post–test. Her data were, therefore, excluded. Apart from these four, 9 more children did not take the post–test. Three children were not present during testing, six had dropped out of the experiment for reasons unknown (10%).

Learning sessions and hardware

Children were assigned to morning or afternoon learning sessions, according to their parents' wishes. In this way learning could fit in with their chores and household tasks. As there were two learning sessions a day, the hardware could be shared. In this pilot laptops were used. Each laptop was used by two different children. Consequently, hardware stayed in the learning centre, locked away until the next session.

Figure 47. Learning session in one of the villages.

Facilitator

Each community had one facilitator. A facilitator encourages the children to work with the mathematics game and helps them with technical problems. They are not supposed to teach or explain the principles of mathematics. Facilitators were trained to take this role and to solve technical problems. During the week, they lived in the communities, in the weekends they could go to their own homes.
During the experiment one facilitator was replaced because he had not followed instructions; he lived in a community nearby, and walked home every day instead of living in the community during the week.

Observers

Local observers from the NCLAE attended the learning sessions twice a week, to observe if the facilitator followed instructions. They were also trained, according to a test protocol, to take the mathematics test with the children.

Staggered approach

A staggered approach was used: the pilot started in Mona, after two weeks Om Tifag started. Last of all, again two weeks later, Wad Almoshmer started. In this way the start of the pilot in each community could be supported by all observers and supervisors. Moreover, the technical issues that arose in the first community could be solved before the other communities started. The control group, Om Okaz, was tested later, but also with a six–week interval between pre–test and post–test.

Mathematics test

An oral test was used because it could not be assumed children were literate. This test was designed on the basis of EGMA (USAID, 2009), and consisted of 30 items (maximum score was 60 points), covering the very basics of mathematics: oral counting, number identification, one–to–one correspondence, quantity discrimination, word problems, addition and writing down numbers. The numbers in this test ranged from 1 to 10 (Appendix C). The same test was used as a pre–test and post–test.

Motivation & attendance

Each day, facilitators were asked to keep notes for attendance and motivation of children. Attendance was marked as 'yes' or 'no'. When the reason for absence is known, this is added to the notes. Motivation was scored on a 4–point Likert scale, ranging from not motivated at all to very motivated. Facilitators' observations are based on 'time on task' and the way the child speaks about the learning sessions and the game.

Logged data

The following actions children take in the game are logged:

- Number of days played (with date stamp)
- Time played per day
- Number of mini–games played
- Number of mini–games completed
- Number of mini–games completed without mistakes
- Number of items (in mini–games) played

Test protocol

As the children live in remote communities, it was assumed they had not been tested before in any formal way. Reports on the testing of children in developing countries mention that children are shy to answer any questions at all (Kanu & van Hengel, 2013). To make sure children were as comfortable as possible taking the test, observers (NCLAE) travelled to the communities a day early, stayed the night and built relationships. The test was taken on the second day. A test protocol was designed and observers were trained to use it. During testing, a local supervisor (NCLAE) was present to ensure that the testing was performed according to protocol.

Technical issues

There was one technical issue in the first week in the first community. The game depends heavily on audio and video, as the children cannot read and write. In the first few days of the pilot, it became clear that the children would need earphones to be able to hear the instruction from their own laptop. This was arranged within a week and was solved before the pilot started in the other two communities. Furthermore, there was a software problem: the first four levels in the game were adequately developed. For the fifth level, the instruction video had not been included, which made it difficult for the children to understand what they needed to do in that level.

Data collection

Although unique numbers were used to ensure anonymity, some observers did not use the numbers and only wrote down the names of the children. As Arabic names are written phonetically in English, they can take many different forms. Therefore, it was hard to match the collected data for nine children. In collaboration with the observers, the names were matched with the unique numbers.

Ethics

The ethics committee of the Ahfad University for Women in Khartoum has approved this pilot study. In addition, agreements have been signed by White Nile State and the participating communities. Parents have signed consent forms for their children to take part in the experiment and to be photographed. All facilitators have signed a child safety protocol. All data collected in this pilot are related to a child–specific number. This is done for privacy reasons, as well as for pragmatic reasons (Arabic names can be spelled in different ways in English).

5.2. Results

The experiment was conducted in the period of December 2012 to February 2013. This paragraph describes the data collected using a mathematics test, logged data and facilitator observations.

Test results

The experimental group had an average of 33% correct answers on the pre–test (N=67, M=20.3, SD= 11.5). The control group had an average of 28% correct answers on the pre–test (N=19, M=16.5, SD= 5.6). An independent T–test showed no significant differences on the scores of the pre–test between the experimental group and the control group (t=–1.4283, fd=79, p=0.16). The average score of the experimental condition on the post–test was 55% correct (N=54, M=33.1, SD=15.5), the control group showed a slight increase to 29% correct answers (N=19, M=17.2, SD=5.3). An independent T–test showed a significant difference between the post–test scores of the experimental condition and the control group (t=–4.5059, df=79, p=0.00). Furthermore, an independent T–test showed significant differences on the delta scores (post–test–score minus pre–test–score) between the experimental group and the control group (t=9.1, df=71, p=0.00) (Figure 48). This means the experimental group has learned significantly more than the control group.

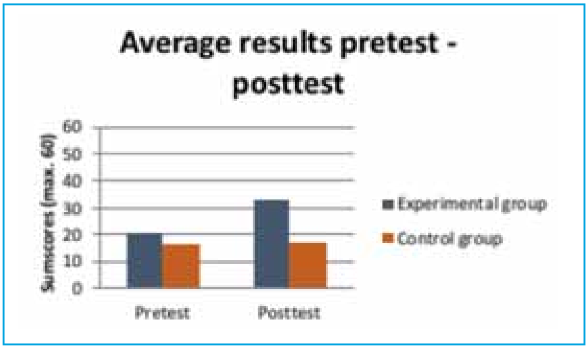


Figure 48. Results pre–test – post–test.

All the children that played the game have increased their scores on the mathematics test. The children that did not play the game (control group) have not improved their score from pre–test to post–test. Moreover, in the experimental group, the children with a lower score on the pre–test increased their scores more than the children with a higher score on the pre–test. The increase of scores varied between 9 and 42 points. There were no significant differences between boys and girls or between the different age groups.

This average score on the test is an indication of what the children have learned. The specific measures used in the test provide more insight in children's knowledge and skills. Table 4 (below) shows the percentage correct per measure, for each measure there were a number of questions.

Table 4.

Percentage correct per measure, pre–test and post–test.

Measures	**Experimental condition**		**Control group**	
	Pre–test	Post–test	Pre–test	Post–test
Oral counting	29.8%	70.5%	33.3%	38.3%
One–to–one correspondence	89.6%	100%	95.8%	97.5%
Number identification	28.3%	87.5%	23.3%	29.2%
Quantity discrimination	47.8%	95.8%	30.0%	35.0%
Word problems (addition)	29.5%	53.3%	17.5%	21.3%
Addition	23.1%	58.8%	17.3%	17.3%
Writing	49.3%	78.5%	48.8%	51.3%

In the experimental, as well as in the control group, the percentages correct on 'one–to–one correspondence' are notably high in the pre–test. The percentages correct on 'quantity discrimination' and 'writing' are higher than the percentage correct on the other measures for both the experimental as well as the control group. Children in the experimental group as well as in the control group improve their scores on all measures, except for the control group on 'addition'. The increase of scores, however, is much higher in the experimental group than in the control group. With 'one–to–one correspondence' this is only 10.4%, likely due to a ceiling effect: the scores on the pre–test were very high, improvement to 100% was only 10.4%. The children in the control condition improved their percentage correct as well, but only with a few percent points per measure.

Logged data

The logged data show that with a few exceptions all the children used the game five days a week during the pilot period. Approximately 30% of the children completed all the materials in the game. The other 70% of the children finished between 50–70% of the materials. The children that had finished before the pilot ended were told to start again from the beginning.

Observations

Observation forms were filled out daily; facilitators scored attendance and motivation for each student. Children played the game for six weeks, five days a week; totalling 30 days. The observation forms show that most children were present during the learning sessions and that they were motivated to learn most of the time (Figure 49). There were differences in motivation in the communities at the start of the experiment. Motivation in Mona was 2.5 at the start of the pilot and decreased from day 1. The reason for this was that there were no headphones, and children had difficulty hearing the audio and video in the game. On day 5 headphones were introduced, from that day motivation increased and was back at the starting point on day 7. During the pilot motivation kept increasing at a more steady pace. In Om Tifag, motivation was rather low at the start of the pilot. The reason for this is not entirely clear. Up to day 7, motivation increased strongly, during the rest of the pilot it stayed more or less the same. In Wad Almoshmer, motivation was very high for the first two weeks. After that, it decreased to an average level, and stayed more or less the same for the rest of the pilot. It is not entirely clear why motivation was so high at the beginning. This might be because that they were the last village to start playing the game, and were very much looking forward to it. The average motivation increased during the six weeks (from 2.7 to 3.2 on a 4–point scale).

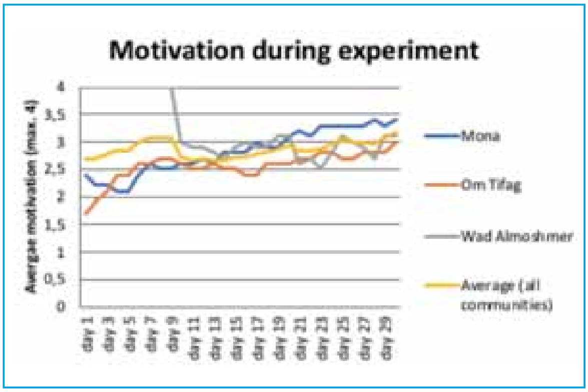


Figure 49. Motivation during experiment.

In addition to the observation forms, facilitators shared their overall observations at the end of the pilot. They mention children loved the instruction videos very much, and some watched them twenty times. When asked about this, children would say that the older children in the videos were their big brother or sisters (role model); 'If she can do it, I can do it as well!' They also loved the many games and the colours in the game.

Initially, the children were rather shy. As the experiment continued and observers came to the communities more often, the children became more outgoing. They were very proud of what they had learned and wanted to show their improvements. Also, adults were more engaged in a range of activities and were interested to learn themselves. One of the children participating in the experiment was a boy who was physically handicapped. Because of his slurred speech, people thought he was retarded as well. He performed very well with an average improvement of 15 points. He is now more accepted by the other children, and even his speech has improved.

After the six–week experiment, the children were taught by teachers in their own community for the rest of the school year. At the end of this period they were tested by a nearby school. Ten children were admitted to Grade 4, five children were admitted to Grade 2 (which would be normal progression) and the rest was admitted to Grade 3. The progress of the ten children admitted to Grade 4 was followed carefully. At the end of Grade 4 they were the top 10 of their year. This shows that the children not only learned their mathematics, but also formed a strong basis for further development.

5.3. Discussion and conclusion

In this pilot we aimed to test if children in rural areas in Sudan could learn mathematics autonomously by playing a mathematics game on a computer. All the children in the experimental condition have improved their scores on a mathematics test significantly in the six weeks that they used the mathematics game. During the same period the control group, who did not play the mathematics game, did not improve their scores. This proves that the increase in mathematics scores in the experimental was not caused by maturation or a test effects – as a result of taking the same test within six weeks – but by playing the game. This shows that children can learn by playing the mathematics game, with only a facilitator to supervise them. There was no significant effect for gender; the game is as effective for girls as it is for boys.

The increase in scores varied between 9 and 42 points. In general, children with a lower score on the pre–test improved more than children with a higher score on the pre–test. This is probably due to a ceiling effect: the game and the test focused on the very beginning of mathematics. Children that already had some knowledge of mathematics achieved a higher score on the pre–test and thus had less room for improvement. In addition, the game taught the basics of numeracy and addition. Children that knew how to do this could not learn very much from the game. They were the ones that went through the initial mini–games quickly. Others took longer to understand the basics of numeracy.

The percentage correct of all measures increased in the experimental condition. Four of the measures increased most: ‘oral counting’, ‘one–to–one correspondence’, ‘number identification’ and ‘quantity discrimination’. The version of the game used in this experiment specifically teaches these subjects. This shows that the game has a strong effect on the increase of knowledge on the subjects taught. Writing was not part of the game, and the instruction video for ‘addition’ had not been implemented. The percentage correct on these measures increased significantly, but not as much as on the other measures.
When children learn autonomously, without a teacher to give instruction, feedback

and motivate them, there is always the issue of motivation. Will children stay motivated to keep on learning for a longer period of time? During the six–week experiment average motivation stayed high, and even increased slightly. There were some differences between the communities: in Mona there was a decrease in motivation during the first week. This can be explained by the fact that the children did not have headphones and could not hear the instruction. After this was solved, motivation increased again. In Wad Almoshmer, motivation in the first week was at a maximum. Later, motivation decreased towards a more average level. Although six weeks (30 days) is quite long for a pilot, it may prove difficult to keep children motivated for an even longer period of time. This should be researched in a longer pilot.

The most important goal of this study was to gather evidence that children can learn by playing the mathematics game autonomously. As this method of learning is completely different from what is generally used in Sudan, a 'proof of concept' was needed before the rest of the game was developed. This experiment has showed just that, and so much more. Children, and parents, in remote rural communities are very motivated to learn when they are given the opportunity. The assessment by nearby schools showed that all children in the experimental group learned as much or more than children in the same time in formal education. Children, and parents, became more active and outgoing during the six–week experiment. Because all children in the communities could participate, a boy that was assumed to be retarded was involved in the experiment. He was able to play the game and learn. This has changed the way others see him, and improved his quality of life.

At the same time, this was only a small experiment in three communities in one state in Sudan. A larger experiment, with more children, in more communities and more states is needed to confirm that these positive results can be repeated with a larger group of children from various backgrounds, over a longer period of time, teaching more, and more difficult mathematical concepts.

6. Sustained learning: Can children learn longer and more from playing the game autonomously?[3]

White Nile state is characterised by its strategic location in central Sudan. The state area is 39,701 km² and the climate of the state has hot, humid rainy summers (June to September) and warm dry winters. About 33% of the state consists of plains. The estimated state's population is about 1,730,600 people, equivalent to about 5% of the total population of Sudan (NSDDRC–SC/ UNDP, 2010).

The state of **North Kordofan** lies in the dry zone in central Sudan. North Kordofan state covers an area of 244,700 km². It is largely an undulating plain, with the Nuba Mountains in the southeast quarter. During the rainy season from June to September, the area is fertile, but in the dry season, it is virtually desert. The estimated population is 3,340,000, equivalent to about 10% of the population. For centuries, North Kordofan was inhabited by nomads and pastoralists. More recently, North Kordofan can be characterised as a conflict–affected state as well: IDPs fleeing the conflict in South Kordofan, settle in North Kordofan. (NSDDRC NKS–SC / UNDP, 2010).

Gedaref state has an area of 75,263 km² and an estimated population of approximately 1,400,000, equivalent to about 4% of the population. The state is characterized by vast land suitable for agriculture. The rainy season lasts from June to September.

[3] *A previous version of the chapter was published as: Stubbé, H., Badri, A., Telford, R., Hulst, A. van der, & Joolingen, W. van (2016). E–Learning Sudan, Formal Learning for Out–of–School Children. The Electronic Journal of e–learning, Vol. 14, issue 2, 2016 (pp. 136–149)*

The results of Pilot I show that children in remote communities in Sudan can learn mathematics by playing the game. Although learning results were positive and motivation stayed high, this was only a small pilot: it lasted six weeks, and involved a total of 67 children in the experimental group and 19 children in the control group from four different communities in White Nile state. Now that a first proof of concept has been established, a scaled trial can provide information on the effectiveness of the game–based learning approach when used for a longer period of time, with more children, and in various contexts. The question that needs to be answered is: *Can out–of–school children in remote villages in Sudan learn mathematics for a longer period of time, covering a diversity of learning objectives, by playing the game autonomously?*

This pilot aims to study the learning results of Pilot I in a larger pilot, lasting six months and involving approximately 600 children in the experimental condition and 300 children in the control group from 30 communities in three states in Sudan: White Nile, Gedaref and North Kordofan.

The most important questions that need to be answered are: *(1) Can children learn more, and more difficult mathematical concepts by playing the game autonomously for a longer period of time? And (2) Can children learn as much as, or more than children enrolled in regular education, by playing the game autonomously?*

From laptop to tablet

After the first pilot, due to a change in legislation, it was no longer possible to bring refurbished laptops into Sudan. New laptops would be too expensive for the sustainability of the programme. Therefore, the choice of hardware changed from laptops to tablets. One of the most striking differences between laptops and tablets is screen size. A study by Reeves, Lang, Kim and Tatar (1999) shows that screen size has an effect on learning: students pay more attention to a larger screen. In addition, smaller screens may create problems with visual perception (Chen, Chang, & Wang, 2008) and small screen size offers only small space for display, thus presenting less data at the same time. This may create difficulties for students when they use the device for complex tasks (Maniar, Bennet, Hand, & Allan, 2008; Chen & Lin, 2016). Moreover, novice learners need a larger font size to be able to read numbers and letters (USAID, 2014). This is why 10.1'' screens are used. On the other hand, tablets have many advantages as well, ranging from intuitive use, touch screens,

overall size and weight, resistance to lower dust, battery life, to lower costs.
As the game design had been made with laptops in mind, changing to a tablet required a number of changes in relation to fitting the content on the smaller screen size. For example, fitting the string of beads into the smaller screen was challenging: the individual beads must stay large enough for children to be able to select one bead by tapping it. This was even more challenging because selecting a bead in the laptop uses the mouse (arrow), which is smaller and more accurate than tapping a touch screen with a finger.

This means a third question needs to be answered in this pilot: *(3) Is the tablet game as effective as the laptop game?*

6.1. Method

This pilot used a pre–test – post–test control group quasi–experimental design. Participants were 591 children in 19 remote communities in three states in Sudan (White Nile, North Kordofan and Gedaref), aged 7–9. The control group consisted of 325 children in 10 additional remote communities in the same three states.
The experimental group used the tablet game for a period of approximately six months, for a maximum of five days a week, 45 minutes a day, in learning sessions while supervised by a facilitator. The children in the control group were enrolled in regular, informal education; they attended two mathematics lessons a day of 45 minutes each, taught by a teacher in out–of–school centres. Three types of research instruments were used: in addition to mathematics tests, taken by observers, the internationally validated Early Grade Mathematics Assessment (EGMA) was taken by independent consultants. Finally, logged data were collected from 532 accounts.

The set–up of the second trial is quite similar to the first one: the children played the game in learning sessions, supervised by trained facilitators. The tests were taken by local observers. Parents were involved and participated in setting up the learning centres, and the Ahfad university for Women in Khartoum approved the research plan. To avoid repetition, the headings below only describe the specific situation of pilot II, not the general set–up as described in the previous chapter.

Participation

In the communities, all children in the relevant age group were invited to participate. Participation of boys and girls was almost equal (49% of the participants were boys, 51% were girls). The average age of the participating children was 7.8 years. Children in North Kordofan were slightly younger (average age 7.4 years), compared to the children in Gedaref (8.0 years) and White Nile (7.9 years).

Three children were excluded from the experimental group; one because he was too young (6 years old), two because they had been to school before. Facilitators reported that 57 children dropped out during the pilot. Five more children were excluded on the basis of the logged data: their logged data showed they had only played the game for a short period, and not finished it. On the other hand, children who had played the game for a short period of time, and had finished it, were included in the analyses. This brings the drop–out rate to 10%. An analysis of the demographic information of the children who dropped out showed no significant effect for gender or age. The data of the remaining 526 children was used in further analyses.

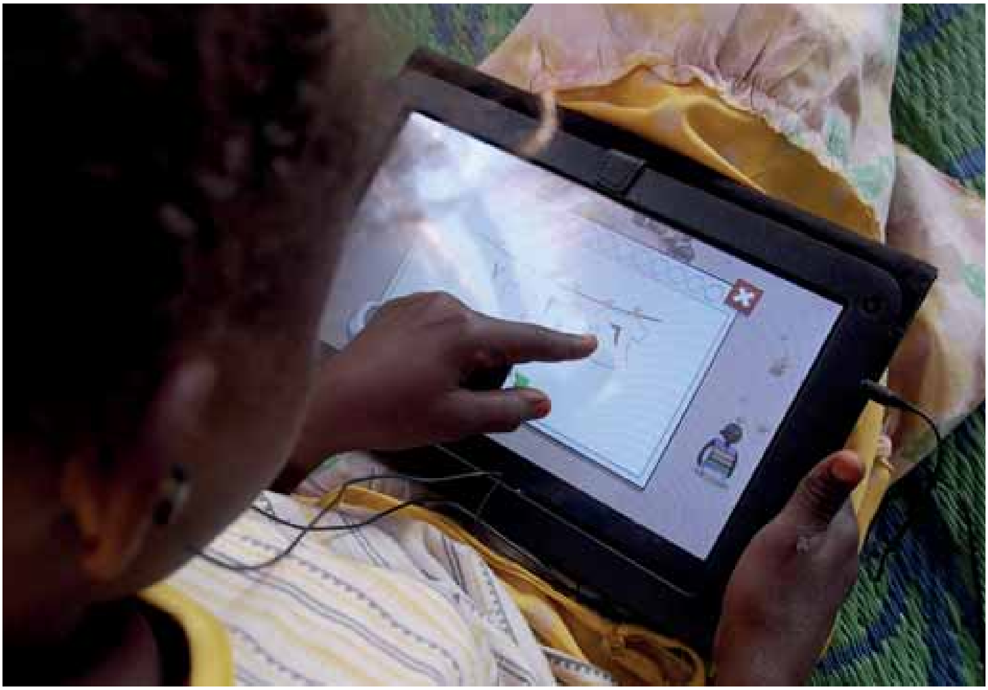


Figure 50. Girl playing the game in one of the villages.

There were some issues with the data collection in the control group: the pre–test and post–test were not taken at the designated times. In Gedaref, the pre–test was taken two months after the children in the control group had started their lessons. Because of this, all data from the Gedaref control group (100 children) was excluded from further analysis. In White Nile and North Kordofan, the pre–test of test A was taken at the correct time in the control group; the post–tests, however, were taken later than planned. Instead of an interval of 6–8 weeks, the post–test was taken after three months in North Kordofan (45 children) and after six months in White Nile (180 children). Consequently, the results for the control groups from these two states were analysed as two different sets. There were no post–test data for 14 children in North Kordofan and for 34 children in White Nile. The data of the remaining 177 children was included in further analyses.

Because of logistic issues, logged data were not collected for two communities (57 children). Also, the matching of logged data to the test data proved difficult, because the facilitators had not used the unique child numbers for this, but had instead used the child's name. Because names in Arabic can be spelled in different ways in English, it was impossible to match 23 files of logged data to children. For 449 of the children in the experimental condition logged data were available and included in further analyses.

Facilitator

In general, communities had two facilitators, taking turns supervising the learning sessions. In White Nile, however, there were four communities in which the only facilitator left in November 2014, and the new facilitator(s) started in January 2015, leaving a one to two–month interval during which learning sessions were not supervised.

Test protocol

The test protocol included four mathematics tests (A, B, C, and D) to be used as pre–test and post–test for all children in the experimental group, and test A for children in the control group. In addition, EGMA (Early Grade Mathematics Assessment, USAID, 2009) was included with a stratified sample of 210 children in the experimental group, at the end of the pilot.

Tests A, B, C, and D were designed on the basis of the EGMA, and consist of 30 items each (maximum score 60 points), covering the very basics of mathematics. Tests A and B cover oral counting, number identification, one–to–one correspondence, quantity discrimination, word problems, addition and writing down numbers. In test A the numbers ranged from 1 to 10 (Appendix C), in test B the numbers ranged from 1 to 20 (Appendix D). Test C tests missing number 1–20, quantity discrimination up to 20, word problems, addition up to 20 (with and without carryover), subtraction under 10 and shapes (square, triangle, rectangle and circle). Test D is similar to test C, but adds subtraction up to 20 (with and without borrowing). Although four tests had been designed, only two were taken during the pilot: tests A and B. The reason for this was that, logistically, it proved difficult to travel to the communities to take the tests. The availability of cars, travel permissions and muddy roads during the rainy season prevented the local observers from travelling to the villages sometimes. Also, the pre–test of test B was taken later than planned. Intervals between pre–tests and post–tests were according to protocol.

Technical issues

There were some technical issues during this pilot. Two mini–games did not function properly, which made it impossible to give the correct answers. These bugs were fixed within two weeks. As a result of the iterative development process used, two updates of the game had to be installed during the pilot period. The progress in the communities in North Kordofan, where the pilot started first, was faster than anticipated: they had to wait two weeks before the first update could be installed.

Pilot II was carried out in the period of October 2014 to March 2015. During the pilot, three types of data were collected: (1) test results on mathematics tests, taken by observers, (2) logged data, and (3) EGMA scores, taken by independent, external consultants with a stratified sample of the children (210). The experimental group was tested using tests A and B. The control group only took test A, as a pre–test and a post–test. The rationale behind this was that the official order of the mathematics curriculum is different from the order in the mathematics game. Test B tests mathematical concepts that children in regular education have not been taught at that time.

6.2. Results

In this section, first the results on test A will be described, including a comparison with the control group. Then, the results on test B for the experimental group will be described. Finally, the results on EGMA are described and compared to the results of the experimental group on test A and B.

6.2.1. Test A

To assess if children have increased their scores on test A, an Anova repeated measures (SPSS GLM) test within subjects factor: Math–A–PRE en Math–A–POST was used. On average children in White Nile, North Kordofan and Gedaref scored 33% correct on the pre–test of test A (20 of a max. of 60 points). The average on the post–test of test A was 68% correct (41 points). This increase is significant (F(1,499)=1170.929; p< .001); r=.85). There were significant differences between the states (F(2,99)=21.710; p < .001; r=.29); White Nile has a higher score than North Kordofan and Gedaref on the pre–test (24 points compared to 16 and 19) as well as on the post–test (47 points compared to 40 and 37) of test A. Posthoc tests (Bonferroni) show that White Nile differs significantly (p < .001) from the other two states (Figure 51).

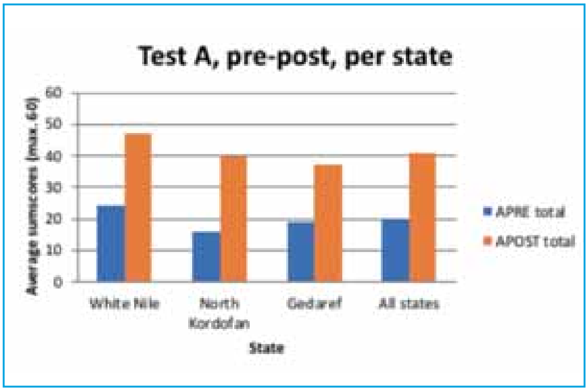


Figure 51. Average test scores test A, pre–post, per state.

There is a significant interaction between mathematics results and State F(2,499)=9.055; p < .001; r=.21). All three states perform better on the post–test than on the pre–test, but Gedaref has a relatively smaller increase of scores from pre–test to post–test (18) than White Nile (23) and North Kordofan (24). This can partly be explained by the significant differences between age groups, with older children having higher scores than younger children (F(2,499)=14.758; p < .001);

r=.25) (Figure 52). The average age in North Kordofan was lowest, in White Nile and Gedaref children are older.

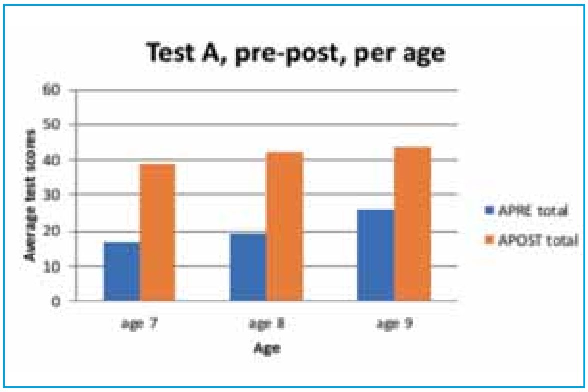


Figure 52. Average test scores test A, pre–post, per age.

Moreover, children with a lower score on the pre–test showed a larger increase in scores than children with a higher score on the pre–test (F(2,488) = 29.17 p<.001, r=.11). This can partly be explained by a ceiling effect: if children have a higher score on the pre–test, there is less room for improvement. In addition, the first levels of the game addressed more basic mathematical concepts. If children already mastered these, they could not learn much in these levels. There were no significant differences for gender: scores as well as increase of scores were similar for boys and girls.

Because of the data collection issues with the control group regarding the timing of testing, differences between the experimental group and the control groups must be interpreted with caution. As the Gedaref data had to be excluded because the pre–test was taken after the lessons had started, and the timing of the post–test was different for North Kordofan and White Nile, comparisons are made per state, not with the total average scores.

North Kordofan

A comparison of the North Kordofan (NK) experimental group with the NK control group shows no significant differences, in pre–test scores, post–test scores or increase of scores between pre– and post–test (Figure 53). This is a positive finding, as the NK control group received twice as much instruction per day, compared to the experimental group (2 times 45 minutes, vs. 45 minutes a day). Moreover, the NK control group had a three month interval between pre– and post–test, whereas the experimental group had a 6–8 week interval between tests. Roughly, the NK control group has had three times as much opportunity to learn as the NK experimental group. However, the NK control group is very small (N=31), which makes it less suitable to compare to the NK experimental group (N=182).

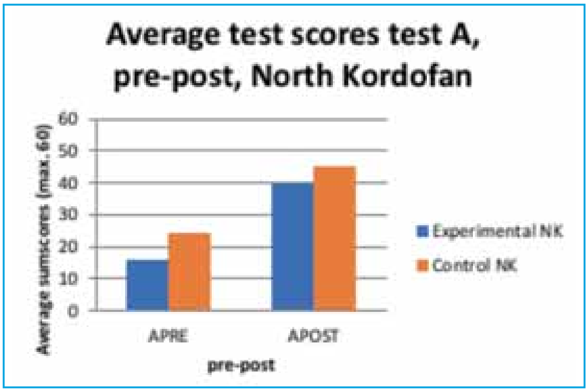


Figure 53. Average test results test A, pre–post, North Kordofan.

White Nile

A comparison of the White Nile (WN) experimental group (N= 148) to the WN control group (N=146) shows that there is a significant difference in increase of scores (31 vs 36 points) between the two groups ($F(1,288)=17.034$; $p < .001$; $r=.24$). The WN control group on average significantly increased its score more than the experimental group (Figure 54).

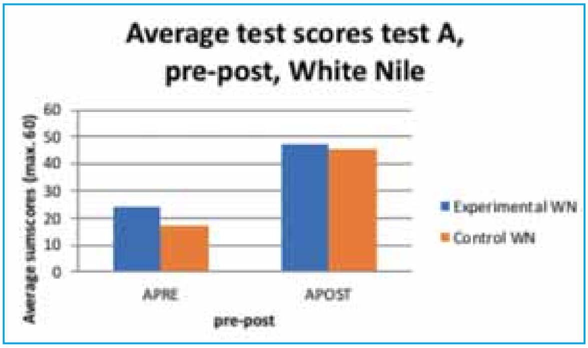


Figure 54. Average results test A, pre–test – post–test, White Nile.

It is important to note that the WN control group had (much) more opportunity to learn: they had two mathematics lessons of 45 minutes per day versus only 45 minutes in the WN experimental group, and a much longer interval between pre–test and post–test (6 months vs. 6–8 weeks). This means the WN control group had roughly six times more learning time than the children in the WN experimental group. From this perspective, the difference in increase of scores is rather small.

6.2.2. Test B

To assess if children have increased their scores on mathematics test B an Anova repeated measures (SPSS GLM) test within subjects factor: Math–B–PRE en Math–B–POST was used. The average score of children in White Nile, North Kordofan and Gedaref on the pre–test of test B was 32 (max. 60). The average score on the post–test of test B was 41. This average increase of 9 points is significant ($F(1,456)=160.067$; $p < .001$; $r=.51$). There were no significant differences for gender (Figure 55) and age groups.

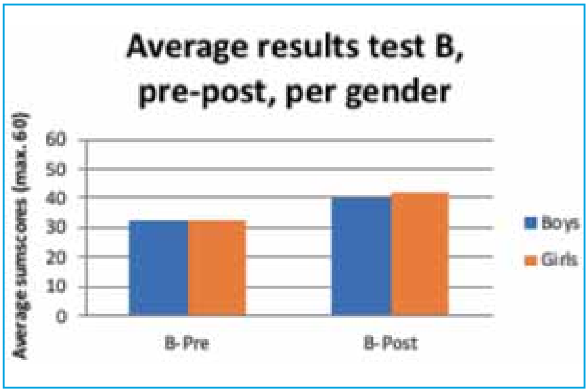


Figure 55. Average results test B, pre–test – post–test for gender.

The pre–test score is remarkably high. This can only partly be explained by the overlap between test A and test B. The high pre–test score on test B is probably caused by the timing: in the research protocol, the pre–test of test B should have been taken at the same time as the post–test of test A. In reality it was taken later. In the meantime children kept on playing the game, and thus increased their knowledge.

6.2.3. Results EGMA

Table 5, below, shows the results on EGMA, per sub measurement. All sub measurements are taken orally, except for Addition II and Subtraction II, children have to answer those items in writing. Results are presented in average percentages

correct. The results do not show any significant differences for gender or age.
As EGMA is a standard test, meant to be taken by the end of grade 2, it includes items and sub measurements that children in the experimental group have not learned.
The range for items in EGMA is from 0–1,000, the first six months of the game only introduces the numbers 0–20. Therefore, in the table, the number of items with a range of 0–20 is presented as well, including percentages correct on those items.
Also, the first six months of the game does not require children to write their answers. Although they will have seen numerals many times, they have not practised writing them.

Table 5.

Average percentages correct on all items per sub measurement, and on the items with a range between 0–20.

Test		Total # of problems	Average % correct	# problems under 20	Average % correct under 20
1	Number identification	20	30.5%	4	100%
2	Quantity discrimination	10	24%	1	100%
3	Missing number	10	14%	4	70%
4	Addition I	20	50%	20	50%
5	Addition II (written)	5	18%	2	45%
6	Subtraction I	20	26%	20	26%
7	Subtraction II (written)	5	4.5%	2	11%
8	Problem solving	5	62%	5	62%
9	Shapes I	4	50%	–	–
10	Shapes II	4	47%	–	–

The percentages correct for the items under 20 are higher than those for all items. This is probably because children have been taught the numbers, addition and subtraction under 20. The percentages correct for subtraction, for all items as well as for items under 20, are the lowest of all sub measurements. This can probably be explained by the fact that subtraction is introduced later in the game. As only 57% of the children finished 90% of the game or more, many children may not have reached the point where subtraction was introduced. This means that for the ranges and sub measurements that were taught in the game, the average percentage correct is 47% (shapes II) and higher, up to 100% correct (number identification and quantity discrimination).

The results on EGMA can be compared to earlier studies with Arabic speaking children in Khartoum and Jordan, because it is an internationally validated test. Figure 56, below, shows that the children in the experimental condition (Pilot II '15) had the highest percentage correct in three sub measurements of EGMA (Shapes I, Shapes II and Word problems) after only six months of learning, compared to children who had attended school for 2.5 years in Khartoum (2014) and Jordan (2012, before the Syrian crisis).

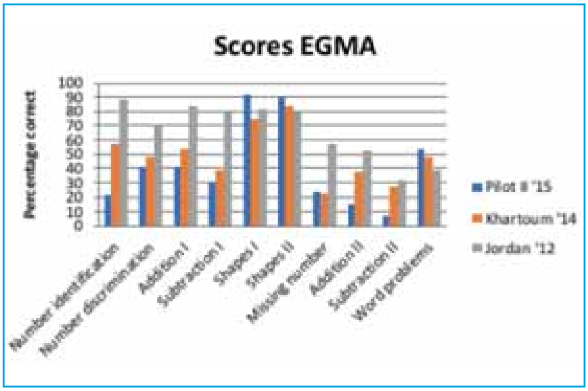


Figure 56. Scores EGMA compared; Pilot II, regular education Khartoum and Jordan.

In a fourth sub measurement (Missing number) the children in the experimental condition had a higher score than the children from Khartoum. The children in the experimental condition had a slightly lower score than the children from Khartoum on: Number discrimination, Addition level 1, and subtraction level 1. The scores on Number identification, Addition II, and Subtraction II were much lower than those for children from Khartoum and Jordan. This can be explained by the fact that the children in the experimental condition had only been taught the numbers under 20, whereas EGMA uses numbers up to 1,000. Also, children were not taught to write in the pilot. Addition and Subtraction II require the child to write answers down.

There are significant positive correlations between the scores on the mathematics tests A and B (pre and post) and the measurements of EGMA. These correlations are not always strong. The strongest correlations are for Addition level 1, Subtraction level 1, and Problem solving, all correlating more than 0.50. Although all tests show significant positive correlations with EGMA, the B–Post–test has the strongest correlations. This can be explained by the fact that test B measures more difficult mathematical concepts than test A, and is, therefore, more similar to EGMA than test A. These correlations indicate that tests A and B measure concepts of mathematics similar to those in EGMA.

6.3. Discussion and conclusion

The aim of this study was to test if children in rural areas in Sudan could learn more, and more difficult mathematical concepts autonomously, by playing a mathematics game on a tablet, only supervised by a facilitator. To assess the effectiveness of the game, a scaled trial was carried out. Pilot II tested a larger, and more diverse, part of the curriculum (6 months) with 591 children playing the game 45 minutes a day for a maximum of five days a week. In a baseline study the mathematical abilities of children were assessed. After approximately 6–8 weeks children were reassessed so that learning gains could be determined. In this pilot two tests were used, both with a 6–8 week interval.

Educational research with a large number of participants in remote areas in Sudan proved to be a challenge. Although observers had been trained to use the test protocol, tests were not taken at the designated times. As a result the pre–test of test B was taken too late, leading to higher scores than expected on the pre–test. This makes it harder to show significant improvement. Using control groups in developing countries is also an issue: there is an ethical element in asking communities to participate in a pilot as a control group without allowing them to benefit from it. As a result the control groups were smaller than the experimental group. As in the experimental group, in the control group tests were not taken at the designated times, leading to an exclusion of the Gedaref control group, and modified analyses for the North Kordofan and White Nile control groups.

Nevertheless, this study shows that using the mathematics game is as effective as, and probably more effective than, informal education for primary school children in Sudan. All children in the experimental condition improved their scores on the mathematics tests significantly. The control groups showed the same or slightly more improvement, even though they had received three to six times as much opportunity to learn than the children in the experimental condition. This confirms that children can learn from playing the game autonomously, and that they can learn more, and more difficult mathematical concepts from the mathematics game, with only a facilitator to supervise them. As there were no significant differences for gender and age, it can be assumed that the game is as effective for girls as it is for boys and for all children aged 7–9.

To ensure external credibility, independent, trained consultants took the standard Sudanese version of EGMA with a stratified sample of the experimental group. The results show that the children in the experimental condition, who had used the game for approximately six months, had higher scores on three sub–test of EGMA than children in Khartoum and Jordan who had been to school for approximately 2.5 years. On a fourth sub–test, the children in the experimental condition had a higher score than the children in Khartoum, but not higher than the children in Jordan. The scores on the ranges and sub measurements that had not been taught in the game were (much) lower. Again, there were no significant differences for gender and age.

For test A, the results of Pilot II were similar to the results of Pilot I. This means that the adapted tablet game is as effective as the laptop game used in Pilot I.

It is important to realise that the children involved in this pilot had never been to school before. In addition, 80% of their parents have never finished primary school and are functionally illiterate. Although mathematics games have been tested in developed countries (Praet & Desoete, 2013; Räsänen et al., 2009), and even in schools in developing countries (Pitchford 2015), this is the first time a mathematics game was tested with this specific target population: out–of–school children in remote areas without any access to school, teachers or learning materials. Representatives of the Ministry of Education in Sudan who visited some communities during the pilots, and the consultants taking the EGMA test with the children, expressed their surprise at how much the children were learning and how confident they were about their knowledge.
Similar to findings in pilot I, children with a lower score on the pre–test of test A improved more than children with a higher score on the pre–test. This is probably due to a ceiling effect: the game and the test focused on the very beginning of mathematics. Children that already had some knowledge of mathematics, achieved

a higher score on the pre–test and thus had less room for improvement. In addition, the game taught the basics of numeracy and addition. Children who knew how to do this could not learn very much from the game. They were the ones that went through the initial mini–games quickly. Others took longer to understand the basics of numeracy.

Although facilitators provided learning sessions for six months, five times a week, the logged data showed that the majority of the children only played an average of two to three times a week, thus decreasing allowed learning time by almost half. Learning results could probably have been even better if children had participated five times a week, but progress was still good. This shows that the use of the mathematics game is a flexible way of learning: if children skip learning sessions for a day or a week at a time, they can always come back and continue where they left off. In a more formal classroom environment this would be very difficult; children would have missed instruction.

This means that tablet technology, including well–designed, curriculum–based, engaging software, could help reach the 2.7 million out–of–school children in Sudan and teach them the basics of mathematics. Although teachers play a very important role in children's learning and children should attend school, this game can provide learning for those who have no access to school (yet).

7. Designing for scale

To address the situation in Sudan, where 2.7 million children are out of school, a mathematics game was designed based on a set of requirements specifically developed for this game (see chapter 2 of this thesis). The resulting game was tested in a small pilot – with about 60 children, over a period lasting six weeks – to establish whether children in remote regions in Sudan can learn by paying the game autonomously. Following positive results of this first pilot, a second, larger pilot was carried out, including a larger part of the curriculum and more children and lasting six months. Again, results were positive, children playing the game learned as much as, and probably more than, children enrolled in regular informal education. Chapters 5 and 6 describe the results of the two pilots in which the effectiveness of the game was studied. All children learned, irrespective of gender and age and, overall, children doubled their scores on test A (from 30% correct to 60% correct). A comparison with a control group shows that children who played the game learned significantly more than children who did not receive any education at all. A comparison with children who did receive education showed that children who played the game learned as much as, but probably more than, children who received regular education, as the children in the control groups had three to six times as much opportunity to learn. The increase of scores on test B was smaller, but still significant. The smaller increase in scores is probably due to the timing of the pre–test.

Now the effectiveness of the game has been established, it is interesting to explore what child–related and context factors influence learning results. This informs further development of the game in two ways: (1) when some children learn more than others, the game may need to be adapted to enable all children in the target population to learn. (2) When the effectiveness of the game is influenced by child–related and context factors, this has consequences for the design of the game for new contexts. In this chapter the following research question will be answered: *What child–related and context factors influence learning effects?*

Adaptations existing game

The design of the game is intended to benefit all children in the target population in Sudan, irrespective of gender, age, family situation or geographic location. As it is the aim to scale the mathematics game to more children and to the complete curriculum for out–of–school children in Sudan, it is important to analyse if the learning effect is related to child–related or context factors. If analyses show that the learning effect for some sub groups in the target population is smaller than for other sub groups, adaptations will need to be made to ensure the mathematics game supports learning for all children in remote villages in Sudan.

Adaptations for new games

A second aim of the programme is to scale the mathematics game, to new contexts (different countries, but also in–school context) and to new games (literacy). Therefore, it is important to understand what is going to be scaled and which mechanisms are most appropriate to achieve scale.

Ottoson and Hawe (2009) describe four approaches to scale, related to what is scaled: (1) a programme, (2) an idea or innovation, (3) a technology or skill or (4) a policy. As scaling of the mathematics game involves more than just increasing the number of people that use the game, according to Ottoson & Hawe (2009) this means scaling a programme. The related scaling mechanisms for this are replication and adaptation. To ensure adoption of new games in the same context and of the programme in new contexts, it is important to understand what can be replicated and what needs to be adapted.

The mathematics game was specifically designed for the Sudanese context; the requirements for the game were identified for the specific situation in Sudan. However, when scaling up, some requirements can be re–used. In general, the game requirements can be divided into three different types: context requirements, curriculum requirements, and requirements related to the effectiveness of game–based learning.
Curriculum requirements and requirements related to the effectiveness of game–based learning do not really change when taking the game to a new context, as they follow international best practices and are based on multiple international studies and meta–reviews. However, context requirements themselves, or their impact on game design, do change. For example, if the game is going to be used in a school setting, requirement 7: The game should enable self–paced, autonomous learning, will probably change. The reason for this is that there are teachers who can, and probably want to, support children in their learning process. A second example shows that requirements can stay the same, but their impact on game

design will change. Requirement 1: The game should be attractive and motivating for the target population is an essential requirement, but will probably lead to a different design. What is attractive and motivating depends on the target population and is related to culture, age, and gender.

The need for adaptation can be studied by assessing the sensitivity of the game to the conditions. Identifying the success and failure factors within the Sudan context and assessing the extent to which the effect of the intervention is sensitive to variation of these factors helps to understand if the game would work in a new context (Dede, 2006). The new context should then be checked for those factors that show high positive correlations with the learning effect. If the factors are the same as in the original context, the game can be replicated. If the factors are different from the original context, the game should be adapted to be as effective in the new context. For example, social support from family and peers might be very high in Sudan, and correlate with learning effects. If social support is not as high in the new context, the game might be less effective. This could then be addressed in the game design and in the implementation process in the new context.

7.1. Child–related and context factors that influence learning

In educational interventions, a relatively small set of factors are often very influential in determining effectiveness. Looking at existing models on the evaluation of learning, a limited set of similar factors that influence learning are included (Oprins et al., 2015; Alvarez, Salas, & Garofano, 2004; Robbins et al., 2004; Kraiger, Ford, & Salas, 1993). The following factors are mentioned: personal factors of students and their background, e.g. education so far and demographic information, psycho–social and study skill factors, e.g. motivation & self–efficacy and persistence with & commitment to action, and knowledge, skills and attitudes, such as test results.

7.1.1. Personal factors

Personal factors are described as personality, cognitive capacity, education so far, experience and demographic features (Oprins et al. (2015). This is partly supported by the meta–review on learner characteristics that influence the treatment effectiveness of early literacy interventions by Nelson, Benner and Gonzales (2003). They conclude that attention or behaviour problems and the level of proficiency influence learning. Attention or behaviour problems influence learning in a negative way, the level of proficiency influences learning in a positive way. Although Nelson et al. (2003) also mention age and parental education levels as possible influencing factors, they did not find a statistically significant effect for these factors. However, in the specific Sudanese situation, it is possible that these, and other family related characteristics such as having a father and mother and the number of siblings, do influence learning.

7.1.2. Psychosocial factors

Psychosocial factors that contribute to learning results are:

- Motivation to learn
- Social support and involvement
- Self–efficacy
- Self–esteem

Motivation to learn

Motivation to learn can be described as one's motivation to achieve success and enjoyment of completing tasks undertaken. Students with a higher motivation to learn achieve better results (Robbins et al., 2004). Motivation in this description is related to future orientation, the extent to which people have the ability to recognise their potential to realise their goals and achieve their personal ideal (Serafini & Adams, 2002).

Social support and involvement

Social support and involvement can be described as the perceived emotional support from family members and the extent to which students feel connected to their (school) environment (Robbins et al., 2004).

Self–efficacy and Self–esteem

Self–efficacy and self–esteem are related concepts. (Global) Self–esteem is typically defined as one's overall sense of worthiness as a person (Schmitt & Allik, 2005), whereas self–efficacy is described as one's beliefs about ability and/or chances for success in a specific (academic) domain (Bandura, 1997) and is closely related to the expectancy component of general expectancy–value model of achievement (Wigfield & Eccles, 2000; Pintrich & De Groot, 1990; Eccles, 1983; Pintrich, 1988). Self–esteem, therefore, seems to be more generic and related to the current situation, while self–efficacy is more specific and related to a future situation. The relationship with performance is reciprocal: although self–esteem and self–efficacy can lead to good performance, they are themselves partly the result of good performance as well (Baumeister, Campbell, Krueger, & Vohs, 2003). This is supported by literature from a psychosocial perspective in which the psychosocial factors relevant to children's learning mentioned above, are related to self–concept and social relations (e.g. De Haan & Huysmans, 2004; Harter, 1993; Jordan, 2004; Krosnick, Anand, & Hartl, 2003).

7.1.3. Study skill factors

The study skill factors mentioned are:

- Academic related skills
- Learning activity
- Mental effort

Academic related skills

Academic related skills can be defined as cognitive, behavioural and affective abilities necessary to successfully complete a task or achieve a goal (Robbins et al., 2004). This is related to self–directed learning in which learners take the responsibility for their own learning process (Oprins et al., 2015).

Learning activity

Learning activities are the cognitive activities the student carries out to learn, such as the use of learning strategies and collaborative activities (Oprins et al., 2015).

Mental effort

Mental effort refers to the amount of attention and concentration during learning (Oprins et al., 2015).

7.1.4. Knowledge, skills and attitudes

Knowledge, skills and attitudes can be described as the result of learning; the knowledge, skills and attitudes that have changed during the learning process (Oprins et al., 2015). The outcome variables are always domain–specific, depending on the learning objectives. These can be measured at the various levels as proposed by Kirkpatrick (1976; 1998): direct reaction, learning effects, transfer of learning and organizational effects. In education, these factors are most often measured in test scores. In addition to the result of learning, other factors can also be influenced during the learning process. For instance, motivation or self–esteem can increase during the pilot, which can positively influence learning results.

7.1.5. Developing context

The factors described above were identified in studies that focused on developed countries. Therefore, it cannot be assumed that these factors will influence learning in the same way in developing countries. Also, there are probably additional factors that influence learning in a developing context. To address the specific situation in Sudan, the choice was made to include two more factors: characteristics of the communities and identity orientation. These factors are described in more detail below.

Community characteristics

Per community, the specific characteristics of that community need to be identified. Living in a rural village is quite different from living in a nomadic community or being internally displaced. Furthermore, as mentioned in the introduction, the single most important determinant of access to education is the proximity of a school (Cremin & Nakabugo, 2012; Novelli & Lopes Cardozo, 2008; Kallaway, 2001; Burnett, 1996). As transportation to school is either not available or too expensive, schools need to be at walking distance. The distance children can walk to school is influenced by their age, the available infrastructure and temperatures. In addition, the road to school may also not be safe enough (The World Bank, 2012). A six year–old cannot walk five kilometres to and from school when there are no clear roads and the temperature is around 35 degrees Celsius. Geographic characteristics, therefore, influence learning.

Identity orientation

Identity orientations refer to the relative importance that individuals place on various identity attributes or characteristics when constructing their self–definitions (Cheek, Smith, & Tropp, 2002). Well known are the differences between individualism versus collectivism (Triandis, 1989) and independent versus interdependent self–construal (Markus & Kitayama, 1991). That is, the relative importance of the individual versus relations with others and the community for constructing one's self–definition. In

collectivist cultures, group benefit is more important than individual benefit, therefore, individual performance is less important than security and loyalty within the group (Kim & McLean, 2014). This may influence individual learning results.
Local experts indicate that Sudan can be seen as a collectivist culture. Although this has not been studied for Sudan, data by Hofstede (accessed 4 March 2018) suggests that this is a correct assumption. On the 6 Dimensions of National Culture Questionnaire, neighbouring countries Egypt and Ethiopia have a relatively low score of 25 and 20 on the dimension for individualist culture. This means they have rather collectivist cultures. For comparison, the United States has a relatively high score of 91 on this dimension, Australia a score of 90, and the United Kingdom a score of 89. Therefore, it was decided to measure children's identity orientation to assess whether it influences learning effects. Also, in collectivist cultures, individuals tend to reflect more on the group than on themselves as individuals (Triandis, 1989). As a result, children may find it difficult to answer questionnaires about themselves.

In addition, a possible change in identity orientations as a result of introducing game–based learning needs to be studied. The reason for this is that, in their study whether ICT changes self–construal and cultural values, Hansen, Postmes, van der Vinne, & van Thiel (2012) found that after one year of using a laptop with internet access, children's self–concept had become more independent and they endorsed individual values more strongly. Although a more independent self–concept is not a negative finding in itself, it might influence social relations in a negative way, thus affecting social support for children and community support for the programme.

7.2. Method

In this study, the factors described above will be measured using quantitative and qualitative questionnaires. Most factors will only be measured once, either at the beginning of the pilot or at the end. The questionnaire on psychosocial factors will be taken twice, at the start of the pilot and again at the end of the pilot, to measure possible changes during the pilot. Where possible, existing questionnaires are used, where needed existing questionnaires are adapted. The results on the mathematics tests A and B, as described in chapter 5 and 6, are used as an indication of the level of proficiency at the start of the pilot and of learning outcomes at the end of the pilot.

For the quantitative questionnaires, a factor analysis will be used to determine whether the results support the a priori scales. Those scales that are found to be valid as well as reliable will be used to analyse whether those factors influence learning outcomes.

7.2.1. Personal factors

In a structured interview with parents/caregivers, the following questions were asked:

- Age
- Gender
- Family situation
  - Does the child have a mother
  - Does the child have a father
  - How many siblings does the child have
  - How many older siblings does the child have

- Parental education
  - What is the highest level of education of the mother
  - What is the highest level of education of the father

7.2.2. Psychosocial factors and Identity orientation

A quantitative questionnaire was developed to measure:

- Psychosocial factors
  - motivation to learn
  - social support and involvement
  - self–efficacy
  - self–esteem
- Identity orientation

It is important to note that the psychosocial factors mentioned above are based on studies performed in western, more individualistic societies. As described before, Sudan, can be characterised as a more collectivist culture. It is, therefore, to be questioned whether asking children about themselves without referencing to interpersonal or intergroup relations, will lead to valid and meaningful answers. In addition, the cross–cultural validity may be an issue: constructs may have a different meaning or may not exist in different cultures.

To address this, the psychosocial factors (motivation to learn, social support, self–esteem, and self–efficacy) and the factor identity orientation were discussed in a meeting with representatives of the School of Psychology in Khartoum. First of all, the proposed constructs and their definitions were recognised by local experts; they had started using the same constructs in evaluations themselves. It was decided to use a quantitative questionnaire with several items per construct and a 5–point Likert scale. For each item, children have to indicate to what extent the statement matches their feelings about themselves on this item. An empty cup means the statement does not match at all, a full cup means it matches very well (see Figure 57, below).

Figure 57. Pictures of cups, 5–point Likert scale for quantitative questionnaire.

The measuring of self–esteem is an exception to this: local researchers had experience measuring self–esteem using a 'tree of life'. Children would draw a tree, based on how they saw themselves. The more leaves and flowers in the tree, the higher the self–esteem. This was designed as a 4–point Likert scale: four pictures of a tree are presented, the child can choose which one fits their feelings about themselves best (see Figure 58 below).

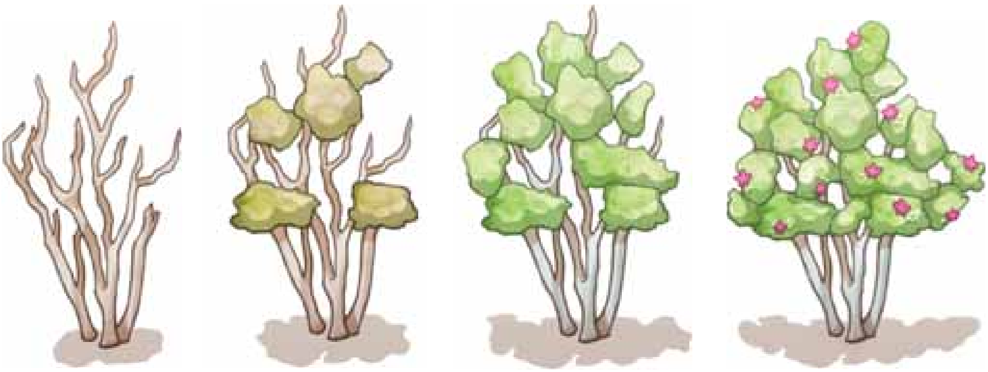


Figure 58. Pictures of trees, 4–point Likert scale for Self–esteem.

Although children grow up in dry areas and trees are scarce, fruits and vegetables are grown in the villages. Therefore, they do know plants and trees with leaves and flowers (Figure 59) and can understand the idea behind the tree of life.

Figure 59. Impression of plants and trees in a remote village in Sudan.

Although the items should cover the constructs, overall length of the questionnaire was an issue because of the age of the children and their related ability to concentrate. It was decided to include a maximum of 20 items in total. The items used were based on existing questionnaires. Each item was discussed with local experts in psychosocial research to ensure that the items, together, covered the construct, and that the language used could be understood by children. The statements themselves were translated from English to (colloquial) Arabic. To verify whether the translation was correct, the Arabic text was translated back to English by a different translator. The two English versions were checked for any differences in meaning.

As children cannot be assumed to be able to read, the statements are read to them, in a one–on–one situation. The child points to the cup that matches his or her feelings about the item. The questionnaire and the answering categories are introduced to children in a group setting, using neutral examples such as: ‘I like eating carrots’.

The table on the next page (Table 6) describes which factors are measured, which questionnaires were used for each factor, and provides one example item per factor.

Table 6.

Questionnaires used per factor and example item.

Factor	Questionnaire	Example
Motivation to learn	Self–directed learning Stubbé & Theunissen (2008)	I like learning new things
	The Functions of Identity Scale Serafini & Maitland (2013)	I know what I want to become
Social support	Fleuren, Paulussen, van Dommelen & van Buuren (2012).	When I have a problem, I can talk to my parents or family
	Lange, Evers, Jansen, & Dolan (2002).	
	Psychosocial Vulnerability Assessment Tool (Gunn, Jordans, Awan, & Hofman, 2015)	I feel like I am part of the group
Self–efficacy	Pintrich & De Groot (1990)	I stay confident, even when things are difficult
	Self–description Questionnaire II, Marsh (1992)	I can do most things as well as my friends
Identity orientation	AIQ IV Cheek, Smith, & Tropp (2002)	My relationships with people I feel close to are important to me

Before using the questionnaire, it was tried out by local researchers with 20 children in the same age group in Khartoum. These children differ from the target population as they live in a large city and are enrolled in school. Still, this was considered to be a good indication if taking the questionnaire would pose any issues. The children understood the questions and knew how to answer them.

A total of 499 children answered the questionnaire at both measurement points. For the questionnaire on psychosocial factors, optimal scaling techniques were used, to control for assumptions about interval distributions of the children's answers to each question (Gifi, 1990; Meulman & Heiser, 1999). The unidimensionality of the separate scales was evaluated by Principal Component Analysis with Varimax Rotation and by calculating Cronbach's alphas. Finally, scale scores were obtained by adding optimal scaling quantification scores within scales, and transforming scores linearly to a 0–100 scale. Higher scores indicating more emphasis on the scale's theme.

The overall reliability of the questionnaire was acceptable (Cronbach's alpha = 0.71). A factor analysis showed that, apart from the measurement of self–esteem which was measured in a different way, five scales could be identified. All four a priori scales could be recognised, the only difference was that a fifth scale could be identified which was labelled as 'belong to group'. However, some of the items loaded on other scales than intended. The first scale, self–efficacy, was reliable (Cronbach's alpha=0.74). The second scale, motivation to learn, has a Cronbach's alpha of 0.63. In the context of this research, we accept this reliability. The other three scales were not reliable. Deleting items did not improve reliabilities. Table 7, below, shows the reliability per construct, in total and per measurement (T0 and T26), and the number of items per construct.

Table 7.

Scales after factor analysis, including reliabilities and number of items.

	Cronbach's alpha			**No of items**
	T0 & T26	T0	T26	
Motivation to learn	.63	.63	.64	4
Social Support	.46	.47	.45	3
Self–efficacy	.74	.71	.77	4
Identity orientation	.56	.63	.47	3
Belong to group	.52	.56	.46	4
Total Psychosocial	.71	.67	.74	18

It is remarkable that the reliability of the construct identity orientation had an acceptable reliability at the baseline, but not at T26. This might indicate that playing the game has in some way influenced identity orientation.

7.2.3. Study skill factors

Of the study skill factors, only data on mental effort was collected. Interactions of the child with the game are logged, which can be used as an indication of attention and concentration:

- Number of days played (with timestamp)
- The time spent on playing per day
- The number of items played

- The number of mini–games finished successfully
- The number of mini–games finished without any mistakes

7.2.4. Knowledge, skills, and attitudes

The outcome of learning was measured at the first two levels of evaluation of Kirkpatrick: (1) direct reaction and (2) learning effect.

(1) The direct reaction was gathered in group discussions and short, structured individual interviews. Per mini–game, children were asked to indicate whether they worked, whether they understood what they had to do, and if they liked the mini–game. The group discussions and the structured interviews are held with a stratified sample of the children: 200 children, equally divided over state, gender, and age.

(2) Performance at the end of the pilots was again tested with a mathematics test, the post–test of test B. A more detailed description of this test is given in chapter 5. In addition, the in–game logged data showed the percentage of the game children had completed. This is an indication of their level of proficiency.

The group discussions provided only positive information; local researchers reported that all children indicated they liked the game and wanted to keep playing it. Although this may be interpreted as a positive finding, it is also possible that children gave socially acceptable answers. For this reason, the results of the group discussions will not be included in further analyses.

7.2.5. Developing context

Finally, geographic characteristics were collected, based on available information: name of state, locality and community, characteristics of the communities, distance to nearest primary school, and distance to nearest secondary school (Table 8).

Table 8.
Names of communities per state, including characteristics and distance to nearest primary and secondary schools and number of participating children per community.

State	Region	Community	Characte–ristics	Distance primary school (Km)	Distance secondary school (Km)	# Children
North Kordofan	Shaykan	Elfatih	Rural	5	15	24
North Kordofan	Shaykan	Om Kateera	Rural	7	30	31
North Kordofan	Shaykan	Alarageab	Rural	7	25	19
North Kordofan	Bara	Om Hagar	Rural	10	8	21
North Kordofan	Bara	Elrgeba	Rural	3	8	40
North Kordofan	Elrahad	Agabtina	Rural	12	12	18
North Kordofan	Elrahad	Redina	IDP	3	12	35
White Nile	Gooli	Mona	Rural	9	12	21
White Nile	Gooli	Om Tifag	Rural	12	7	14
White Nile	Gooli	ElTalha	Rural	7	13	21
White Nile	Tandalty	ElTben	Rural	7	25	18
White Nile	Tandalty	Om Dresa	Rural	7	25	45
White Nile	Tandalty	Om Gowa	Rural	14	25	38
White Nile	Elsalam	GoriEltkeal	Rural	9	35	40
Gedaref	Alfawo	ElRimela	IDP/rural	6	30	18
Gedaref	Alfawo	WadNorien	Nomadic/ rural	5	12	19
Gedaref	Almafaza	ElDabseen	Nomadic/ rural	8	17	42
Gedaref	Galabat	TaybaLah – ween	Nomadic/ rural	6	29	113
Gedaref	Wasat AlGadaref	WadSanad	IDP/rural	7	9	16

Rural communities can be characterised as communities living in remote areas, growing vegetables and herding goats and cows.
IDP communities can be characterised as communities of internally displaced people, Sudanese families fleeing from conflict in other regions of the country.
Rural/IDP communities can be characterised as rural communities that have taken in a number of internally displaced people.
Nomadic/rural communities can be characterised as communities that herd goats and cows, and move with their animals to find food and water.

In total, 19 communities in three states participated in pilot II, with approximately 200 children per state. Of the 19 communities, 12 are rural villages, only one is an IDP village (North Kordofan), two are IDP/rural villages and four are nomadic/rural villages (all of these in Gedaref). As there is only one IDP community, and no nomadic communities, any differences between the IDP community and the other communities can also be due to other factors. The results will, therefore, not be analysed according to characteristics of the communities.

The distances to the nearest primary schools varied between three and fourteen kilometres, with an average of 7.5 kilometres. The average distance in Gedaref is 6.3 kilometres, and in North Kordofan 6.7 kilometres. The average distance to the nearest primary school was largest in White Nile: 9.3 kilometres. The distances to the nearest secondary schools varied between seven and 35 kilometres, with an average of 18.5 kilometres. The average distance in White Nile is largest with 20.2 kilometres. The average distance in North Kordofan is 15.7 kilometres, and in Gedaref 19.4 kilometres.

The table below (Table 9) shows when and how data on the various factors that may influence learning is collected. T is measured in weeks.

Table 9.

Overview of measurements per factor that influences learning, T in weeks.

Factor	T0	T26
Level of proficiency	Mathematics test A–PRE	–
Demographic information	Structured interview with parents	–
Community characteristics	Information from ministry	–
Psychosocial factors	Questionnaire with children	Questionnaire with children
Study skills	–	Observations by facilitator
	–	Log data
Performance	–	Mathematics test B–POST
	–	Logged data
Direct reaction	–	Group discussion with children
	–	Structured interview with children

The questionnaire with children on emotional–motivational factors is the only measuring instrument that is taken twice. The reason for this is their reciprocal relation with learning: these factors can influence learning and performance, but can also be influenced by learning and performance. By measuring at the beginning and the end of the pilot, any changes can be captured.

7.3. Results

In this paragraph the results will be described. For the quantitative questionnaires, only the reliable constructs are included.

7.3.1. Personal factors

51% of the participating children are girls, 49% of them are boys. The participating children are between 7–9 years old. Most of them (47%) were seven years old. 29% is eight years old and 24% is nine years old. The average age of the participating children is 7.8 years. Children in North Kordofan are slightly younger (average 7.4 years), compared to the children in Gedaref (average 8.0 years) and White Nile (average 7.9 years).

Most children reported they had both their parents (White Nile: 92%; Gedaref: 99%; North Kordofan 75%). Children from North Kordofan reported more often that they only had a mother (24%) or no parents at all (1%).

On average, children were reported to have 5.3 siblings. In North Kordofan this is less, with 4.8 siblings on average, whereas children from Gedaref reported 5.8 siblings per child on average. Most of the participating children (80%) are second in the row of children in their family, meaning they have one older brother or sister. About 15% of them are the oldest, about 5% are the third child in their families.

Only about 20% of the parents has finished primary education (fathers 21%; mothers 18%). 1% of the mothers and 2% of the fathers have finished secondary education as well. There was no significant difference between fathers and mothers with respect to the level of education.

7.3.2. Psychosocial factors

The average Self–Esteem score at T0 of all children participating in the study is 1.9 which is just below the average of the scale (1 = low; 4 = high) (Figure 60). There are no differences with respect to Self–esteem between boys and girls. Self–esteem seems to decrease with age, but this difference is not statistically significant. Self–esteem is the only scale that showed significant differences between the two measurements (T0 and T26); it has increased from 1.9 to 2.5 on a 4–point Likert scale.

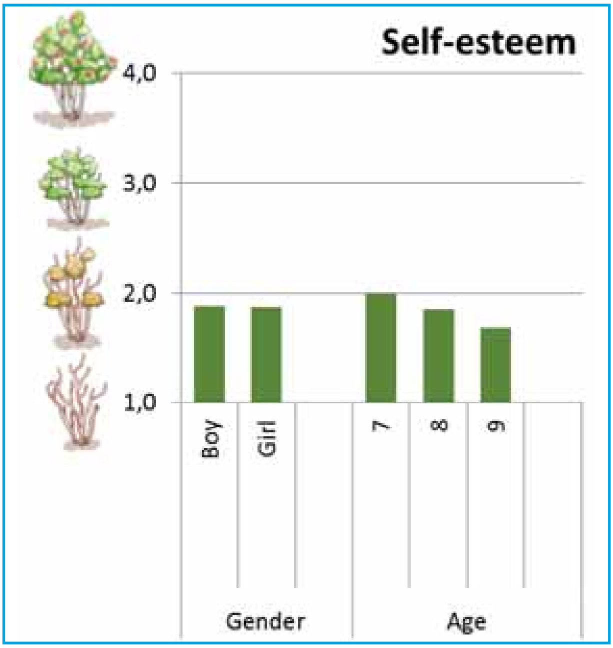


Figure 60. Self–esteem per gender and age at T0.

The average Self–efficacy score at T0 of all children participating in the study is 2.8 (1 = low; 5 = high). There are no statistically significant differences with respect to gender, age or state. There are no significant differences with results at T26.

The average score for Motivation to learn at T0 for all children participating in the pilot is 2.8 (1 = low, 5 = high). There are no differences between boys and girls or children with a different age (Figure 61). There are no significant differences with results at T26.

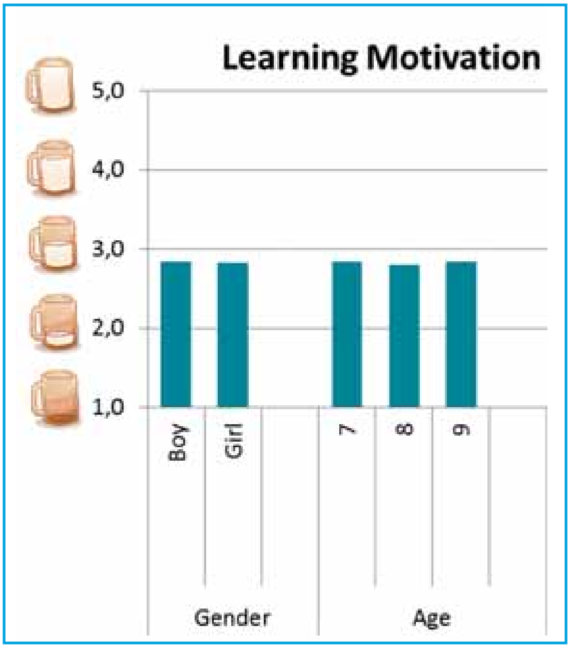


Figure 61. Motivation to learn per gender and age at T0.

7.3.3. Study skill factors

The logged data show that most of the children played the game for a period of 5 to 7 months (average number of days between first and last play: 135). Girls were found to participate for a significantly longer period than boys (average of 141 versus 129 days; $F(1,378) = 7.73$; $p < 0.05$). No differences were found for age. Children from North Kordofan played a significantly shorter period (122 days), compared to White Nile (138 days) and Gedaref (145 days; $F(2,377) = 11.114$; $p < 0.001$). Correcting for both gender and age, children were found to only differ in the number of days between first and last play based on state ($F(2,363) = 6.123$; $p < 0.05$).

Only a small percentage of the children played the game five times a week during the pilot (5%). On average, most children were found to participate two to three times a week. Figure 62 represents the frequency of playing (average plays per week), in categories. No differences were found for gender. Age was found to be significantly related to frequency of playing: 7–year olds played more often (2.7 days a week) than 8–year olds (2.3 days a week), who in turn played more often than 9–year olds (2.0 days a week; $F(2,377) = 17.91$; $p < 0.001$). There was also a difference between states: children from North Kordofan played more often (3.2

days a week) than children from White Nile (2.2 days a week), who in turn played more often than children from Gedaref (1.7 days a week; $F(2,377) = 143.95$; $p < 0.001$). Correcting for both gender and age, children were found to only differ in the frequency of playing based on state ($F(2,363) = 80.09$; $p < 0.001$). This can be explained by the fact that in some villages facilitators left and it took some time to replace them.

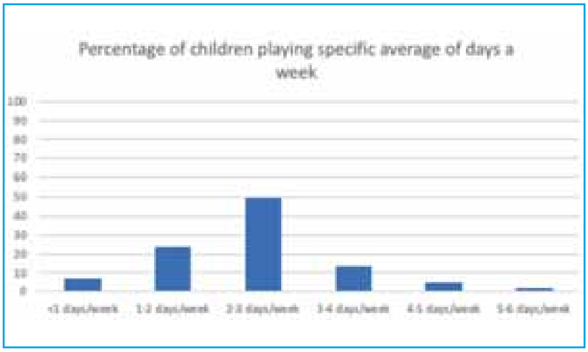


Figure 62. Percentage of children playing the game per average number of days a week.

For this pilot, part of the mathematics curriculum was gamified. Although it is not clear at what pace children would play the game, an educated guess was made with respect to the content that would need to be included in the game to enable six months of learning. The logged data show that 57% of the children completed 90% or more of the game (Figure 63). It can be assumed they finished the content provided. A total of 70% of the children finished 70% of the game or more. They have finished most of the game. 23% of the children completed less than 50% of the game; they have missed out on instruction and practice. There were small differences between states that were not statistically significant. On average, children in White Nile completed 75.3% of the game, children in North Kordofan finished 80.2% and children in Gedaref 74.2%.

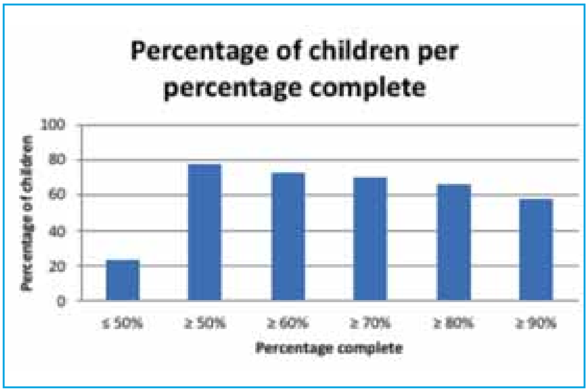


Figure 63. Percentage of children per percentage complete.

There is a positive relation between the number of times played and the percentage of the game completed ($F(1,377) = 122.41$; $p < 0.001$). However, percentage complete is better for children who participated for a longer period, even if their frequency of playing during that period was lower ($F(1,394) = 5.37$; $p < 0.001$) (Figure 64).

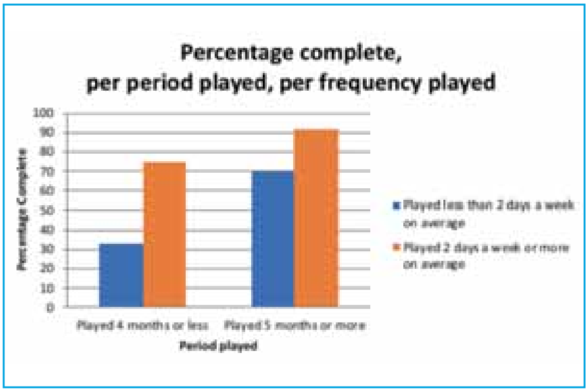


Figure 64. Percentage of the game completed, per period played, per frequency played.

Test results are higher for children who have a higher percentage complete in the game ($F(1,378) = 4.36$; $p < 0.037$).

7.3.4. Knowledge, skills, and attitudes

Performance at the end of pilot II is described in chapter 6. The direct reaction of children to the game is described below.

Direct reaction

When asked about the mini–games, children's answers on whether the mini–game worked, whether they knew what to do and if they liked the mini–game, the average answers on all questions were between 2.5 and 2.9 on a 5–point Likert scale. This is just above the mean of the scale. There were no statistically significant differences for age, gender, or state.

The children were also asked whether they liked the visions; the 'jobs' in the overall narrative of the game. Three of the visions were about a boy (goat herder, brick maker and growing vegetables), the other two visions were about a girl (cooking lady, tea lady). The average scores for all visions varied between 2.6 and 2.9 on a 5–point Likert scale. There were no significant differences for age, gender, or state. These scores indicate that children are moderately positive about the game and suggests that the very positive responses in the group discussions were not realistic.

7.4. What factors contribute most to the learning outcomes

Differences between groups on the factors described above were analysed using multivariate analysis of variance for general linear modelling (Multivariate_GLM). The relationship between demographic variables with the main dependent variables was investigated in two steps: in step one Pearson correlations were calculated between demographic variables and research factors. Demographic variables that had at least one significant correlation with a factor were selected. It appeared that all variables had to be selected: Community, Age, Gender, Number of siblings, Row, Family, Mother, Father, Distance to primary school, Distance to secondary school. In step two, the selected demographic variables were added as covariates in all consecutive multivariate–GLM tests to correct for initial differences between participants.

The influence of studied factors on the post–test scores on Math A and B, was tested using two hierarchical regression analyses with Math A or B as independent variables. Results were summarised with the estimated marginal means and the standard errors. Overall, results of statistical analyses were reported as significant with a P value of $\leq .05$ or as trends with a P value between .05 and .10. In addition, effect size estimates will be evaluated when available, using the partial R squared (R^2), which assists in interpretation of its practical importance. A partial R^2

of. 01 is defined as a small effect size, .06 as a medium, and .14 as a large effect size (Cohen, 1987).

Table 10, on the next page, shows the summary of the hierarchical regression analysis of variables predicting final maths scores.

Table 10.

Summary of hierarchical regression analysis of variables predicting final mathematics scores.

Variables	**Test A–POST**		**Test B–POST**	
	Beta	Delta R^2	Beta	Delta R^2
Step 1: math results		0.21*		0.40*
A–PRE	0.40*		0.12*	
B–PRE	n.a.		0.44*	
Step 2: personal factors		0.06*		0.05*
Age	0.00		0.01	
No of siblings	0.07		-0.03	
Place in row	-0.08#		-0.03	
Has a mother	-0.02		0.00	
Has a father	-0.01		-0.11*	
Mother's education	-0.10*		-0.10*	
Father's education	0.00		-0.01	
Distance to nearest primary school (Km)	0.09*		-0.07	
Distance to nearest secondary school (Km)	-0.09#		-0.04	
Gender	0.02		0.05	
Step 3: psychosocial factors, T0		0.02*		0.01*
Self–esteem	0.13*		0.13*	
Self–efficacy	0.11*		0.07*	
Step 4: mental effort		0.07*		0.07*
Percentage complete	0.29*		0.31*	
No of days played/week	-0.07		-0.04	
Step 5: psychosocial factors at T26		n.a		0.01
Self–esteem	n.a.		-0.08*	
Self–efficacy	n.a.		0.03	
R^2		0.59		0.72
Adjusted R^2		0.35		0.52

*significant P≤.05, # trend p≤.10, n.a.=not applicable because time of measurement is later than A-Post.

As can be seen in Table 10, above, the model with selected predictors explains 59% of the variance in the A Post–test scores and 72% of the variance in the B Post–test scores. An explained variance between 50 and 75% is seen as strong.

Results on mathematics test show a large effect: test A–Post scores are mainly defined by the scores on A–Pre and test B scores are mainly defined by scores on A–Post and B–Pre test scores. This could be an indication that children who already have mathematical knowledge before the start of the pilot, benefit most from playing the game. To investigate whether children with higher scores on the pre–test benefit more from playing the game, the children were divided in three groups with an equal number of children per group: (1) test scores on A–Pre 0–13; (2) test scores on A–Pre 14–23; test scores on A–Pre 24–60. Analysis shows that in test A the children with the lowest scores on the pre–test (0–13), had the highest increase in scores on A–Post ($F(2,488) = 29.17$, $p<.001$, $r=.11$), although their absolute score on A–Post was still lower than children with a higher score on A–Pre (Figure 65).

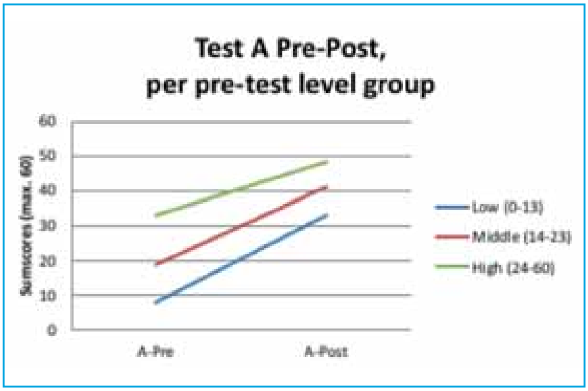


Figure 65. Test A Pre–Post, per pre–test level group.

In test B, this effect has almost disappeared (Figure 66). On the whole, according to a multivariate test there was a trend but not a significant difference between groups ($F(2,443)= 2.48$, $p=.08$, $r= .01$). A univariate test contrasting results between groups, however, did differ significantly ($p=<.001$) This indicates that there was still some difference between groups with respect to improvements on test B but not as much as in test A. This means that all children can learn from playing the game, whether they have a lower or a higher score on the pre–test. Children with a lower score on the pre–test even show a slightly higher increase in test scores than children with a higher score on the pre–test.

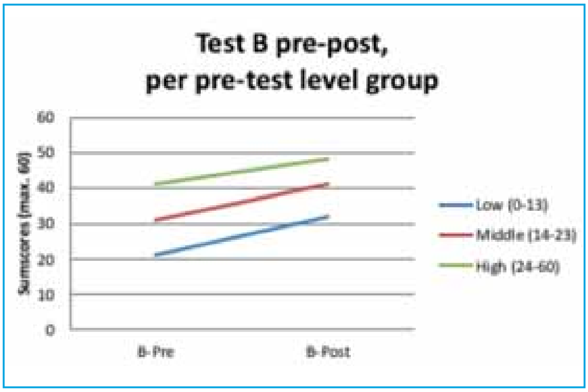


Figure 66. Test B pre–post, per pre–test level group.

Personal factors have a medium effect on learning results. They add a little, but still significantly to the explained variance of the model. Three demographic factors have a small to medium significantly effect on the mathematics results. There is a medium negative effect of the education level of the mother on learning results: the higher the education level of the mother, the lower the test scores on both mathematics tests. There is a medium positive effect of the distance to the nearest primary school on learning results: the larger the distance to the nearest primary school, the higher the test scores on A–Post. This effect does not appear with test B, Having a father has a small negative effect on the test scores on B–Post.
Age, gender, and the family situation do not show significant effects on learning.

Psychosocial factors in the baseline have a small effect on learning results. A higher self–esteem and self–efficacy at the beginning of the pilot relate to higher scores on the mathematics tests at the end (medium effect). In this light, it is a positive finding that self–esteem increases because of playing the game. This again may influence learning results in a positive way (Baumeister, Campbell, Krueger, & Vohs, 2003).
It does show, however, that the game design should very much focus on supporting self–esteem and self–efficacy. In new contexts it is important to identify the level of self–esteem and self–efficacy and explore ways to increase them.

Mental effort, measured in logged data, can be seen as a predictor as well (small effect). Specifically percentage completed relates positively to the mathematics scores at the end (medium effect for A–Post; large effect for B–Post).

Finally, psychosocial factors measured at the end of the pilot relate to test B results. Self–esteem has a medium negative relation with test B. However, it is not clear if these scores can be seen as real predictors, as the psychosocial data at the end of the pilot were collected at about the same time as test B–Post was taken. Therefore, causality cannot be assumed.

7.5. Conclusion

The sub–question answered in this chapter was: What child–related and context factors influence learning? These factors were identified and measured in pilot II. Analyses showed that not all factors were measured reliably. All child–related and context factors that were measured reliably have a positive effect on learning results in pilot II. Together, they predict 50–75% of the results on the post–tests which makes it a strong model. The factors are indeed relevant when deciding whether the game needs to be adapted for the Sudanese context and what needs to be adapted in a new context or for a new game. Prior knowledge (results on pre–tests) has a large effect, personal factors have a medium effect, psychosocial factors in the baseline have a small effect, and mental effort, measured in logged data, has a small effect on learning results. This suggests that the existing and new games need to be adapted to support learning for all children. In the paragraphs below, the effects per factor will be discussed to determine whether and how the existing game or new games would need to be adapted.

Mathematics results

The analysis shows that prior knowledge (higher score on the pre–test) has a large effect on learning results. Children who have a higher score on the pre–test, will also have a higher score on the post–test. However, children with a lower score on the pre–test show a larger increase in scores. This means the game supports learning for all children, independent of the knowledge and experience they have when they start playing the game. Therefore, the game does not need to be adjusted for this factor, either for the same or for a new context.

Personal factors

There is a medium negative effect for the education of the mother: the higher the education of the mother, the lower the score on the post–tests. This is in contrast with previous findings that higher levels of maternal education are positively associated with academic outcomes for children (Magnusen, Sexton, Davis–Kean, & Huston, 2009). The same applies to developing countries, where parental education and literacy are consistently found to be associated with learning outcomes of children; children with lower levels of academic performance were more likely to have illiterate mothers and fathers (UNICEF, 2016). Harding, Morris, & Hughes (2015) offer a possible explanation for this. They argue that higher levels of maternal education are associated with children's academic outcomes, but that this does not automatically imply that maternal education is the cause of children's outcomes. Their theoretical model describes that through their education, mothers develop characteristics that support their children to learn, such as language skills, the ability to negotiate benefits for their children throughout children's education, or being embedded in social networks that are relevant to children's academic success. It is possible that in the specific context of these pilots, mothers could not benefit from their education in this way. For example, in remote villages it is hardly possible to have a social network outside of the village. Therefore, a difference in level of education will not automatically lead to a different social network. However, it is not clear why there is a negative effect of maternal education.

There is a small negative effect for having a father: children who have a father have a lower score on the post–test of test B. It is not clear how this can be explained.

The distance to the nearest primary school initially has a medium positive effect on learning results. This was an expected result: children benefit more from playing the game when there is no reasonable educational alternative. After playing the game for some time, this effect disappears. In itself, this is a positive finding: especially the specific target population for this game benefits most. At the same time, this also means the elements of the game already support a mitigation of this effect over time. This mean no adaptations are needed for the Sudanese context. However, this effect may mean that introducing the game closer to a primary school, or even in the classroom, might initially lead to a lower increase in test scores. The game could be adapted to facilitate embedding it in the classroom.

Self–esteem and self–efficacy both have a medium positive effect on scores on the post–tests. Children with higher scores on self–esteem and self–efficacy at the start of using the game benefit more. In relation to this, it is a very positive finding that self–esteem has increased during the pilot. Although this reciprocal relationship is supported by literature (Baumeister et al., 2003; De Haan & Huysmans, 2004; Harter, 1993; Jordan, 2004; Krosnick, Anand, & Hartl, 2003), the fact that the game increases self–esteem means it will also support children who start playing the game with a lower score on self–esteem. Nevertheless, these are important factors to keep in mind for the Sudanese context as well as for new contexts. The design of the game, and the environment in which it is used, should support children's feelings that they can learn and that learning matters.

Apart from the personal factors with a significant effect on learning outcomes, there are also some personal factors that do not show a statistically significant effect: age, gender and family situation. This is a positive finding as it shows that the game supports learning for the complete target population and would not need specific adaptations when taking it to a context in which these factors are different.

Mental effort

The medium to large positive effect of percentage completed of the game is mostly an indication that the in–game assessment system works: children can only progress to a next level in the game when they have mastered the level before. This effect, therefore, shows the correlation between the level of mastery of mathematics measured by a mathematics test and by the in–game continuous assessment system. As a result, in the future it will not be necessary to include elaborate research protocols to assess if children have learned. It will be sufficient to test them in the regular school test–cycles or before they enter school. This makes the programme easier and less expensive to implement.

In addition, it is a positive finding that there is no effect of frequency of playing (average number of days played per week). This means the game–based learning approach is quite flexible, and effective even when children do not play on a daily basis. This is very important in the Sudanese context, but will probably benefit children in new contexts as well.

Summarising, an analysis of the predictive value of child–related and context factors on learning outcomes does not show that the existing mathematics game for Sudan needs to be changed. The effect of the personal factors self–esteem and self–efficacy on learning outcomes, however, does indicate that continued attention should be given to elements of the game that support children's feelings that they are able to learn and that learning matters.

When scaling the game to new contexts, it should always be adapted for culture and characteristics of the target population. The elements that may need adaptation are the storyline/narrative, the graphics and colours, and language (dialects and pronunciation). Again, specific attention should be given to elements that can support self–esteem and self–efficacy. Finally, when the game is used in a school setting, adaptations are probably needed: the game will no longer be the only opportunity to learn, which might make it less effective, and teachers probably want some control over their students' learning.

Besides the adaptations needed when taking the game to a new context, some elements can stay the same. When the learning objectives in the new context are similar to the Sudanese curriculum, the mathematical elements of the game can be replicated.

Chapter 8. Discussion and conclusion

The research presented in this thesis aims to contribute to solving the global learning crisis by exploring alternative solutions to traditional education. Worldwide, 61 million primary age children are out of school, and despite many campaigns and initiatives, this number has not decreased over the last ten years. There is a growing recognition that especially the most marginalised children will not be reached by simply expanding the current education system. Innovative education technology, coupled with a context specific approach, could provide these children with a previously unimagined chance to access quality education opportunities.

Following a research–based approach as described by Clements and Sarama (2002; 2007), a mathematics game was designed, developed and evaluated. The game targets children in Sudan who live in rural areas without ready access to schools, nomadic children, and children living in communities of internally displaced persons. This chapter describes the results for the specific Sudan context and discusses the implications of this research for game–based learning in general and for taking the mathematics game to new contexts.

8.1. Research questions

The overall question that needs to be answered is: *How can children in remote villages in Sudan learn mathematics from playing a mathematics game without additional instruction from teachers?* The question whether children van learn can be answered by a wholehearted 'yes'. Children who played the game have learned as much as, and probably more, than children in formal education during the same period. To answer how children can learn, six research questions were identified. Below, the results per question are discussed.

8.1.1. What are the general game requirements for successful learning for out–of–school children in remote villages in Sudan?

In chapter 2, research question 1 is answered: *What are the general game requirements for successful learning for out–of–school children in remote villages in Sudan?*

Three different types of requirements could be identified:

1. Context requirements
2. Curriculum requirements
3. Requirements related to the effectiveness of game–based learning

1. Context requirements

The context requirements address the specific situation of the target population. Children live in remote villages, without running water, electricity or reliable internet connections. There are no schools within walking distance and no teachers to support learning. Most parents have not finished primary education and cannot provide additional instruction. As children have not been to school, it cannot be assumed they are able to read and understand written text. In addition, children contribute to their families by doing household tasks such as fetching water or herding goats. To provide access to education for this target population, learning needs to take place in their own village. As a result, it should be possible to access the game in rural settings with unreliable internet connections and children should be able to learn without additional instruction from teachers or parents. Moreover, it is essential to engage and motivate this target population.

Although this is always an important requirement, it is even more so in this context as children must be able to learn autonomously for a longer period of time. Finally, the game must be culturally appropriate.

2. Curriculum requirements

Curriculum requirements address the educational context in which the game is used. For the game, and learning, to be accepted, the learning objectives in the game should be aligned with the national mathematics curriculum for out–of–school children. The relevant Ministry department, in this case the National Council for Literacy and Adult Education of the Ministry of Education in Sudan, should endorse the curriculum in the game. This supports embedding the game in the Ministry's strategy and allowing children to stream into regular education, when possible.

3. Requirements related to the effectiveness of game–based learning

Requirements related to the effectiveness of game–based learning refer to more general game characteristics that increase the effectiveness of learning, such as the alignment between learning objectives and game design, and control over order and pace in the game.

Some of these requirements are quite specific; they support the design of a game that will be used autonomously by Sudanese children in remote villages. In a different context some of these requirements probably need to be adapted. For instance, if the game is going to be used in a school setting, with additional instruction from teachers, learning would not have to be completely autonomous. Also, good internet connectivity would have opened up possibilities of adaptive teaching and continuous feedback on children's progress. However, the connectivity in the villages will be unreliable at best. Other requirements stay the same, but the way in which they are addressed in the game will be different for a new context. For example, what is motivating or culturally appropriate for children in rural areas in Sudan, may not be motivating or culturally appropriate for children in urban areas or refugee camps in Jordan or Lebanon. Also, countries have slightly different curricula per grade, meaning some learning objectives need to be taken out and others put in. Finally, there is a set of requirements that should be addressed in the same way when the game is taken to a new context; the teaching of mathematics, the alignment of learning objectives and game design, and control over order and pace in the game do not change for a new context.

8.1.2. How do the general game requirements translate into a working game design?

In chapter 3, research question 2 is answered: *How do the general game requirements translate into a working game design?*
The resulting game incorporates two distinct levels, each with a different pedagogy. The first level is that of game worlds which provide the connecting narratives for the second level, that of separate mini–games. This can be described as a *games within games* game design pattern (Bjork & Holopainen, 2004). In addition, instruction videos and a management system are included in the game. The actors in the instruction videos are slightly older children, explaining the mathematics concepts. The top level of the game environment, that of the game worlds, uses a predominantly *experiential learning approach*. The narrative in game world 1 is about helping other children to achieve goals in their lives by doing mini–games. Game world 2 is a shop where children can buy and sell products. The two game worlds are interconnected: from game world 2, the shop, children go back to game world 1, the village, to collect products to sell in the shop. The lower level of the game environment, with the mini–games, has a different pedagogy: *mastery learning* with direct feedback on performance, and consequently children have less control over the learning environment. Progress through the game is structured and

based on performance: the number of correct answers within a certain time–frame decides whether children can continue to a more difficult mathematical concept. To ensure cultural appropriateness of the game and correct motivational elements, there was a collaboration with local experts and a selection of children from the target population. The narratives, graphics, colours, and language in the game are based on this collaboration and were endorsed by the NCLAE. Feedback during this process revealed that children liked strong colours and preferred to stay away from graphics and colours that are associated with negative emotions. The smileys that are used to show progress now have an orange colour (instead of red) when children give an incorrect answer. Also, these smileys have a neutral face instead of a sad face. To support autonomous learning from an interface point of view, the use of navigation buttons is consistent throughout the game. Colours and symbols were checked for cultural appropriateness. Although complex at times, the collaboration with local experts and children from the target population has been essential to address the context requirements. When the design team and the target population have different backgrounds, it is a necessary step to understand the problem and explore possible solutions.

To support learning in areas with unreliable internet connections, the game was designed as an online–offline game. Children can always play the game at their own level; synchronisation of results only takes place when there is internet, or can be done by hand.

Although all game requirements have been incorporated into the game design, there are a few areas that required careful consideration. First of all, there seems to be a contradiction between learner control and guided learning. This was solved by the two–level game design, each with a different pedagogy. Secondly, adaptive feedback was not incorporated in the game. Although it is known to support children to learn from their mistakes, it is quite difficult to do this digitally in an offline game. Finally, although social interaction between children and between child and adult is regarded as motivating, it was not incorporated into the game itself, as such within–game interaction would depend on a reliable internet connection which is not available in the target area. Additionally, children should play the game individually to be able to track the individual progress needed to support learning at their own level.

When designing a mathematics game that allows out–of–school children in rural areas in Sudan to learn autonomously, several research domains come together. In addition, the very specific context factors in rural areas in Sudan need to be taken into account. Each of the requirements for the game is based on one research domain. As a result, some of the requirements may contradict each other. In the game design, these contradictions need to be negotiated; is one requirement more important than another, or is it possible to make a combination that will work? When deciding on priorities and possibilities, two criteria were used: (1) Will the game work technically? and (2) Can children understand what to do when playing the game without learning support? The reasons for this were quite simple: if the game crashes, children cannot learn from it and if children do not understand what they have to do, they cannot play the game, and thus cannot learn from it. This means, for instance, that any solutions that require an internet connection were not feasible as connectivity is unreliable in the rural areas. Also, when choices had to be made between guided learning and experiential learning, guided learning was chosen. When taking this game to new contexts, these criteria may have different implications for the design: if there is reliable internet, or if there is support from teachers or parents, different choices can be made.

The resulting game will be played in learning sessions under the supervision of facilitators. In this way, learning can be organised, and tablets taken care of. Facilitators do not teach. Therefore, any responsible adult can fulfil this role, they do not need to be qualified teachers.

8.1.3. What are the specific requirements for learning mathematics and how do they translate into a working game design?

In chapter 4, research question 3 is answered: *What are the specific requirements for learning mathematics and how do they translate into a working game design?*

In addition to the national curriculum, the internationally recognised learning objectives and best practices for learning mathematics were studied. A check of the Sudanese mathematics curriculum against internationally accepted learning objectives for grades 1 to 3 showed that there is much overlap, although the Sudanese curriculum does not describe learning objectives to the same level of detail as the international ones. The Sudanese curriculum includes four more learning objectives relating to the imperial measurement system and time, and does not contain the kindergarten learning objectives for mathematics. As children in the target population do not attend kindergarten, the choice was made to include the kindergarten learning objectives in the objectives of the game. In addition, the specific Sudanese learning objectives about measurements were maintained. Also, all learning objectives were described in a more detailed way, including sub–goals. Finally, the Sudanese Ministry of Education approved a change in the order of the curriculum to match a more accepted natural sequence of acquisition of mathematical skills and concepts. In this way, the curriculum was aligned with the Sudanese curriculum for out–of–school children and, at the same time, based on internationally recognised learning objectives and good practices for these grades. The specific mathematics requirements are based on existing good practices of teaching mathematics. Their translation into game design needs to address instruction, practice and feedback, but also the manipulation of objects that helps children to understand mathematical concepts. In the game, each learning objective is supported by one or more instruction videos and mini–games. Instruction videos are brief, explicit introductions to the mathematical concepts; one instruction video per concept, 1–3 minutes each. Mini–games provide active practice of learning objectives. There is a large variety of mini–games, with different interaction types. Some mini–games allow children to actively manipulate (2–dimensional) objects. Finally, immediate feedback is provided on the correctness of answers.

When taking the mathematics game to a new, Arabic speaking context, the requirements for learning mathematics and the design could stay the same. There should be a check, however, on the learning objectives in the national curriculum of the new country. It is possible that there are small differences. When taking the game to a non–Arabic speaking country, or with a non–Arabic language, instruction and mini–games need to be adapted to match the direction of writing.

8.1.4. Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?

In chapter 5, research question 4 is answered: *Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?*

The learning effect of the game was determined using a quasi–experimental design with a control group. A mathematics test was used, test A, to assess children's level of mathematics at the beginning and at the end of pilot I. Test A includes number knowledge, quantity discrimination and simple addition for the numbers up to 10. Results show that all children in the experimental condition significantly increased their scores on test A (average test score increased from 18 to 36, max. 60), compared to a control group who did not receive any education at all. There were no differences for gender. Younger children achieved lower scores than older children, but had a higher increase of scores than older children. Motivation of children, as reported by facilitators, increased during the 6–week experiment (average of 2.7 to 3.2 on a 4–point scale). Although there was a 10% drop out, attendance of the remaining children stayed high; the frequency of playing was 4–5 days a week.

These results show that it is possible for children in remote areas in Sudan to learn from playing the mathematics game autonomously, irrespective of gender and age. These are very promising findings which warrant a further development of the game. As this was a small experiment, in time as well as in the number of participants, conclusions cannot be generalised. Sustained learning, including more learning objectives and more children, needs to be demonstrated.

8.1.5. Can out–of–school children in remote villages in Sudan learn mathematics autonomously for a longer period of time, covering a diversity of learning objectives, by playing the game autonomously?

In chapter 6, research question 5 is answered: *Can out–of–school children in remote villages in Sudan learn mathematics autonomously for a longer period of time, covering a diversity of learning objectives, by playing the game autonomously?*

The learning effect of the game was determined using a quasi–experimental design with a control group. Two tests were used to assess children's level of mathematics at the beginning, halfway, and at the end of pilot II. Test A, as used in pilot I, and test B. Test B includes number knowledge, quantity discrimination, simple addition and simple subtraction for the numbers up to 20. Results show that all children in the experimental condition significantly increased their scores on a mathematics test (Test A: average test score increased from 20 to 41, max. 60; test B: average test score increased from 32 to 41, max. 60). There were no differences for gender. Younger children achieved lower scores than older children, but had a higher increase of scores than older children. A comparison of the experimental group with control groups that had access to informal education showed that the increase in scores in both groups was similar, but the time spent on learning in the experimental group was (much) shorter. A comparison with EGMA results (internationally validated mathematics test) showed that the children in the experimental group had higher scores on four measurements of EGMA than children who had been to school for 2.5 years. The scores on three measurements of EGMA were much lower than those for children from Khartoum and Jordan. This can be explained by the fact that the children in the experimental condition had only been taught the numbers under 20, whereas EGMA uses numbers up to 1,000. Also, children were not taught to write in the pilot. Addition and Subtraction II require the child to write answers down.

These results show that there is sustained learning, over a longer period of time, including more learning objectives and more children, in more villages. These results are even more remarkable when taking into account that children did not play the game as often as planned; most children played 2–3 days a week on average, instead of five days a week. It is a negative finding that the frequency of playing was lower than intended, especially because a learning session only takes 45 minutes and takes place in the children's villages. At the same time, it is a very positive finding that children have achieved significant increases in mathematics scores in only half of the time allowed. In this way, unintentionally, the flexibility of the game–based learning approach was proven. These results show that the game allows children to be absent for some time and then resume the programme successfully, which supports this target population to keep on learning. This flexible way of learning is unique to the autonomous, game–based learning approach and difficult to achieve in regular education.

The dropout rate pilot II was substantial (10%), but less than out–of–school rates in Sudan (45%, UNESCO , 2017), and similar to dropout in a tablet intervention for mathematics in a school in Malawi (Pitchford, 2015). Age and gender did not influence dropout, which indicates that boys and girls and different age groups have a similar risk of dropping out. This is a positive finding, showing no indication that the game–based learning solution puts children at a disadvantage based on gender or age.

Although gaming with tablets is a flexible learning solution – children could take the tablet with them when they travel to another community, and keep on learning – in this pilot children had to stay in one village to stay involved. All children that moved to another village were consequently seen as dropouts. When the programme scales, more communities will be involved. This increases the possibility of children moving to another community that is using the game as well. Allowing children to take a tablet or enrolling them in the same programme in another community, at their own level, will probably reduce drop–out significantly.

8.1.6. What child–related and context factors influence learning effects?

In chapter 7, research question 6 is answered: *What child–related and context factors influence learning effects?*

To establish whether child–related and context factors influence learning, the factors that can influence learning were identified and measured during the pilot. For the factors that were measured reliably, a multivariate regression analysis was used to determine to what extent these factors predict learning outcomes. Together, these factors predict 50–75% of the results on the post–tests. This makes it a strong model.

Analyses show that the scores on the pre–tests contribute most to scores on the post–tests. This might imply that prior informal knowledge, or intelligence in general, determines the learning outcomes. Looking at the increase of scores on the tests, this is probably not the case. All children significantly improve their scores on both mathematics tests that were used to assess children's level of mathematical knowledge in this study. In test A, children who have the lowest scores on the pre–test show the highest increase of scores. It is remarkable that gender and age do not significantly explain variance of the model. In educational research, gender and age usually have an effect on learning outcomes, with differences in learning styles (Severiens & ten Dam, 1994) and older children having acquired more informal knowledge. These results show that the mathematics game supports learning for girls and boys, aged 7–9 equally.

Apart from the scores on the pre–test, the following factors also predict post–test scores: distance to the nearest primary school, self–esteem, self–efficacy, and percentage of the game completed.
The longer the distance to the nearest primary school, the higher the test scores on the post–test of test A. These results show that this game benefits the target population. When taking the game to a school context, the initial learning results may be lower. A higher self–esteem and self–efficacy at the beginning of the pilot

relate to higher mathematics scores at the end. These results indicate that a subset of the children benefits more from the game than others. This is something to keep in mind when taking the game to new context. However, it is a positive finding that self–esteem increased during the pilot. This implies that children with a lower self–esteem at the beginning can increase their scores on self–esteem and thus influence their learning in a positive way. Finally, percentage complete in the game contributes to learning outcomes: the higher the percentage complete, the higher the scores on the tests. This is a positive finding as it implies that, when scaling up in the same context, percentage complete can be used as an indicator of progress. When scaling up to a new context, the learning effect of the (adapted) game should be properly researched.

8.2. Scaling up

The Can't Wait To Learn programme started with a mathematics game for grades 1, 2, and 3 in Sudan. After the first six months of the game were tested, the complete three–year game was developed. Since then, the programme has expanded to two more countries, Jordan and Lebanon, and now also includes a literacy game for grades 1, 2, and 3. Currently a mathematics game for grades 4, 5, and 6 is being developed and it is the intention to add English as a Foreign Language and scale up to more countries in the near future. Although the mathematics game was successful in the pilots in Sudan, it cannot be assumed that the same game will be effective in new contexts. Clarke and Dede (2009, p. 353) have pointed out that 'one–size–fits–all educational innovations do not work because they ignore contextual factors that determine an innovation's efficacy in a particular local situation'. They state that adapting an educational innovation that is successful in one context to a variety of contexts is quite a challenge. McClure and Gray (2015) refer to the same issue when stating that 'key assumptions that have been 'baked' into a program's design may not be true in a different situation.' To support 'design for scalability', Clarke and Dede (2009) suggest five dimensions of scale, each with its own activities.

Dimensions of scale (Clarke & Dede, 2009, p. 354):

- Depth: evaluation and research (design–based research) to understand and enhance causes of effectiveness.
- Sustainability: 'robust design' to enable adapting to inhospitable contexts
- Spread: modifying to retain effectiveness while reducing resources and expertise required

- Shift: moving beyond 'brand' to support users as co–evaluators, co–designers, and co–scalers
- Evolution: learning from users' adaptations to rethink the innovation's design model

These dimensions do not aim to prescribe a linear progression, but outline the processes designers and developers can use to design for scale. In the design and development of the mathematics game for Sudan three of these dimensions were taken into account: depth, sustainability and spread. Although the dimensions shift and evolution were explored, they were left for a later moment in the programme. However, during development and testing, feedback from facilitators, teachers and children was gathered.

Below, the way in which the dimensions of scale were addressed, are described.

Depth: to understand the effectiveness of the game, it was evaluated with respect to learning results, but also with regard to the factors that influenced effectiveness. This is described in detail in chapter 7. In addition, users (children and facilitators) evaluated the game.

Sustainability: to support a robust design, the game was developed in components. This means the overall structure of the game stays the same, while components can be changed, when necessary. The choice of the components was based on the requirements; all requirements that can lead to a different design and development in a new context were made in a flexible way. For instance, cultures differ from one country to another. In the game, graphics and colours can be changed without creating a complete new game world structure. As the language of instruction can be different in different countries, all audio and video can be replaced easily. Also, mini–games can be added or left out, as curricula do not always cover exactly the same learning objectives.

Spread: the robust design ensures that adaptations for new contexts can be done in a simple way. The structure of the game and the mini–games have shown to be effective to learn mathematics. Changes only need to be made to curriculum and cultural aspects. This reduces resources.

During the process of scaling so far, the following issues were identified and addressed:

From laptop to tablet

After the first experiment, due to a change in legislation, the hardware changed from laptops to tablets. Looking at how technology has developed over the past few years, it was a wise decision to change from laptops to tablets. The fact that the results in the second experiment were similar to those in the first experiment proves that the effectiveness of the game has not changed as a result of the change to tablets.

Complete curriculum

To limit the resources needed to develop the game to be used in the pilots, learning objectives were addressed by a minimal set of mini–games. Although this allowed for a timely development within budget, it resulted in less variety of activities in the game. The new mathematics games, also for Jordan and Lebanon, include mini–games that were designed but never implemented in the research phase in Sudan (e.g. writing numerals).

Co–creation

Although access to children in the target population in Sudan was limited, due to restrictions in travel permissions, the cooperation with local experts and children was essential in the design of the game. To ensure this cooperation is captured in a structured way, new processes were developed. In each new context, a needs analysis is carried out, involving children, parents, teachers and local experts, focusing on what should be learned and how they would prefer to learn this. In addition, a co–creation process is followed, involving children and local artists. Together, they develop the narrative (including objects), art style and colour scheme of the game world (Figure 67).

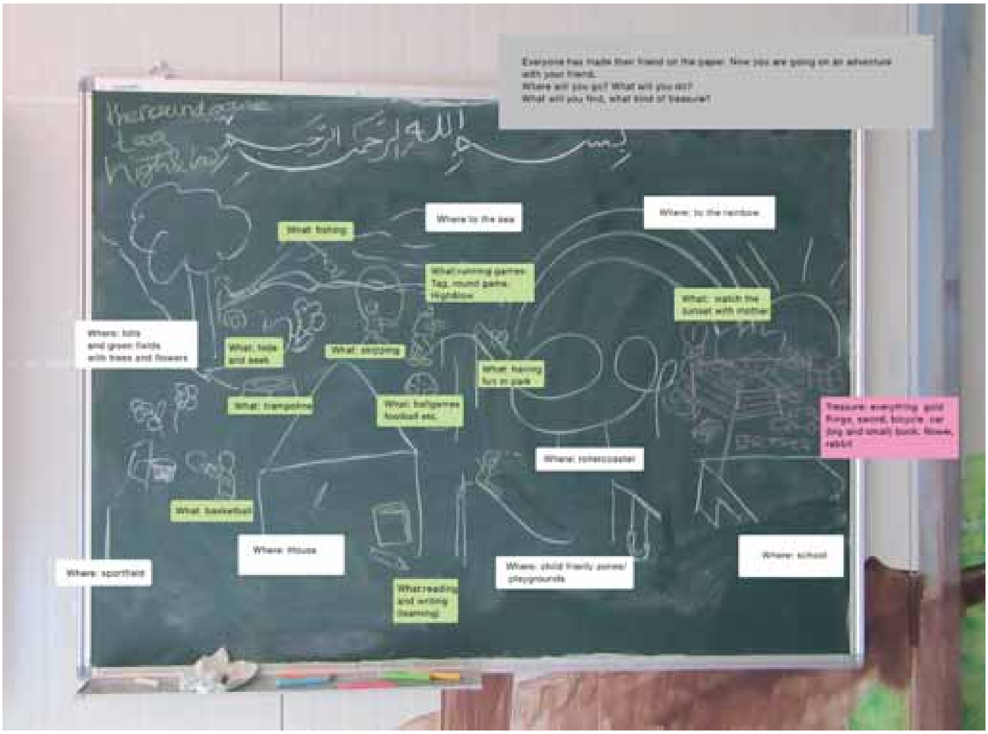


Figure 67. Developing the basis for the narrative with children's input in Jordan.

Below, two illustrations (Figures 68 and 69) show the cultural differences in the graphic design of the game worlds for the mathematics game in Sudan and Jordan.

Figure 68. Shop, Sudan mathematics game grades 1, 2, and 3.

Figure 69. Shop, Jordan mathematics game grades 1, 2, and 3.

Both illustrations show the shop in the mathematics game; both have a shopkeeper and shelves with products. Figure 69 also shows a few customers: the characters with a speech bubble above their heads are customers. The speech bubble shows what they want to buy. The Sudan game also has customers, in the same way. At the same time, there are quite a few differences as well:

- In Sudan, the graphics are quite basic, showing less detail than in Jordan. This is visible in the way characters are drawn and in the decorations of the shop in the background;
- The characters for Sudan and Jordan are different, with different clothes and hairstyles. This resembles the real–life situation in Sudan and Jordan;
- The products that are sold in the shop are different for Sudan and Jordan; mostly food in Sudan and mostly tools & toys in Jordan. This is in line with products that can be expected in shops per country and children's preferences as shared in the co–creation process.

Placement test

In Sudan, all children started playing the game from the beginning. None of them had been to school before, and it was the assumption their level of mathematics was low. Even in Sudan, results showed there was a difference in mastery level between children at the beginning of the experiment that could have been addressed. When taking the game to contexts in which children do have access to education, or have been to school before, it is even more important to ensure children can learn at their own level. That is why a placement test has been added to the structure of the game. The placement test uses a selection of mini–games from the game and is structured according to the curriculum in the game. Although children can still start playing from the beginning, it is now also possible to start by playing the placement test. The child can first play the mini–games and get to know them. Then it has to successfully finish the mini–games to get to the next level of the placement test. When the child fails at a specific level of the placement test, it will stream in to the game at one level lower than the one that is failed.

School context

In Sudan, the mathematics game was used in an out–of–school context. As it will now also be used in schools in Jordan, alternative delivery models of the game have been explored (Stubbé, McCance, Twissi, & Ibrahim, 2017). Four different delivery models were identified: full gaming model, part–time gaming model, embedded in classroom teaching model and pick & mix model. Where a full gaming model was used in Sudan, in Jordan the model in which gaming is embedded in classroom teaching will be tried out. To support this approach, a new functionality was added to the game: mini–bubbles. The teacher can select a specific combination of mini–games at a specific level that, together, address one learning objective. In this way teachers can provide instruction on a specific learning objective and have children practise that learning objective. After finishing the mini–bubble, children automatically continue playing at their own level, allowing each child to learn at their own mastery level.

Expanding to Literacy

To address a completely new subject, literacy, a similar design process was followed as in the mathematics game. In addition to the national curriculum, the internationally recognised learning objectives and best practices for learning to read were studied. In addition, the specific characteristics of Arabic were studied. As there were no existing digital materials that support learning to read in Arabic without a teacher, a feasibility study was carried out (Jetten & Stubbé, 2015). As could be expected, the design of a literacy game entails its own, specific challenges. Examples of these are, amongst others, font size, where an optimal balance had to be found between the screen size of the tablet and the font size beginning readers need to understand what they are reading; the characteristics of Arabic letters that change according to their place in a word; and reading materials that were not readily available and had to be developed. Recently, first trials of literacy games have started in Jordan and Sudan.

To summarise, the research in this thesis aims to contribute to solving the global learning crisis in two different ways. First of all, it has shown that children in remote villages in Sudan can learn mathematics by playing a game without learning support from teachers and parents. This opens up possibilities to achieve education for hard–to–reach children, either in Sudan or in other countries. At the same time, the game itself was carefully designed to support learning for a specific target population in their specific context. The design process and the game requirements identified can and have been used to adapt the mathematics game for new contexts, and to design literacy games. In this way, the Can't Wait To Learn programme hopes to reach 170,000 children in marginalised communities in multiple countries by 2020.

Relation of chapters to previous publications

Chapter 1. Introduction
Previous versions of this introduction have been published in:

Stubbé, H., Telford, R., & Hulst, A. van der (2015). The role of pedagogy and assessment in game–based learning. Proceedings of the 13th International Conference on Education and Development (UKFIET), Oxford, 15–17 September 2015.

Stubbé, H., Badri, A., Telford, R, Oosterbeek, S., & Hulst, A. van der (2016). Formative Evaluation of a Mathematics Game for Out–of–School Children in Sudan. In Cai, Y., Goei, S.L., & Trooster, W. (eds.) Simulation and Serious Games for Education. Springer Science+Business Media, Singapore.
ISBN 978–981–10–0860-3

Stubbé, H., Badri, A., Telford, R., Hulst, A. van der, & Joolingen, W. van (2016). E–Learning Sudan, Formal Learning for Out–of–School Children. The Electronic Journal of e–learning, Vol. 14, issue 2, 2016 (pp. 136–149)

Stubbé, H. McCance, G. Twissi, Z., & Ibrahim, N. (2017). Flipping the teachers' role: What to Teach when Using Game–Based Learning? Proceedings of the European Conference on Games Based Learning 2017, Graz, Austria, 5–6 October 2017.

Chapter 2. Game requirements
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ISBN 978–981–10–0860–3.

Chapter 5. Can children learn from playing the game?

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Stubbé, H., Badri, A., Telford, R., Hulst, A. van der, & Joolingen, W. van (2016). E–Learning Sudan, Formal Learning for Out–of–School Children. The Electronic Journal of e–learning, Vol. 14, issue 2, 2016 (pp. 136–149).

Chapter 6. Sustained learning: Can children learn longer and more from playing the game autonomously?

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References

Alvarez, K., Salas, E., & Garofano, C.M. (2004). An integrated model of training evaluation and effectiveness. *Human Resource Development Review, Vol. 3*, No. 4, pp. 385–416.

Aunio, P., Hautamäki, J., Sajaniemi, N., & van Luit, J.E.H. (2009). Early numeracy in low–performing young children. *British Educational Research Journal, Vol. 35*, issue 1, pp. 25–46. DOI: 10.1080/01411920802041822.

Bandura, A. (1997). *Self–efficacy: The exercise of control*. New York: Freeman.

Baroody, A.J. (1999). Children's Relational Knowledge of Addition and Subtraction. *Cognition and Instruction, Vol. 17*, No. 2, pp. 137-175, DOI: 10.1207/S1532690XCI170201.

Baroody, A.J. (2004). The Development bases for early childhood number and operation standards. https://www.researchgate.net/profile/Arthur_Baroody/publication/255660499_THE_DEVELOPMENTAL_BASES_FOR_EARLY_CHILDHOOD_NUMBER_AND_OPERATIONS_STANDARDS/links/54942b380cf2ff65955828e3.pdf. Retrieved 21 February, 2015.

Baumeister, R.F., Campbell, J.D., Krueger, J.I., & Vohs, K.D. (2003). Does high self–esteem cause better performance, interpersonal success, happiness or healthier lifestyles? *Psychological Science in the Public Interest, Vol. 4*, No. 1, May 2003.

Beetham, H. & Sharpe, R. (ed.) (2007). *Rethinking Pedagogy for a Digital Age: Designing and Delivering E–Learning*. Routledge Taylor and Francis group.

Bender, W., Kane, C., Cornish, J., & Donahue, N. (2012). *Learning to change the world: the social impact of one laptop per child*. New York: Palgrave Macmillan, 2012. ISBN: 9780230337312.

Biggs, J. (1999). What the student does: teaching for enhanced learning. *Higher Education Research & Development, Vol. 18*, No. 1, p. 57–75.

Bjork, S. & Holopainen, J. (2004). *Patterns in game design (game development series)*. Charles River Media. ISBN–10: 1584503548.

Bloom, B.S. (ed). (1985). *Developing Talent in Young People.* New York: Ballentine Books.

Blumberg, R.L. (2007). *Gender bias in text books: a hidden obstacle on the road to gender equality in education.* United Nations Educational, Scientific and Cultural Organization. 008/ED/EFA/MRT/PI/18.

Blumberg, R.L. (2008). The invisible obstacle to educational quality: gender bias in text books. *Prospects* (2008) No. 38, pp.345–361. DOI: 10.1007/s11125-009-9086-1.

Bodovski, K., and Farkas, G. (2007). Mathematics Growth in Early Elementary School: The roles of Beginning Knowledge, Student Engagement and Instruction. *Elementary School Journal, Vol. 108*, No. 2, pp. 115–130.

Boissiere, M. (2004) *Determinants of Primary Education Outcomes in Developing Counties.* The World Bank Operations Evaluation Department, 39157.

Burnett, N. (1996). Priorities and strategies for education–a world bank review: the process and the key messages. *International Journal of Educational Development, Vol. 16,* No. 3, pp. 215–220.

Chard, D.J., Baker, S.K., Clarke, B., Jungjohann, K., Davis, K., & Smolkowski, K. (2008) Preventing Early Mathematics Difficulties: The Feasibility of a Rigorous Kindergarten Mathematics Curriculum. *Learning Disability Quarterly, Vol. 31,* Winter 2008, pp. 11–20.

Cheek, J. M., Smith, S.M., & Tropp, L. R. (2002, February). *Relational identity orientation: A fourth scale for the AIQ.* Paper presented at the meeting of the Society for Personality and Social Psychology, Savannah, GA.

Chen, G.D., Chang, C.K., & Wang, C.Y. (2008). Ubiquitous learning website: Scaffold learners by mobile devices with information–aware techniques. *Computers & Education, Vol. 50* (2008), pp. 77–90.

Chen, C. & Lin, Y. (2016). Effects of different text display types on reading comprehension, sustained attention and cognitive load in mobile reading contexts. *Interactive Learning Environments, Vol. 24*, issue 3, pp. 553–571. DOI: 10.1080/10494820.2014.891526.

Clark, R.E., Yates, K., Early, S., & Moulton, K. (2008). An analysis of the failure of Electronic Media and Discovery–based learning: Evidence for the performance benefits of Guided Training Methods. In Silber, K.H., & Foshay, R. (Eds.) *Handbook of Training and Improving Workplace Performance, Volume 1*: Instructional Design and Training Delivery. Somerset, NJ: Wiley.

Clarke, J. & Dede, C. (2009). Design for Scalability: A case Study of the River City Curriculum. *Journal of Science Education Technology (2009), Vol. 18*, pp.353–365. DOI: 10.1007/s10956–009–9156–4.

Clements, D.H. & Sarama, J. (2007). Effects of a preschool mathematics curriculum: Summative research on the Building Blocks project. *Journal for Research in Mathematics Education, Vol. 38,* No. 2, pp. 136–163.

Clements, D.H. & Sarama, J. (2009). *Learning and teaching early math: The learning trajectories approach.* New York: Routledge.

Connolly, T.M., Boyle, E.A., MacArthur, E. Hainey, T., & Boyle, J.M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers and Education, Vol. 59*, No. 2, pp. 661–686. DOI: 10.1016/j. compedu.2012.03.004.

Cremin, P. & Nakabugo, M. G. (2012). Education, development and poverty reduction: A literature critique. *International Journal of Educational Development (2012), Vol. 32*, pp. 499–506.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*, Harper and Row, New York.

Daniel, J. (2010). *Mega–Schools, Technology and Teachers: achieving education for all.* Routlegde: London and New York.

Daroczy, G., Wolska, W., Meureres, W.D., & Nuerk, H. (2014). Word problems: a review of linguistic and numerical factors contributing to their difficulty. *Frontiers in Psychology, Vol. 6*, article 348. DOI: 10.3389/fpsyg.2015.00348.

Dede, C. (2006). Scaling up: Evolving Innovations beyond Ideal Settings to Challenging Contexts of Practice. In R.K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences*. Cambridge, England: Cambridge University Press.

Dembélé, M. & Lefoka, P. (2007). Pedagogical Renewal for Quality Universal Primary Education: Overview of trend in Sub–Saharan Africa. *International Review of Education, Vol. 53*, pp. 531–553.

Drijvers, P. (2013). Digital technology in mathematics education: why it works (or doesn't). *PNA, Vol. 8*, Issue 1, pp. 1–20.

Duncan, G.J., Claessens, A., Huston, A.C., Pagani, L.S., Engel, M., Sexton, H., Dowsett, C.J., Magnuson, K., Klebanov, P., Feinstein, L., Brooks–Gunn, J., Duckworth, K., & Japel, C. (2007) School Readiness and Later Achievement. *Developmental Psychology, 2007*, Vol. 43, No. 6, pp. 1428–1446.

Eccles, J. (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motives: Psychological and sociological approaches* (pp. 75–146). San Francisco, CA: W. H. Freeman.

Evans, L. & Davies, K. (2000). No sissy boys here: a content analysis of the representation of masculinity in elementary school reading textbooks. *Sex Roles, Feb. 2000, Vol. 42*, Issue 3-4, pp. 255–270.

Fleuren, M. A. H., Paulussen, T. G. W. M., van Dommelen, P., & van Buuren, S. (2012). *Meetinstrument voor Determinanten van Innovaties (MIDI).* Leiden: TNO.

Freeman, S., Eddy, S.L., McDonough, M., Smith, M.K., Okoroafor, N., Jordt, H., & Wenderoth, M.P. (2014). Active learning increases student performance in science, engineering, and mathematics. *PNAS (June 10, 2014), Vol. 111*, No. 23, pp. 8410–8415. www.pnas.

Freudenthal, H. (2002). *Revisiting mathematics education–China lectures.* Kluwer Academic Publishers New York, Boston, Dordrecht, London, Moscow.

Gerdes, P. (1988). On culture, geometrical thinking and mathematics education. *Educational studies in Mathematics, Vol. 19* (1988) pp. 137–162.

Gifi A. (1990). *Nonlinear multivariate analysis*. Chichester: Wiley; 1990.

Ginsberg, H.P. & Russel, R.L. (1981) Social class and racial influences on early mathematical thinking. *Monographs of the Society for Research in Child Development, Vol. 46*, No. 6, pp. 1–69.

Girard, C., Ecalle, J., & Magnant, A. (2013). Serious games as new educational tools: how effective are they? A meta–analysis of recent studies. *Journal of Computer Assisted Learning, June 2013, Vol. 29*, Issue 3, pp. 207–219. DOI: 10.1111/j.1365-2729.2012.00489.x.

Greenman, E., Bodovski, K., and Reed, K. (2011). *Neighbourhood characteristics, parental practices and children's math achievements in elementary school.* The Pennsylvania State University, PA, United States.

Guberman, S.R. (1996) The Development of Everyday Mathematics in Brazilian Children with Limited Formal Education. *Child Development, Vol. 67*, Issue 4, pp. 1609–1623, August 1996. DOI: 10.1111/j.1467–8624.1996.tb01817.x.

Gunn, S., Jordans, M., Awan, S., & Hofman, M. (2015). *Development of an instrument for the psychosocial assessment of child workers.* International Labour Organisation.

Haan, J. de & F. Huysmans (2004) 'IT/Media Use and Psychological Development among Dutch Youth', *IT and Society, Vol. 2,* No. 1, pp. 40–53.

Hansen, N., Postmes, T., van der Vinne, N., & van Thiel, W. (2012). Information and Communication Technology and Cultural Change. How ICT usage changes self–construal and values. *Social Psychology, Vol. 43*, No. 4, pp. 222–231. DOI: 10.1027/1864–9335/a000123.

Hanushek, E.A., Jamison, D.T., Jamison, E.A., & Woessmann, L. (2011). *Education and Economic Growth–It's not just going to school, but learning something while there that matters.* Taub Center–Herbert M. Singer Conference Series, Socioeconomic Impact of Education, September 2011.

Harding, J.F., Morris, P.A., & Hughes, D. (2015). The Relationship Between Maternal Education and Children's Academic Outcomes: A Theoretical Framework. *Journal of Marriage and Family, Vol. 77*, pp. 60-76. DOI: 10.1111/jomf.12156.

Hardman, F., Abd–Kadir, J., & Smith, F. (2008). Pedagogical renewal: Improving the quality of classroom interaction in Nigerian primary schools. *International Journal of Educational Development, Vol. 28* (2008), pp. 55–69.

Harter, S. (1993) Causes and Consequences of Low Self–esteem in Children and Adolescents'. In R.F. Baumeister (ed.) Self–esteem: *the Puzzle of Low Self–regard*, pp. 87–116. New York: Plenum Press.

Hattie, J (2009). *Visible learning–a synthesis of over 800 meta–analyses relating to achievement.* Routledge, Taylor and Francis Group, London and New York.

Hofstede (2018). https://www.hofstede–insights.com/country–comparison/ accessed 4 March 2018.

Inglehart, R. F. & Baker, W. E. (2000). Modernization, cultural change, and the persistence of traditional values. *American Sociological Review, Vol. 65*, pp. 19–51.

Jernudd, B. H. (1979). *The language survey of Sudan: the first phase: a questionnaire survey in schools*. Doctoral thesis, Umeå University, Faculty of Arts.

Jetten, A. & Stubbé, H. (2015). Autonomous reading acquisition in Arabic supported by a gamified version of the curriculum–A feasibility Study. TNO 2015 R11383.

Jong, T. de, van Joolingen, W.R., Swaak, J., Veermans, K, Limbach, R., King, S. & Gureghian, D. (1998). Self–directed learning in simulation–based discovery environments. *Journal of Computer Assisted Learning, Vol. 14*, Issue 3, pp. 235–246, September 1998.

Jonker, V. & Wijers, M. (2008). Th!nklets for mathematics education: re–using computer game characteristics in educational software. *In Proceedings of the 8th International Conference for the Learning Sciences, Vol. 1*, pp. 406–413. International Society of the Learning Sciences.

Jordan, A. (2004) 'The Role of Media in Children's Development: an Ecological Perspective', *Journal of Developmental and Behavioral Pediatrics, Vol. 25*, No. 3, pp. 196–206.

Kallaway, P. (2001). The need for attention to the issue of rural education. *International Journal of Educational Development, Vol. 21* (2001), pp. 21–32.

Kalloo, V., Mohan, P., & Kinshuk, (2015). A Technique for Mapping Mathematics Content to Game Design. *International Journal of Serious Games, Vol. 2*, No. 4, pp. 73–92, September 2015, ISSN: 2384–8766 http://dx.doi.org/10.17083/ijsg.v%vi%i.95.

Kanu, A.S. & Hengel, C. van (2013) *A Report on the Baseline Assessment of Children's Early Literacy Abilities in Selected Primary Schools in Classes I, II, III.* Woord en Daad, 2013.

Ke, F. (2008) A Case Study of Computer Gaming for Math: Engaged Learning from Gameplay? *Computers & Education, Vol. 51* (2008) pp. 1609–1620.

Kegel, C.A.T., Bus, A.G., & IJzendoorn, M.H. van (2011). Differential susceptibility in early literacy instruction through computer game: The role of the Dopamine D4 Receptor Gene (DRD4). *Mind, Brain, and Education, Vol. 5*, pp. 71–78.

Kim, D. & Kim, D. (2010). Effect of screen size on multimedia vocabulary learning. *British Journal of Educational Technology, Vol. 43*, Issue 1, pp. 62–70. DOI: 10.1111/j.1467–8535.2010.01145.x.

Kim, S. & McLean, G.N. (2014). The Impact of National Culture on Learning in the Workplace. *Adult Education Quarterly, 2014, Vol 64*, No. 1, pp. 39–59.

Kirkpatrick, D.L. (1976). Evaluation of training. In Craig, R.L. (Ed.): *Training and Development Handbook: A guide to human resource development,* McGraw Hill, New York, pp. 301–319.

Kirkpatrick, D.L. (1998). *Evaluating Training Programs: The four levels*, 2nd ed., Berret–Koehler, San Francisco.

Kobia, J.M. (2009). Femininity and Masculinity in English Primary School Textbooks in Kenya. *The International Journal of Language Society and Culture*, Issue 28, pp. 57–71.

Kraiger, K., Ford, J.K., & Salas (1993). Application of cognitive skill–based, and affective theories of learning outcomes to new methods of training evaluation. *Journal of Applied Psychology, Vol. 78*, No. 2, pp. 311–328.

Krosnick, J.A., S.N. Anand and S.P. Hartl (2003) 'Psychosocial Predictors of Heavy Television Viewing among Pre–adolescents and Adolescents', *Basic and Applied Social Psychology, Vol. 25*, No. 2, pp. 87–110.

Krstić, I. (2008). Sic transit gloria laptopi. Retreived from: http://radian.org/notebook/sic–transit–gloria–laptopi.

Lange, A., Evers, A., Jansen, H., & Dolan, C.2 (2002). PACHIQ–R. The Parent–Child Interaction Questionnaire– Revised. *Family Process, Vol. 41*, pp. 709–722.

Lavy, V. (2012) *Do differences in schools' instruction time explain international achievement gaps? Evidence from developed and developing countries.* Retrieved from http://www.nber.org/papers/w16227 (16–07–2013).

Latchem, C. (2012). *Quality assurance toolkit for open and distance non–formal education.* Vancouver, Canada: Commonwealth of Learning.

Li, Q. & Ma, X. (2010) A Meta–Analysis of the Effects of Computer Technology on School Students' Mathematics Learning. *Educational Psychology Review (2010), Vol. 22*, pp. 215–243. DOI: 10.1007/s10648–010–9125–8.

Lipsey, M.W., Puzio, K., Yun, C., Hebert, M.A., Steinka–Fry,K., Cole, M.W., Roberts, M., Anthony, K.S., & Busick, M.D. (2012). *Translating the Statistical Representation of the Effects of Education Interventions Into More Readily Interpretable Forms.* U.S. Department of Education, NCSER 2013–3000.

Lockheed, M.E. & Verspoor, A.M. (1991). *Improving primary education in developing countries.* Published for the World Bank Oxford University Press.

Magnuson, K., Sexton, H.R., Davis–Kean, P.E., & Huston, A.C. (2009). Increases in maternal education and young children's language skills. *Merril–Palmer Quarterly, Vol. 55*, pp. 319–350.

Maniar, N., Bennet, E., Hand, S., & Allan, X (2008). The effect of mobile phone screen size on video based learning. *Journal of Software, Vol. 3*, pp. 51–61.

Markus, H.R. & Kitayama, S. (1991). Culture and the Self: Implications for Cognition, Emotion, and Motivation. *Psychological Review 1991, Vol. 98*, No. 2, pp. 224–253.

Marsh, H.W. (1992). *Self–Description Questionnaire (SDQ) II: A theoretical and empirical basis for the measurement of multiple dimensions of adolescent self–concept. An interim test manual and research monograph.* Macarthur, New South Wales, Australia: University of Western Sydney, Faculty of Education.

Marsh, T., Ma, M., Oliveira, M.F., Hauge, J.B., & Göbel, S. (eds.) (2016). *Serious Games: Second Joint International Conference*, JCSG 2016, Brisbane, QLD, Australia, September 26–27, Proceedings (Vol. 9894). Springer.

Martin, M.O. & Mullis, I.V.S (eds.) (2013). *TIMSS and PIRLS 2011: Relationships among Reading, Mathematics, and Science Achievement at the Fourth Grade—Implications for Early Learning.* TIMSS & PIRLS International Study Center, Lynch School of Education, Boston College and International Association for the Evaluation of Educational Achievement (IEA). ISBN: 978–1–889938–18–9.

Mayer, R.E. & Moreno, R. (2002). Animation as an Aid to Multimedia Learning. *Educational Psychology Review, March 2002, Vol. 14*, Issue 1, pp. 87–99.

McClure, D. & Gray, I. (2015). *Scaling: Innovation's Missing Middle.* Retrieved from https://thoughtworks.fileburst.com/articles/scaling–innovations–missing–middle–dan–mcclure–ian–gray.pdf (11–01–2015).

McEwan, P.J. (2014). Improving Learning in Primary Schools of Developing Countries: A Meta–Analysis of Randomized Experiments. *Review of Educational Research, September 2015, Vol. 85*, No. 3, pp. 353–394. DOI: 10.3102/0034654314553127.

Meulman, J.J., Heiser, W.J. (1999). *Inc. S. SPSS categories.* Chicago: SPSS Inc.; 1999.

Miller, C. (1989). Langues et Identité. In *Le Soudan Contemporain*, Lavergne, M. 1989, Karthala editions.

Miller, C. (2006). Language, identities and ideologies: a new era for Sudan. *Proceedings 7th International Sudan Studies Conference*, 2006, Bergen, Norway.

Milo, B. (2003), *Mathematics instruction for special–needs* students. Thesis University of Leiden, Heerenveen: Brouwer & Wielsma.

Moloi, F., Morobe, N., & Urwick, J. (2008). Free but inaccessible primary education: A critique of the pedagogy of English and Mathematics in Lesotho. *International Journal of Educational Development, Vol. 28* (2008), pp. 612–62.

Mtika, P., Gates, P. (2010). Developing learner–centered education among secondary trainee teachers in Malawi: The dilemma of appropriation and application. *International Journal of Educational Development, Vol. 30*, pp. 396–404.

Mugaddam, A.R. H. & Dimmendaal, G.J. (2006). Sudan Linguistic Situation. *International Encyclopedia of Language and Linguistics, Vol. 12*, pp. 265–270.

Nelson, J.R., Benner, G.J., & Gonzales J.(2003). Learner Characteristics that Influence the Treatment Effectiveness of Early Literacy Interventions: A Meta–Analytic Review. *Learning Disabilities, research and practice, Vol. 18*, Issue 4, pp. 255–267.

Novelli, M. & Lopes Cardozo, M.T.A. (2008) Conflict, education and the global south: New critical directions. *International Journal of Educational Development, Vol. 28* (2008), pp. 472–488.

O'Neill, H.F., Wainess, R., & Baker, E.L. (2005). Classification of learning outcomes: evidence from the computer games literature. *The Curriculum Journal, Vol. 16*, No. 4, December 2005, pp. 455–474.

Oprins, E., Visschedijk, G., Bakhuys–Roozeboom, M., Dankbaar, M., Trooster, W. & Schuit, S.C.E. (2015). The Game–based learning evaluation model (GEM): measuring the effectiveness of serious games using a standardised method. *International Journal of Technology Enhanced Learning, Vol. 7*, No. 4, pp. 326–345.

Ottoson, J.M. & Hawe, P. (2009). Knowledge utilization, diffusion, implementation, transfer, and translation: Implications for evolution. *New Directions for Evaluation, Vol. 124*, pp. 1–108.

Pagani, L.S., Fitzpatrick, C., Archambault, I., & Janosz, M. (2010). School Readiness and Later Achievement: A French Canadian Replication and Extension. *Developmental Psychology 2010, Vol. 46*, No. 5, pp. 984–994.

Pellegrino, J.W. & Goldman, S.R. (1987). Information processing and elementary mathematics. *Journal of Learning Disabilities, Vol. 20*, pp. 23–32.

Petrosino A., Morgan C., Fronius T., Tanner–Smith E., & Boruch R. (2012). *Interventions in developing nations for improving primary and secondary school enrolment of children: A systematic review.* Oslo, Norway: The Campbell Collaboration.

Pintrich, P.R. (1988). A process–oriented view of student motivation and cognition. *New Directions for Institutional Research, Vol. 1988*, Issue *57*, pp. 1–88.

Pintrich, P.R. & De Groot, E.V. (1990). Motivational and Self–Regulated Learning Components of Classroom Academic Performance. *Journal of Educational Psychology, 1990*, Vol. 82, No. 1, pp. 33–40.

Pitchford, N.J. (2015). Development of early mathematical skills with a tablet intervention: a randomized control trial in Malawi. *Frontiers in Psychology, Vol. 6* (April 2015), article 485.

Pol, J. van de, Volman, M., & Beishuizen, J. (2010). Scaffolding in Teacher–Student Interaction: A Decade of Research. *Educational Psychology Review, Vol. 22*, Issue 3, pp. 271–296. DOI: 10.1007/s10648–010–9127–6.

Power, T. Gater, R., Grant, C., & Winters, N. (2014). *Educational Technology Topic Guide*. HEART Topic Guides. London: The Health & Education Advice & Resource Team (HEART). Department for International Development (DFID).

Praet, M. & Desoete, A. (2014). Enhancing young children's arithmetic skills through non–intensive computerized kindergarten interventions: A randomized controlled study. *Teaching and Teacher Education, Vol. 39* (2014), pp. 56–65.

Räsänen. P., Salminen, J., Wilson, A.J., Aunio, P., & Dehaene, S. (2009). Computer–assisted intervention for children with low numeracy skills. *Cognitive Development (2009), Vol. 24,* Issue 4, pp. 450–472. DOI:10.1016/j.cogdev.2009.09.003.

Raveh, I., Koichu, B., Peled, I., & Zaslavsky, O. (2016). Four (algorithms) in one (bag): an integrative framework of knowledge for teaching the standard algorithms of the basic arithmetic operations. *Research in Mathematics Education, Vol. 18*, Issue 1 (2 January 2016), pp. 43–60.

Reeves, B., Lang, A., Kim, E., & Tatar, D. (1999). The effects of screen size and message content on attention and arousal. *Media Psychology, Vol. 1*, pp. 49–68.

Resnick, L.B., Wang, M.C., & Kaplan, J. (1973). Task analysis in curriculum design: a hierarchically sequenced introductory mathematics curriculum. *Journal of Applied Behavior Analysis, Vol. 6*, No. 4 (Winter 1973), pp. 679–710.

Robbins, S.B., Le, H., Davis, D., Lauver, K., Langley, R., & Carlstrom, A. (2004). Do Psychosocial and Study Skill Factors Predict College Outcomes? A Meta–Analysis. *Psychological Bulletin 2004, Vol. 130*, No. 2, pp. 261–288.

Rosas, R., Nussbaum, M., Cumsille, P., Marianov, V., Correa, M., Flores, P., Grau, V., Lagos, F., López, X., López, V., Rodriguez, P., & Salinas, M. (2003) "Beyond Nintendo: Design and Assessment of Educational Video Games for First and Second Grade Students". *Computers & Education, Vol. 40* (2003), pp. 71–94.

Saine, N.L., Lerkkanen, M–J., Ahonen, T. Tolvanen, A., & Lyytinen, H. (2011). Computer–assisted remedial reading interventions for school beginners at risk for reading disability. *Child Development, Vol. 82*, pp. 1013–1028.

Sarama, J. & Clements, D.H. (2002). Building blocks for young children's mathematical development. *Journal of Educational Computing Research, Vol. 27*, Issue 1–2, pp. 93–110.

Sarama, J. & Clements, D.H. (2004). Building Blocks for early childhood mathematics. *Early Childhood Research Quarterly, Vol. 19* (2004), pp. 181–189.

Schmitt, D.P. & Allik, J. (2005). Simultaneous Administration of the Rosenberg Self–Esteem Scale in 53 Nations: Exploring the Universal and Culture–Specific Features of Global Self–Esteem. *Journal of Personality and Social Psychology, Vol. 89*, pp. 623–642.

Schweisfurth, M. (2011). Learner–centred education in developing country contexts: From solution to problem? *International Journal of Educational Development, Vol. 31* (2011), pp. 425–432.

Selinger, M. (2009). ICT in education: Catalyst for development. In T. Unwin (Ed.), ICT4D: *Information and communication technology for development* (pp. 206–248), Cambridge, UK: Cambridge University Press.

Serafini, T.E. & Adams, G.R (2002). Functions of Identity: Scale Construction and Validation. *Identity: an International Journal of Theory and Research, Vol. 2*, No. 4, 363–391.

Serafini, T.E. & Maitland, S.B. (2013). Validating the Functions of Identity Scale: Addressing Methodological and Conceptual Matters. *Psychological Reports: Measures & Statistics 2013, Vol. 112*, No. 1, pp. 160–183.

Severiens, S.E. & ten Dam, G.T.M. (1994). Gender differences in learning styles: A narrative review and quantitative meta–analysis. *Higher Education, June 1994, Vol. 27*, Issue 4, pp. 487–501.

Sherry, J.L., Lucas, K., Greenberg, B.S., & Holmstrom, A. (2010). Child development and genre preference: research for educational game design. *Cyberpsychology, Behavior, and Social Networking, Vol. 16*, No. 5, pp. 335–339. DOI: 10.1089/cyber.2012.0242.

Sitzmann, T. (2011). A meta–analytic examination of the instructional effectiveness of computer–based simulation games. *Personnel Psychology, Vol. 64*, pp. 489–528.

Sriprakash, A. (2010). Child–centered education and the promise of democratic learning: Pedagogic messages in rural Indian primary schools. *International Journal of Educational Development, Vol. 30,* pp. 297–304.

Steenbergen–Hu, S. & Cooper, H. (2013) A Meta–Analysis of the Effectiveness of Intelligent Tutoring Systems on K–12 Students' Mathematical Learning. *Journal of Educational Psychology 2013, Vol. 105*, No. 4, pp. 970–987.

Stubbé–Alberts, H.E., van der Klauw, M., & Langefeld, J.J. (2014). E–Learning Sudan–Pilot II. *Descriptive analysis of the baseline study.* TNO 2014 R11794.

Stubbé, H. McCance, G. Twissi, Z., & Ibrahim, N. (2017). Flipping the teachers' role: What to Teach when Using Game–Based Learning? *Proceedings of the European Conference on Games Based Learning 2017, Graz, Austria, 5–6 October 2017.*

Stubbé, H.E. & Theunissen, N.C.M. (2008). Self–directed learning in a ubiquitous learning environment: a meta–review. *Proceedings of Special Track on Technology Support for Self–Organised Learners, Vol. 2008*, pp. 5–28.

Sweller, J. (2008). Evolutionary bases of human cognitive architecture: implications for computing education. In proceedings ICER '08 *Proceedings of the Fourth international Workshop on Computing Education Research*, pp. 1–2.

The World Bank (2012). *The status of the education sector in Sudan*. African Human Development Series, 66608).

Thompson, P. (2013). Learner–centred education and 'cultural translation'. *International Journal of Educational Development, Vol. 33* (2013), pp. 48–58.

Timmermans, R. (2005), *Addition and subtraction strategies. Assessment and instruction,* Nijmegen: Radboud University.

Toll, S.W.M. & van Luit, J.E.H. (2014). Effects of remedial numeracy instruction throughout kindergarten starting at different ages: Evidence from a large–scale longitudinal study. *Learning and Instruction, Vol. 33* (2014), pp. 39–49.

Triandis, H.C. (1989). The self and social behavior in differing cultural contexts. *Psychological Review, Vol. 96*, No. 3, pp. 506–520. http://dx.doi.org/10.1037/0033–295X.96.3.506.

United Nations Educational Scientific Cultural Organization (UNESCO) (2009). *Promoting gender equality for textbooks, a methodological guide.*

United Nations Educational Scientific Cultural Organization (UNESCO) (2012). World Data on Education, VII ed. 2010/11. IBE/2012/CP/WDE/SJ.

United Nations Educational Scientific Cultural Organization (UNESCO) (2015). Education for All 2000–2015: achievements and challenges; EFA global monitoring report, 2015. ISBN 978–92–3–100085–0.

United Nations Educational Scientific Cultural Organisation (UNESCO) (2017). *Reducing Global Poverty through Universal Primary and Secondary Eduation.* UNESCO policy paper 32/fact sheet 44, June 2017.

United Nations Educational, Scientific and Cultural Organization Institute for Statistics. (2009). *Guide to measuring information and communication technologies (ICT) in education* (Technical Paper No. 2). Quebec, Canada. Author.

United Nations International Children's Emergency Fund (UNICEF) (2009). *Open and Distance Learning for Basic Education in South Asia.*

United Nations International Children's Emergency Fund (UNICEF) (2016). Improving Quality Education and Children's Learning Outcomes and Effective Practices in the Eastern and Southern Africa Region. Report for UNICEF ESARO.

United States Agency for International Development (USAID) (2009). *Early Grade Mathematics Assessment (EGMA): A Conceptual Framework Based on Mathematics Skills Development in Children* – EdData II Technical and Managerial Assistance, Task Number 2 Contract Number EHC–E–02–04–00004–00 Strategic Objective 3. December 31, 2009.

United States Agency for International Development (USAID) (2014). *Best Practices for Developing Supplementary Reading Material.*

Vavrus, F. (2009) The cultural politics of constructivist pedagogies: Teacher education reform in the United Republic of Tanzania. *International Journal of Educational Development, Vol. 29* (2009), pp. 303–311.

Vogel, J.J., Vogel, D.S., Cannon–Bowers, J., Bowers, C.A., Muse, K., & Wright, M. (2006) "Computer Gaming and Interactive Simulations for Learning: A Meta–Analysis". *Journal of Educational Computing Research, Vol. 34*, pp. 229–243.

War Child (2018). https://www.warchild.nl/cant–wait–to–learn, retrieved 9 February 2018.

Wigfield, A. and Eccles, J.S. (2000). Expectancy–Value Theory of Achievement Motivation. *Contemporary Educational Psychology, Vol. 25,* Issue 1, January 2000, pp. 68–81.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E.D. (2013, February 4) A meta–Analysis of the Cognitive and Motivational Effects of Serious Games. *Journal of Educational Psychology, Vol. 5,* Issue 2. DOI: 10.1037/a0031311.

Wouters, P., van der Spek, E.D., & van Oostendorp, H. (2009). *Current Practices in Serious Game Research: A review from a Learning Outcomes Perspective.* IGI Global.

Xiang, P., McBride, R.E., & Bruene, A. (2004). Fourth graders' motivation in an elementary physical education running program. *The Elementary School Journal, Vol. 104*, Issue 3, pp. 253–266.

Yelland, N. & Kilderry, A. (2010). Becoming numerate with information and communications technologies in the twenty–first century. *International Journal of Early Years Education, Vol. 18*, No. 2, June 2010, pp. 91–106.

Appendix A: Overview of comparison of learning objectives between TIMMS Fourth Grade, TIMMS Numeracy Fourth Grade, EGMA and the Sudanese curriculum

TIMMS Fourth Grade	TIMMS Numeracy Fourth Grade	EGMA (Grade 1–2/3)	Sudan (Grade 1–3)
Numbers			
Whole numbers: place value, recognize numbers, write numbers, represent numbers using words, diagrams or symbols.	Demonstrate knowledge of whole numbers (through thousands) including representing numbers and understanding place value.	Understand whole numbers up to 1,000, represent numbers using words, match sets, one–to–one correspondence, and place value to at least 1,000.	Numbers up to 1,000 (recognise verbal and written numbers, and write numerals).
Compare, order and round whole numbers.	Order whole numbers.	Compare and order sets of objects or whole numbers. Understand sequential order and place numbers on a number line.	Place numbers on number line, identify given number on number line Sequence: place numbers in the correct order, identify missing number. More & less (incl. symbols < and >) Successor and predecessor.

Compute (+, −, ×, ÷) with whole numbers. Solve problems set in contexts, including those involving measurements, money, and simple proportions.	Add and subtract whole numbers and demonstrate knowledge of these operations in simple problem settings. Multiply and divide whole numbers by one–digit numbers and demonstrate knowledge of these operations in simple problem settings. Solve problems with whole numbers including those involving more than one operation, patterns, and simple number sentences.	Add and subtract whole numbers. Estimate sums and differences or calculate them mentally—depending on context. Word problems: Solve problems set in contexts, addition and subtraction.	Addition and subtraction up to 1,000, horizontal. Vertical addition and subtraction up to 1,000 Simple addition and subtraction word problems up to 100 Multiplication and division Tables 1–10, in order of tables as well as random multiplication problems, memorised, but also automated. Multiplication 2–digit number by 1 digit number and multiplication of two two–digit numbers.
Identify odd and even numbers, identify multiples and factors of numbers.	–	–	Components of numbers up to 14.

Fractions and decimals			
Recognize fractions as parts of wholes, parts of a collection or locations on number lines and represent fractions using words, numbers or models.	Recognize simple fractions (halves, thirds, fourths, fifths, sixths, eighths, and tenths).	–	Recognize 1/2, 1/3, 1/4, in illustrations of objects and as a mathematical notation.
Compare and order simple fractions.	Compare simple fractions (halves, thirds, fourths, fifths, sixths, eighths, and tenths).	–	–
Add and subtract simple fractions including those set in problem situations.	Add and subtract simple fractions (halves, thirds, fourths, fifths, sixths, eighths, and tenths).	–	–
Demonstrate knowledge of decimals including place value, representing decimals using words, numbers, or models.	Demonstrate knowledge of decimals including place value.	–	–
Compare, order, and round decimals.	Order decimals.	–	–
Add and subtract decimals, including those set in problem situations.	Add and subtract one–place decimals.	–	–
Expressions, solve or write simple equations (e.g., 17 + w = 29).	–	–	–

Shapes & measures			
Points, lines, and angles. Use elementary properties to describe and compare common two– and three–dimensional geometric shapes, including line and rotational symmetry. Relate three–dimensional shapes with their two–dimensional representations.	Identify and compare common geometric figures (lines, angles, and basic two– and three–dimensional shapes).	Identify and describe shapes and space. Composing and decomposing geometrical shapes. Shapes: square, rectangle, triangle and circle.	Shapes (square, rectangle, triangle, circle): passive recognition of names of the shapes and characteristics of shapes.
Measure and estimate lengths Calculate perimeters of polygons; calculate areas of squares and rectangles; and estimate areas and volumes of geometric figures by covering with a given shape or by filling with cubes. involve circles, triangles, quadrilaterals, and other polygons, as well as cubes, rectangular solids, cones, cylinders, and spheres.	Compare, measure, and estimate lengths, areas, and volumes.	–	Length: meter, decimeter, centimeter & yard, foot, inch, incl. conversion.

–	Solve problems involving measurements, including time and money.	Computing lengths.	Conversion of metric system to imperial system.
Identify and draw parallel and perpendicular lines.	–	–	–
Identify, compare, and draw different types of angles (e.g., a right angle, and angles larger or smaller than a right angle).	–	–	–
Use informal coordinate systems to locate points in a plane.	–	–	–
–	–	–	Time: read & set the clock, analogue & digital, hours, half hours and quarters.
–	–	–	Time: read calendar western and Islamic (days & months).
–	–	–	Weight : kilogram, gram & pound, ounce, incl. conversion.

Data display			
Read, compare, and represent data from tables, pictographs, bar graphs, line graphs and pie charts.	Read data from tables, bar graphs, and pictographs.	–	–
Use information from data displays to answer questions that go beyond directly reading the data displayed.	Use the data from tables, bar graphs and pictographs to solve simple problems.	–	–

Appendix B. Description of mini–games

Mini–game 1: Numbers, 1–10

[Numbers]

A number is stated. The child has to select the picture with the correct number of objects.

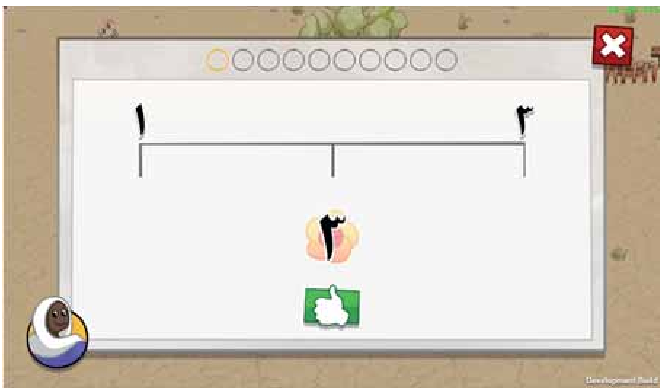
Variations include:

- A number is stated. The child has to select the correct numeral.
- A number of objects is shown. The child has to select the numeral that equals the number of objects.

Mini–game 2: Numberline

[Number discrimination]

A number is given, the child has to place this number in the right position on the number line.



Mini–game 3: Number line Addition

[addition]

A number is given. The child has to select the place on the number line that is 1 or more higher on the number line. Then the child has to answer which number matches that place on the number line.

Mini–game 4: Number line Subtraction

[subtraction]

A number is given. The child has to select the place on the number line that is 1 or more lower on the number line. Then the child has to answer which number matches the place on the number line.

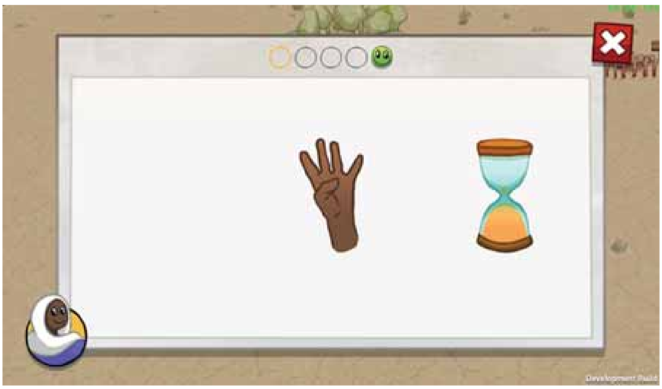
Mini–game 5: Flash card game

[Numbers]

A picture of a hand showing a certain number of fingers is shown for a limited period of time. Then, the picture disappears. In the next screen, the child has to select the numeral that equals the number of fingers they have just seen.

Variations of this mini–game include:

- One or two dice are shown for a limited period of time. In the next screen the child has to select the numeral that equals the number of dots on the dice.
- A numeral is shown for a limited period of time. In the next screen, the child has to select the same numeral.
- Twins: A numeral is shown for a limited period of time. In the next screen, the child has to select the numeral that equals twice this number.
- Friends of 10: A numeral is shown for a limited period of time. In the next screen, the child has to select the numeral that is needed to make 10.



Mini–game 6: Egg game, drag eggs

[Numbers]

A number is stated. The child has to drag the correct number of eggs into the egg box.

Mini–game 7: Egg game, count eggs

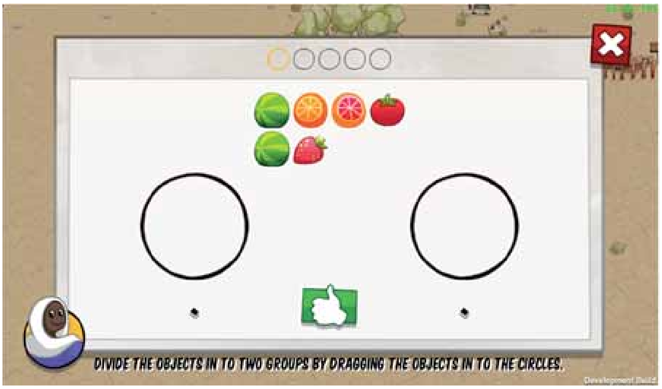
[Numbers]

A number of eggs is shown is an egg box. The child has to select the numerals that equals the number of eggs in the egg box.

Mini–game 8: Divide in circles

[Splitting numbers]

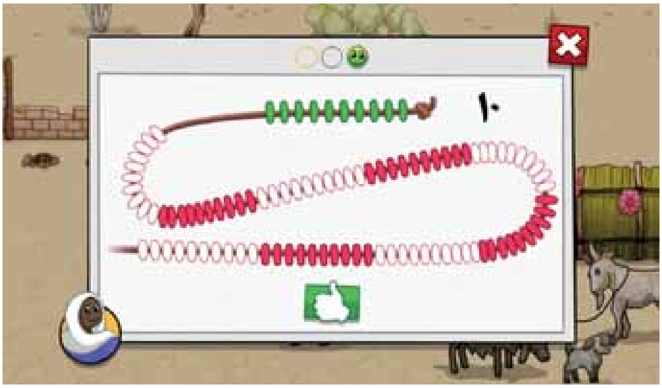
A number of objects are shown. The child has to divide the objects over two circles. The numerals below the circles show how many objects are in that circle. There is no correct answer.



Mini–game 9: Bead game

[Numbers]

There is a string of beads. Children have to separate a given number of beads from the rest of the beads on the string.



Mini–game 10: Bead game, Addition

There is a string of beads. The child has to separate a given number of beads from the rest of the beads on the string. Then, the child is asked to separate 1 or more additional beads from the rest of the beads on the string. Finally, the child has to select the numeral that equals the total number of beads that were separated.

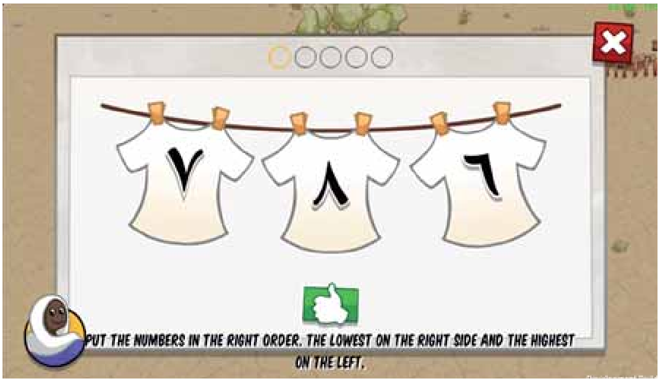
Mini–game 11: Bead game, Subtraction

There is a string of beads. The child has to separate a given number of beads from the rest of the beads on the string. Then, the child is asked to move 1 or more beads back to the rest of the beads on the string. Finally, the child has to select the numeral that equals the total number of beads that are still separated for the rest of the beads on the string.

Mini–game 12: Order shirts

[Number discrimination]

There are three shirts with numbers on them on a clothesline. The child has to drag the shirts (and the numbers) in the correct order.



Mini–game 13: Bus game, Addition

[Word problems, addition]

There is a drawing of a bus with a number of people in it. The child has to select the numeral that equals the number of people on the bus. Then, more people get in the bus. The child has to select the correct numeral that equals the total number of people that is in the bus now (also supported by audio).

Mini–game 14: Bus game, Subtraction

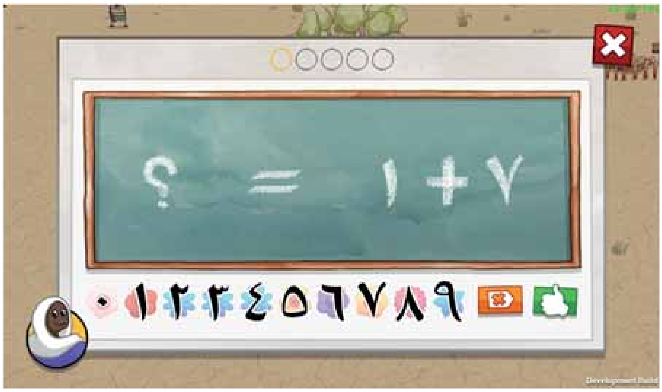
[Word problems, subtraction]

There is a drawing of a bus with a number of people in it. The child has to select the numeral that equals the number of people on the bus. Then, some people get off the bus. The child has to select the correct numeral that equals the total number of people that is in the bus now (also supported by audio).

Mini–game 15: Addition problems

[Addition]

An addition problem is shown. The child has to answer the addition problem by selecting the numeral that answers the addition.



Mini–game 16: Subtraction problems

[subtraction]

A subtraction problem is shown. The child has to answer the subtraction problem by selecting the numeral that answers the subtraction.

Mini–game 17: Addition with objects

[Addition]

An addition is shown, with objects instead of numbers. The child has to answer the addition by selecting the number that answers the addition.

Mini–game 18: Subtraction with objects

[subtraction]

A subtraction is shown, with objects instead of numbers. The child has to answer the subtraction by selecting the number that answers the subtraction.

Mini–game 19: Friends of 10

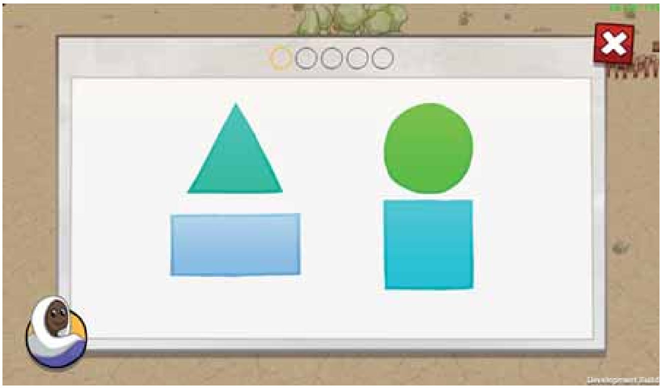
[Numbers]

A numeral is shown. The child has to select the numeral that is needed to make 10 in total.

Mini–game 20: Shapes, recognition

[shapes]

Different shapes are shown. The child has to click on the shape that is mentioned in the audio.



Mini–game 21: Missing number

[Missing number]

Three numbers are given. There is a fourth, empty space somewhere between these numbers. Children have to click on the number that should go into this empty space.

Mini–game 22: Three in a row, Addition

[Addition]

An answer to an addition is given. The child has to select the addition that gives this answer. The additions are presented in a matrix. The goal is to have three additions in a row (horizontal, vertical or diagonal).

Variations include:

- A grid of 4x4
- A grid of 5x5

Mini–game 23: Three–in–a–row, Subtraction

[subtraction]

An answer to a subtraction is given. The child has to select the subtraction that gives this answer. The subtractions are presented in a matrix. The goal is to have three subtractions in a row (horizontal, vertical or diagonal).

Variations include:

- A grid of 4x4
- A grid of 5x5

Mini–game 24: Find the shapes

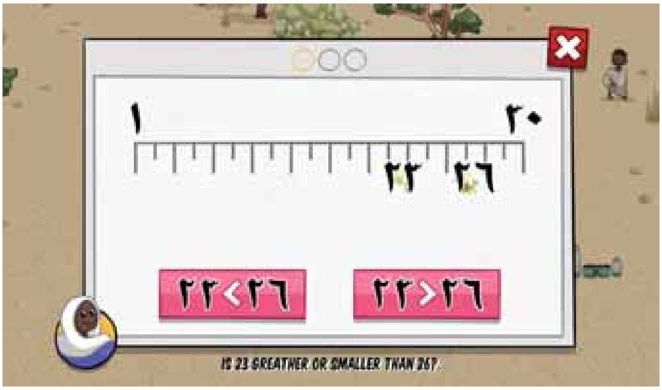
[Shapes]

A picture with many shapes is shown. A specific shape is stated. The child has to find as many shapes of this type as possible.

Mini–game 25: Bigger or smaller

[Bigger/smaller]

Two numbers are stated, one by one. The child has to place the two numbers on the number line. Then, the child has to select whether one number is smaller or bigger than the other one.



Appendix C: Test A

1. Can you count to 10?

2. Can you count on from 4?

3. Can you count on from 6?

4. Can you count back from 5?

5. Can you count back from 7?

6. Can you tell me how many tomatoes you see?
   [picture with 3 tomatoes]

7. Can you tell me how many tomatoes you see?
   [picture with 1 tomato]

8. Can you tell me how many tomatoes you see?
   [picture with 2 tomatoes]

9. Can you point at the picture which has the most carrots
   [two pictures with: 1 carrot and 3 carrots]

10. Can you point at the picture which has the most carrots
    [two pictures with: 2 carrots and 5 carrots]

11. Can you say what this number is?
    3

12. Can you say what this number is?
    6

13. Can you say what this number is?
    2

14. Can you say what this number is?
    8

15. How many carrots do you see? Point at the right number.
    [picture with 3 carrots]
    [1   3   5]

    How many tomatoes are this? Point at the right number.
    [picture with 1 tomato]
    [1   2   6]

16. Can you write down the number 3?

17. Can you write down the number 12?

18. Can you write down the number 9?

19. I have one tomato, and I buy two more. How many tomatoes do I have?

20. There are two people in the bus, and three more people get in the bus.
    How many people are there in the bus?

21. What number comes after the number 7?

22. What number comes before number 6?

23. Can you point at the highest number
    5–16–10

24. Can you point at the lowest number?
    11–17–9

25. Which number should be in the empty box?

9	10		12	13

26. Can you say the answer to this sum?
    3 + 1 =

27. Can you say the answer to this sum?
    2 + 1 =

28. Can you say the answer to this sum?
    1 + 4 =

29. Can you say the answer to this sum?
    3 + 2 =

30. Can you say the answer to this sum?
    1 + 1 =

Appendix D: Test B

1. Can you count to 20?

2. Can you count on from 8 [to 20]?

3. Can you count back from 16?

4. How many tomatoes do you see? [picture with 8 tomatoes]

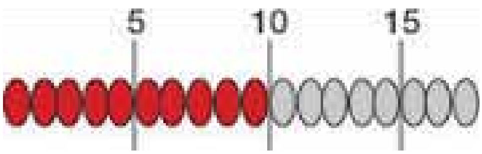
5. Can you point at the picture with most carrots?
   [two pictures with: 12 carrots and 16 carrots]

6. Can you say what number this is? [17]

7. Can you write down the number 8?

8. Can you write down the number 14?

9. Point at the bead that is number 12 in the line.



10. Point at the person who is number 16 in the queue.
    [picture with a queue of 20 people, in 4 groups of 5 people]

11. Can you what number should be in the empty box?

8		10	11	12	13

12. Can you point at the picture which has most goats?
    [four pictures with: 16 goats, 9 goats, 19 goats, and 15 goats]

13. Point at the number that is the lowest.
    [13   11   18]

14. Point at the number that is the highest.
    [18   15   9]

15. Point at the picture with the least tomatoes.
    [three pictures with: 6 tomatoes; 3 tomatoes; 4 tomatoes]

16. Point at the number that is bigger than 18.
    [12   16   20]

17. Point at the number that is smaller than 15?
    [12   16   19]

18. Can you put the numbers in the right order (from low to high)?
    [13 –14 –12 –11–15]

19. Can you put the pictures in the right order (from most people to least people)?
    [four pictures with: 6 people; 12 people; 9 people; 15 people]

20. Can you count back from 20 in steps of 2?
    [20, 18 ….]

21. Can you fill in the empty boxes with the right numbers?

2	4	6		

22. Fatma has 4 carrots. She gets 2 more. How many carrots does she have now?

23. There are 7 children in one hut. There are 2 children in another hut. How many children are there in total?

24. Can you say the answer to this sum?
    [4+1=   ]

25. Can you say the answer to this sum?
    [3+ 5 =   ]

26. How many tomatoes do you need to make 6?

6	
	

27. Can you split number 8 in three different ways?

8	

28. Can you say the numbers you need to make 10? (horizontal)

10	
7	
	5
3	
	4

29. Can you say the answer to this sum?
    [5 + 2 =   ]

30. Can you say the answer to this sum?
    [6 + 2 =   ]

Appendix E: Psychosocial questionnaire

Self–esteem	Ask the children to pick the tree that matches their feelings about themselves.		
Self–efficacy	1	I am certain I can accomplish my goals	Pintrich & De Groot (1990)
	2	I can handle whatever comes my way	Pintrich & De Groot (1990)
	3	I stay confident, even when things are difficult	Pintrich & De Groot (1990)
	4	I can do most things as well as my friends	Self–description Questionnaire II, Marsh (1992)
	5	I expect to do well in my learning	Self–description Questionnaire II, Marsh (1992)
Motivation to learn	6	I like learning new things	Self–directed learning, (Stubbé & Theunissen, 2009)
	7	I think learning new things is important	Self–directed learning, (Stubbé & Theunissen, 2009)
	8	I am doing my best to learn new things	Self–directed learning, (Stubbé & Theunissen, 2009)
	9	I know what I want to become	The Functions of Identity Scale (Serafini & Maitland, 2013)
	10	I know what I want to be	The Functions of Identity Scale (Serafini & Maitland, 2013)
Social support	11	When I have a problem, I can talk to my parents or family	Fleuren, Paulussen, van Dommelen & van Buuren (2012). Lange et al. (2002)
	12	I feel supported to learn by my parents or family	Fleuren, Paulussen, van Dommelen & van Buuren (2012). Lange et al. (2002)

	13	I feel supported to learn by others in my community	Fleuren, Paulussen, van Dommelen & van Buuren (2012). Lange et al. (2002)
	14	I am accepted by my community	Psychosocial Vulnerability Assessment Tool (Gunn, Jordans, Awan, & Hofman, 2015)
Identity orientation	15	My feelings of being a unique person, being distinct from others, is important to me	Personal Identity, AIQ IV (Cheek et al.,2002)
	16	My reputation, what others think of me, is important to me	Relational identity, AIQ IV (Cheek et al.,2002)
	17	My relationships with people I feel close to are important to me	Social identity, AIQ IV (Cheek et al.,2002)
	18	My feeling of belonging to my community is important to me	Collective identity AIQ IV (Cheek et al.,2002)

Summary

Worldwide, 61 million primary age children are unable to receive primary education. There are three major reasons for this: the long distances to school, inequality – girls and minority groups have less access to education – and conflict. In effect, a girl in a rural village from a poor family has a much lower chance to be enrolled in school than a boy in a city from a rich family. Sudan is one of the countries worldwide with the highest out–of–school rates (45%), meaning 2.7 million children are not in school.
In their study on open and distance learning for basic education in developing countries, UNICEF (2009) concluded that to increase access to education for children who are hardest to reach, learning opportunities should be created close to their homes. This automatically implies learning will take place outside of schools, and without teachers. As children have little to no access to education, it cannot be assumed that they can read and write. This thesis describes a project that attempts to provide education for hard to reach children. To support children to learn, without instruction from a teacher, it was decided to design and develop a mathematics game. The assumption is that a well–designed game may provide enough instruction, practice, feedback and support for children to learn mathematics while playing it autonomously. The overall question that needs to be answered in this research is: *How can children in remote villages in Sudan learn mathematics from playing a mathematics game without additional instruction from teachers?*

To answer this question, a number of sub–questions need to be answered. As there was no existing curriculum–based Arabic mathematics game, a new game had to be designed. To ensure a thorough design of the game, the following sub–questions were answered:

1. What are requirements for an educational mathematics game for out–of–school children in remote villages in Sudan?
2. How do the general game requirements translate into a working game design?
3. How do the specific requirements for learning mathematics translate into a working game design?

To study whether children in remote villages in Sudan can learn mathematics from playing the game autonomously, two pilots were carried out, answering the following sub–questions:

4. Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?
5. Can out–of–school children in remote villages in Sudan learn mathematics autonomously for a longer period of time, covering a diversity of mathematics learning objectives, by playing the game autonomously?

Finally, to assess whether the game needed to be adapted, for the Sudanese situation and for possible new contexts, the influence of child–related and context factors on learning effect was studied. The following sub question was answered:
6. What child–related and contextual factors influence learning effects?

In chapter 2, the first sub–question is answered: *What are requirements for an educational mathematics game for out–of–school children in remote villages in Sudan?*
Following an instructional design approach, the target population, the learning objectives, and context in which they have to learn were analysed. In addition, more general literature on education in developing countries and learning with technology was studied. The method used is a combination of a literature search, interviews with local experts and subject matter experts, and input from children in the target population. A total of nine requirements were identified. These requirements can be divided into three different types. (1) Context requirements that address the specific situation of the target population. For example requirement 1: The game should be attractive and motivating for the target population. (2) Curriculum requirements that address the educational context in which the game is used. For example requirement 3: The game should enable progress to formal education in Sudan. (3) Requirements related to the effectiveness of game–based learning that refer to more general game characteristics that increase the effectiveness of learning. For example requirement 8: The game should be based on an active learning approach.

In chapter 3, sub–question 2 is answered: *How do the general game requirements translate into a working game design?*
To answer this question, relevant literature on game design was used, in combination with collaboration with local experts and children. In the translation of the general requirements into a working game design, all requirements were addressed. The resulting game incorporates two distinct levels, each with a different pedagogy.
The first level is that of game worlds which provide the connecting narratives for

the second level, that of separate mini–games. In addition, instruction videos and a management system are included in the game.
The top level of the game environment, that of the game worlds, uses a predominantly experiential learning approach. The narrative in game world 1 is about helping other children to achieve goals in their lives by doing mini–games. Game world 2 is a shop where children can buy and sell products. The lower level of the game environment, with the mini–games, has a different pedagogy: mastery learning with direct feedback on performance, and consequently children have less control over the learning environment. Progress through the game is structured and based on performance: the number of correct answers within a certain time–frame is used to determine whether children can continue to a more difficult mathematical concept.
The narratives, graphics, colours, symbols and language in the game are based on the collaboration with local experts and children in the target population, and were endorsed by the National Council of Literacy and Adult Education, the relevant department of the Ministry of Education in Sudan. To support autonomous learning, the use of navigation buttons is consistent throughout the game.
To support learning in areas with unreliable internet connections, the game was designed as an online–offline game. Children can always play the game at their own level; results can be synchronised to a server when there is internet, or can be uploaded by hand.

In chapter 4 sub–question 3 is answered: *How do the specific requirements for learning mathematics translate into a working game design?*
In addition to the national curriculum, the internationally recognised learning objectives and best practices for learning mathematics were studied. A check of the Sudanese mathematics curriculum against internationally accepted learning objectives for grades 1 to 3 showed that there is much overlap, although the Sudanese curriculum does not describe learning objectives to the same level of detail as the international ones. The Sudanese curriculum includes four more learning objectives relating to the imperial measurement system and time, and does not contain the kindergarten learning objectives for mathematics. As children in the target population do not attend kindergarten, the choice was made to include the kindergarten learning objectives in the objectives of the game. In addition, the specific Sudanese learning objectives about measurements were maintained. Finally, the Sudanese Ministry of Education approved a change in the order of

the curriculum to match a more natural sequence of acquisition of mathematical skills and concepts. In this way, the curriculum was aligned with the Sudanese curriculum for out–of–school children and, at the same time, based on internationally recognised learning objectives and good practices for these grades.
The translation of these specific mathematics requirements needs to address instruction, practice and feedback, but also the manipulation of objects that helps children to understand mathematical concepts. In the game, each learning objective is supported by one or more instruction videos and mini–games. Instruction videos are brief, explicit introductions to the mathematical concepts; one instruction video per concept, 1–3 minutes each. Mini–games provide active practice of learning objectives. There is a large variety of mini–games, with different interaction types. Some mini–games allow children to actively manipulate (2–dimensional) objects. Finally, immediate feedback is provided on the correctness of answers.

In chapter 5 sub–question 4 is answered: *Can out–of–school children in remote villages in Sudan learn mathematics by playing the game autonomously?*
To address this question, a pilot was carried out with a quasi–experimental design with a pre–test and post–test and control group. Following the 'fastest route to failure' a small part of the game was developed and tested with children to establish whether out–of–school children in remote villages in Sudan can learn mathematics by playing the game autonomously at all. Pilot I involved 54 children in the experimental condition who participated in 30 learning session of 45 minutes each, over a period of 6 weeks. The control group consisted of 19 children who received no education during the same period.
Results show that all children in the experimental condition improved their scores on the mathematics test, used in this study to determine the level of mathematics, significantly (average test scores from 18 to 36, max. 60), irrespective of age and gender. Children in the control group did not show any increase in test scores. Effectively, children who could not count to 10 before using the game, were able to do simple addition problems after six weeks. This provided sufficient evidence for a larger part of the game to be developed.

In chapter 6 sub–question 5 is answered: *Can out–of–school children in remote villages in Sudan learn mathematics autonomously for a longer period of time, covering a diversity of mathematics learning objectives, by playing the game autonomously?*

In a six–month pilot using a quasi–experimental design with a pre–test and post–test and a control group, a larger part of the game was tried out with 594 children using the game in 45–minute learning session on weekdays (130 days). The control group consisted of 200 children enrolled in regular education. Results show that all children in the experimental condition significantly increased their scores on the mathematics tests used in this study to determine the level of mathematics (Test A: average test score increased from 20 to 41, max. 60; test B: average test score increased from 32 to 41, max. 60). There were no differences for gender. Younger children achieved lower scores on the post–test than older children, but had a higher increase of scores than older children. A comparison of the experimental group with control groups that had access to informal education showed that the increase in scores in both groups was similar (no significant difference in one state, a small, significant higher increase of scores for the control group in another state), but the time spent on learning in the experimental group was (much) shorter. This means children who played the game learned as much as, but probably more than children enrolled in regular education. A comparison with EGMA results (internationally validated mathematics test) showed that the children in the experimental group had higher scores on four measurements of EGMA than children who had been to school for 2.5 years. The scores on three measurements of EGMA were much lower than those for children from Khartoum and Jordan. This can be explained by the fact that the children in the experimental condition had only been taught the numbers under 20, whereas EGMA uses numbers up to 1,000. Also, children were not taught to write in the pilot. Addition and Subtraction II require the child to write answers down. These results show that there is sustained learning, over a longer period of time, including more learning objectives and more children, in more villages. These results are even more remarkable when taking into account that children did not play the game as often as planned; most children played 2–3 days a week on average, instead of five days a week. In this way, unintentionally, the flexibility of the game–based learning approach was proven. These results show that the game allows children to be absent for some time and then resume the programme successfully, which supports this target population to keep on learning. This flexible way of learning is unique to the autonomous, game–based learning approach and difficult to achieve in regular education.

In chapter 7, sub–question 6 is answered: *What child–related and contextual factors influence learning effects?*

To assess whether the game needs to be adapted, for the Sudanese situation and for possible new contexts, the influence of child–related and context factors on learning effect was studied. First, the factors that can influence learning were identified, using relevant literature. The identified factors were then measured during pilot II. For the factors that were measured reliably, a multivariate regression analysis was used to determine to what extent these factors predict learning outcomes. Together, these factors predict 50–75% of the results on the post–tests, which makes it a strong model.

Analyses show that the scores on the pre–tests contribute most to scores on the post–tests. This might imply that prior informal knowledge, or intelligence in general, determines the learning outcomes. Looking at the increase of scores on the tests, this is probably not the case. All children significantly improve their scores on both mathematics tests that were used to assess children's level of mathematical knowledge in this study. In test A, children who have the lowest scores on the pre–test show the highest increase of scores. It is remarkable that gender and age do not significantly explain variance of the model.

Apart from the scores on the pre–test, the following factors also predict post–test scores: distance to the nearest primary school, self–esteem, self–efficacy, and percentage of the game completed.

The longer the distance to the nearest primary school, the higher the tests scores on the post–test of test A. These results show that this game benefits the target population. When taking the game to a school context, the initial learning results may be lower. A higher self–esteem and self–efficacy at the beginning of the pilot relate to higher mathematics scores at the end. These results indicate that a subset of the children benefits more from the game than others. This is something to keep in mind when taking the game to new context. However, it is a positive finding that self–esteem has increased during the pilot. This implies that children with a lower self–esteem at the beginning can increase their scores on self–esteem and thus influence their learning in a positive way. Finally, percentage complete in the game contributes to learning outcomes: the higher the percentage complete, the higher the scores on the tests. This is a positive finding as it implies that, when scaling up in the same context, percentage complete can be used as an indicator of progress. When scaling up to a new context, the learning effect of the (adapted) game should be properly researched.

These results show that the game supports learning for the target population in Sudan. Still, continued attention should be given to elements that can increase self–

esteem and self–efficacy. When taking the game to new contexts, the factors that predict test scores (distance to nearest school, self–esteem, and self–efficacy) should be checked in that context. It is, for example, possible that the game will be less effective in a school setting, which would require adaptations.

Chapter 8 discusses the conclusions of the sub–questions and answers the overall question of this thesis. The overall question how children in remote villages in Sudan can learn by playing the mathematics game autonomously, without additional instruction from teachers or learning support from parents or caregivers can be answered in two steps: first of all the question whether children can learn can be answered with a wholehearted 'yes'. The question how children can learn is answered by requirements and careful game design that has resulted in a mathematics game that is engaging and motivating for the target population to play, leading to significant learning results, with children learning at least the same but probably more than children in formal education in the same period. In formal education, children attend two lessons a day, compared to one lesson a day in the experimental condition. Moreover, the interval between the pre–test and the post–test for the control groups was 1.5 to 3 times as long as in the experimental condition. Unintentionally, even the flexibility of the game–based learning approach was proven: children did not play for the planned five days a week (the average frequency of playing was 2–3 days a week) and still increased their test scores significantly. This shows that skipping a few days a week or even a whole week once in a while does not get in the way of learning. This means the game can be used to reach more children in remote villages in Sudan.
At the same time, this research contributes to solving the global education crisis in another way as well. The game was designed with scale in mind, which means much of the game design and the design process can be reused when scaling to another context. As the game was specifically designed for the Sudanese context, the context requirements will probably have to be adapted for the new context. This leads to changes in the narrative, graphics, colours and language. As the game is developed in components, these are simple to change. Curriculum requirements only need adaptations in the game when the national curriculum in the new context includes different learning objectives. This is also facilitated by the structure of the game: mini–games can be taken out or added, and their order can be changed without having to develop a complete new game.

Future works

In the meantime, the mathematics game has been adapted for Lebanon and Jordan, with Syrian refugees in mind. Pilots have started to measure effectiveness. Also, following a similar design process, a literacy game for grades 1, 2, and 3 was designed. Two country–specific versions of the game are tested in Sudan and Jordan. So far, all games have been developed in Arabic, it is the aim to add more languages in the near future. By 2020, the Can't Wait to Learn programme hopes to have reached 170,000 children in marginalised communities in multiple countries.

Samenvatting

Wereldwijd hebben 61 miljoen basisschool leerlingen geen toegang tot onderwijs. De drie belangrijkste redenen hiervoor zijn: de afstand tot school, ongelijkheid– meisjes en kinderen uit minderheidsgroepen hebben minder toegang tot onderwijs– en conflicten. Effectief heeft een meisje uit een arme familie in een dorp in landelijk gebied een veel kleinere kans om naar school te gaan dan een jongen uit een rijk gezin in de stad. Soedan is een van de landen in de wereld met het hoogste percentage kinderen dat niet naar school gaat (45%); het gaat om 2,7 miljoen kinderen.

In hun onderzoek naar open en afstandsleren voor het basisonderwijs in ontwikkelingslanden heeft UNICEF (2009) geconcludeerd dat de toegang tot onderwijs voor kinderen die het moeilijkst bereikt kunnen worden alleen kan worden verbeterd door leermogelijkheden dicht bij hun huis te creëren. Dit betekent automatisch dat leren buiten school plaats zal vinden, en zonder leerkrachten. Omdat kinderen nauwelijks tot geen toegang tot onderwijs hebben, kan niet aangenomen worden dat ze kunnen lezen en schrijven.

Dit proefschrift beschrijft een project dat beoogt onderwijs te bieden aan deze groep moeilijk te bereiken kinderen. Om kinderen te ondersteunen om te leren zonder aanvullende instructie van een leerkracht, is besloten een rekengame te ontwerpen en ontwikkelen. Het idee hierachter is dat een zorgvuldig ontworpen game voldoende instructie, oefening, feedback en ondersteuning zou kunnen bieden om kinderen te leren rekenen door de game zelfstandig te spelen. De hoofdvraag die in dit onderzoek beantwoord moet worden is: *Hoe kunnen kinderen in afgelegen dorpen in Soedan leren rekenen door zelfstandig een rekengame te spelen, zonder aanvullende instructie van een leerkracht?*

Om deze vraag te beantwoorden moeten een aantal deelvragen beantwoord worden. Aangezien er geen bestaande game was, gebaseerd op het rekencurriculum, in het Arabisch, moest een nieuwe game ontworpen worden. Om een zorgvuldig ontwerp te garanderen zijn de volgende deelvragen beantwoord:

1. Wat zijn de randvoorwaarden voor een educatieve rekengame voor kinderen in afgelegen dorpen in Soedan die niet naar school gaan?

2. Hoe kunnen deze randvoorwaarden vertaald worden naar een werkend ontwerp van de game?
3. Hoe kunnen de specifieke randvoorwaarden om te leren rekenen vertaald worden naar een werkend ontwerp van de game?

Om te onderzoeken of kinderen in afgelegen dorpen in Soedan kunnen leren rekenen door de game zelfstandig te spelen zijn twee pilots uitgevoerd die de volgende vragen beantwoorden:

4. Kunnen kinderen in afgelegen dorpen in Soedan, die niet naar school gaan, leren rekenen door zelfstandig een rekengame te spelen?
5. Kunnen kinderen in afgelegen dorpen in Soedan, die niet naar school gaan, leren rekenen door zelfstandig een rekengame te spelen, gedurende een langere tijd, met een diversiteit aan rekenleerdoelen?

Tenslotte is de invloed van kind–gerelateerde en context factoren op het leereffect onderzocht, om vast te stellen of en hoe de game aangepast moet worden voor ofwel de situatie in Soedan, ofwel voor mogelijke nieuwe contexten. Hiermee is de volgende deelvraag beantwoord:

6. Welke kind–gerelateerde en context factoren beïnvloeden het leereffect?

In hoofdstuk 2 wordt de eerste deelvraag beantwoord: *Wat zijn de randvoorwaarden voor een educatieve rekengame voor kinderen in afgelegen dorpen in Soedan die niet naar school gaan?*
Met behulp van een onderwijskundig ontwerp aanpak zijn de doelgroep, de leerdoelen en de context waarin geleerd moet worden, geanalyseerd. Aanvullend is literatuur bestudeerd met betrekking tot onderwijs in ontwikkelingslanden en leren met behulp van digitale leermiddelen. De onderzoeksmethode bestaat uit een combinatie van een literatuurstudie, interviews met lokale deskundigen en experts op het gebied van rekenen, en inbreng van kinderen uit de doelgroep. In totaal konden negen randvoorwaarden geïdentificeerd worden. Deze randvoorwaarden kunnen in drie types onderverdeeld worden. (1) Context randvoorwaarden die de specifieke situatie van de doelgroep adresseren. Bij voorbeeld randvoorwaarde 1: De game zou aantrekkelijk en motiverend moeten zijn voor de doelgroep. (2) Curriculum randvoorwaarden die de onderwijskundige context waarin de game

ingezet moet gaan worden adresseren. Bij voorbeeld randvoorwaarde 3: De game zou de overstap naar formeel onderwijs in Soedan mogelijk moeten maken. (3) Randvoorwaarden die gerelateerd zijn aan de effectiviteit van leren met behulp van games. Deze randvoorwaarden raken aan de meer generieke kenmerken die de effectiviteit van leren vergroten. Bij voorbeeld randvoorwaarde 8: De game zou gebaseerd moeten zijn op een *active learning* aanpak.

In hoofdstuk 3 wordt deelvraag 2 beantwoord: *Hoe kunnen deze randvoorwaarden vertaald worden naar een werkend ontwerp van de game?*
Om deze vraag te beantwoorden is gebruik gemaakt van relevante literatuur met betrekking tot het ontwerp van games. Daarnaast is samengewerkt met lokale deskundigen en kinderen. In de vertaling van de randvoorwaarden naar een werkend ontwerp van de game zijn alle randvoorwaarden geadresseerd.
De uiteindelijke game omvat twee onderscheidende niveaus, elk met een eigen didactiek. Het eerste niveau is dat van de game werelden die het overkoepelende verhaal bieden voor het tweede niveau, dat van de mini–games. Daarnaast zijn instructie video’s en een management systeem opgenomen in de game.
Het eerste niveau van de game, dat van de game werelden, heeft een voornamelijk ontdekkende didactiek. Het verhaal in game wereld 1 gaat over het helpen van andere kinderen om doelen in hun leven te bereiken door mini–games te spelen. Game wereld 2 is een winkel waarin kinderen producten kunnen kopen en verkopen. Dit tweede niveau van de game heeft een mastery learning aanpak met directe feedback op resultaat. Als gevolg daarvan hebben kinderen minder controle over de leeromgeving. Voortgang in de game is gestructureerd en gebaseerd op resultaten: het aantal correcte antwoorden binnen een bepaalde tijd wordt gebruikt om vast te stellen of kinderen verder kunnen gaan naar een moeilijker rekenconcept. De verhalen, tekeningen, kleuren, symbolen en taal in de game zijn gebaseerd op de samenwerking met lokale deskundigen en kinderen uit de doelgroep. Deze zijn vervolgens goedgekeurd door het National Council for Literacy and Adult Education, de betrokken afdeling van het ministerie van onderwijs in Soedan. Om zelfstandig leren verder te ondersteunen is het gebruik van navigatieknoppen in de game consistent.
De game is ontwikkeld als een online–offline game om leren in een omgeving met onbetrouwbaar internet mogelijk te maken. Kinderen kunnen de game altijd op hun eigen niveau spelen; hun resultaten kunnen met een server gesynchroniseerd worden als er wel internet is, of kunnen met de hand ge–upload worden.

In hoofdstuk 4 wordt deelvraag 3 beantwoord: *Hoe kunnen de specifieke randvoorwaarden om te leren rekenen vertaald worden in een werkend ontwerp van de game?*
Allereerst is het rekencurriculum van Soedan geanalyseerd. Daarnaast zijn de internationaal erkende rekenleerdoelen en best practices om te leren rekenen bestudeerd. Een vergelijking van het Soedanese curriculum met de internationaal erkende rekenleerdoelen voor *grades* 1 tot en met 3 liet zien dat er veel overeenkomsten zijn, hoewel het Soedanese curriculum de doelen met minder detail beschrijft dan de internationaal erkende doelen beschreven zijn. Het Soedanese curriculum bevat vier extra leerdoelen die gerelateerd zijn aan het Angelsaksische meet systeem en tijd. Tegelijkertijd ontbreken de rekenleerdoelen die in de kleuterklassen aangeboden worden. Omdat de kinderen in de doelgroep niet naar de kleuterschool gaan is de keuze gemaakt om deze rekenleerdoelen op te nemen in de game. Ook zijn de specifiek Soedanese leerdoelen met betrekking tot meten opgenomen. Tenslotte heeft het Soedanese ministerie van onderwijs akkoord gegeven op een verandering van de volgorde van leerdoelen in de game; de volgorde van leerdoelen in de game past nu bij beter bij de natuurlijke volgorde van leren rekenen. Op deze manier sluit het curriculum in de game aan bij het Soedanese rekencurriculum, maar is het, tegelijkertijd, gebaseerd op de internationaal erkende rekenleerdoelen en *best practices*.
Om deze rekenleerdoelen te vertalen naar een game, zal er aandacht gegeven moeten worden aan instructie, oefenen en feedback. Tegelijkertijd zouden kinderen de kans moeten krijgen om objecten te manipuleren, omdat hen dat helpt om rekenkundige concepten te begrijpen. In de game wordt elk leerdoel ondersteund door één of meer instructie video's en mini–games. Instructie video's zijn korte, directe instructies van een rekenconcept; één concept per video, 1–3 minuten per stuk. Mini–games bieden de mogelijkheid om leerdoelen actief te oefenen. Er zijn veel verschillende soorten mini–games, met verschillende interactie types. In sommige mini–games kunnen kinderen actief (2–dimensionale) objecten manipuleren. Tenslotte wordt onmiddellijke feedback gegeven of antwoorden juist zijn.

In hoofdstuk 5 wordt deelvraag 4 beantwoord: *Kunnen kinderen in afgelegen dorpen in Soedan, die niet naar school gaan, leren rekenen door zelfstandig een rekengame te spelen?*
Om deze vraag te beantwoorden is een pilot uitgevoerd met een quasi–

experimenteel design, met een voortoets en natoets en een controlegroep. Om zo snel mogelijk te kunnen vaststellen of de aanpak met een rekengame werkt om kinderen in afgelegen dorpen in Soedan te leren rekenen is een klein deel van de game ontwikkeld en getest. In pilot I waren 54 kinderen betrokken in de experimentele conditie; zij speelden de game in 30 leersessies van 45 minuten elk, gedurende een periode van zes weken. De controlegroep bevatte 19 kinderen, zij kregen geen onderwijs in dezelfde periode.
De resultaten laten zien dat alle kinderen in de experimentele conditie hun scores op de rekentest die in dit onderzoek gebruikt is om het rekenniveau van kinderen vast te stellen, significant hebben verbeterd (gemiddelde test scores van 18 naar 36, max. 60), onafhankelijk van leeftijd of geslacht. Kinderen in de controlegroep verbeterden hun scores op de rekentoets niet. Effectief betekent dit dat kinderen die nog niet tot 10 konden tellen, na zes weken simpele optelsommetjes konden maken. Dit bood voldoende bewijs om een groter deel van de game te ontwikkelen.

In hoofdstuk 6 wordt deelvraag 5 beantwoord: *Kunnen kinderen in afgelegen dorpen in Soedan, die niet naar school gaan, leren rekenen door zelfstandig een rekengame te spelen, gedurende een langere tijd, met een diversiteit aan rekenleerdoelen?*
In een pilot van zes maanden, met een quasi–experimenteel design, met een voortoets en natoets en een controlegroep, is een groter deel van de game getest bij een grotere groep kinderen. In pilot II waren 594 kinderen betrokken in de experimentele conditie; zij speelden de game in 130 leersessies van 45 minuten elk, gedurende een periode van zes maanden. De controlegroep bevatte 200 kinderen, die regulier onderwijs volgden. De resultaten laten zien dat alle kinderen in de experimentele conditie hun scores op twee rekentoetsen die in dit onderzoek gebruikt zijn om het rekenniveau van kinderen vast te stellen, significant hebben verbeterd (test A: gemiddelde test scores van 20 naar 41, max. 60; test B: gemiddelde test scores van 32 naar 41, max. 60). Er waren geen verschillen tussen jongens en meisjes. Jongere kinderen hadden een lagere score op de post–test dan oudere kinderen, maar hadden tegelijkertijd een grotere toename van test scores tussen voortoets en natoets dan de oudere kinderen. Een vergelijking van de experimentele groep met de controle groep, die toegang had tot regulier onderwijs, laat zien dat de toename in scores tussen de voortoets en de natoets vergelijkbaar was (geen significant verschil in één staat, een klein maar significant hogere score voor de controlegroep in een andere staat), maar de tijd besteed aan

leren was (veel) korter in de experimentele groep. Dit betekent dat kinderen die de game gespeeld hebben evenveel, maar misschien wel meer, geleerd hebben als de kinderen die regulier onderwijs volgden. Een vergelijking van EGMA resultaten (internationaal gevalideerde rekentoets), laat zien dat de kinderen in de experimentele groep op vier onderdelen van EGMA een hogere score hadden dan kinderen die ongeveer 2,5 jaar naar school waren geweest in Khartoem en Jordanië. Op drie andere onderdelen van EGMA hadden de kinderen uit de experimentele groep veel lagere scores dan kinderen uit Khartoem en Jordanië. De reden hiervoor is waarschijnlijk dat de kinderen in de experimentele conditie de getallen tot en met 20 geleerd hadden, terwijl EGMA getallen tot en met 1.000 gebruikt. Daarnaast hebben de kinderen in de experimentele conditie de getallen niet leren schrijven in deze pilot. Bij twee onderdelen van EGMA, optellen II en aftrekken II, moeten kinderen de antwoorden opschrijven.
Deze resultaten laten zien dat het leren bestendig is, gedurende een langere periode, met een diversiteit aan leerdoelen, in meer dorpen. Deze resultaten zijn nog opmerkelijker als rekening gehouden wordt met het feit dat kinderen de game niet zo vaak gespeeld hebben als gepland; de meeste kinderen speelden de game 2–3 dagen per week in plaats van vijf dagen per week. Hiermee is, onbedoeld, ook de flexibiliteit van de game bewezen. De resultaten tonen dat de game het mogelijk maakt dat kinderen leersessies kunnen overslaan en dan het programma succesvol kunnen hervatten. Dit is juist voor deze doelgroep zeer ondersteunend om te kunnen leren. Deze flexibele manier van leren is uniek voor de zelfstandige, *game–based* leren aanpak en moeilijk om te realiseren in regulier onderwijs.

In hoofdstuk 7 wordt deelvraag 6 beantwoord: *Welke kind–gerelateerde en context factoren beïnvloeden het leereffect?*
Om vast te stellen of de game aangepast moet worden, hetzij voor de Soedanese context, hetzij voor een eventuele nieuwe context, is de invloed van kind–gerelateerde en context factoren op het leereffect onderzocht. Op basis van literatuur zijn eerst de factoren die leren kunnen beïnvloeden geïdentificeerd. Deze factoren zijn gemeten tijdens pilot II. Voor de factoren die betrouwbaar gemeten waren, is vervolgens met gebruik van een regressieanalyse vastgesteld in welke mate zij leeruitkomsten voorspelden. Samen voorspellen de betrouwbaar gemeten factoren 50–75% van de resultaten op de natoetsen, wat dit een betrouwbaar model maakt.

De analyses laten zien dat de scores op de voortoetsen de belangrijkste voorspellers zijn van scores op de natoetsen. Dit zou kunnen betekenen dat de leerresultaten vooral bepaald worden door voorkennis, of intelligentie in het algemeen. Kijkend naar de toename van test scores, lijkt dit toch niet het geval te zijn. Alle kinderen verbeteren hun scores op de twee rekentoetsen. Op test A is de toename van scores het hoogst voor kinderen die de laagste score op de voortoets hadden. Verder valt het op dat leeftijd en geslacht geen voorspellende waarde hebben in dit model. Naast de scores op de voortoets, hebben de volgende factoren een voorspellende waarde voor de scores op de natoets: afstand tot de dichtstbijzijnde basisschool, zelfvertrouwen, vertrouwen in eigen kunnen en het percentage van de game dat voltooid is. Hoe groter de afstand tot de dichtstbijzijnde basisschool, hoe hoger de scores op de natoets van test A. Deze resultaten laten zien dat de doelgroep voordeel heeft van de game. Wanneer de game in een school setting ingezet zou worden, zouden de resultaten in het begin lager kunnen zijn. Een hoger zelfvertrouwen en vertrouwen in eigen kunnen aan het begin van de pilot hangen samen met een hogere score op de natoetsen. Deze resultaten wijzen erop dat een deel van de kinderen meer profiteert van de game dan anderen. Dit is iets om in het achterhoofd te houden wanneer de game ingezet wordt in een nieuwe context. Tegelijkertijd is het positief dat zelfvertrouwen toegenomen is tijdens de pilot. Dit impliceert dat kinderen met een lager zelfvertrouwen aan het begin, hun scores op zelfvertrouwen kunnen verhogen en zo hun leren op een positieve manier kunnen beïnvloeden. Tenslotte draagt het percentage van de game dat kinderen voltooid hebben bij aan de leerresultaten: hoe hoger het percentage van de game dat voltooid is, hoe hoger de scores op de natoetsen. Dit is een positieve bevinding omdat dit betekent dat het percentage van de game dat voltooid is in toekomstige pilots in dezelfde context gebruikt kan worden als indicatie van voortgang. In een nieuwe context zal het leer effect van de (aangepaste) game opnieuw onderzocht moeten worden.

Deze resultaten laten zien dat de game de doelgroep in Soedan ondersteunt bij het leren. Toch zou er blijvende aandacht moeten zijn voor de elementen die zelfvertrouwen en vertrouwen in eigen kunnen versterken. Als de game in een nieuwe context ingezet gaat worden, zou in die context bekeken moeten worden hoe het staat met de factoren die test resultaten voorspellen (afstand tot dichtstbijzijnde basisschool, zelfvertrouwen en vertrouwen in eigen kunnen). Het is bij voorbeeld mogelijk dat de game minder effectief is in een school setting. Hiervoor zouden aanpassingen nodig zijn.

Hoofdstuk 8 bespreekt de conclusies van de deelvragen en beantwoordt de hoofdvraag van deze thesis. De hoofdvraag hoe kinderen in afgelegen dorpen in Soedan kunnen leren rekenen door zelfstandig een rekengame te spelen, zonder verdere instructie van leerkrachten of hulp van ouders kan in twee stappen beantwoord worden: allereerst kan de vraag of kinderen kunnen leren met een volmondig 'ja' beantwoord worden. De vraag hoe kinderen kunnen leren wordt beantwoord door de randvoorwaarden en het zorgvuldige ontwerp van de game die hebben geresulteerd in een game die aantrekkelijk en motiverend is voor de doelgroep en leidt tot significante leerresultaten. Kinderen leren evenveel en misschien wel meer dan kinderen die regulier onderwijs volgen in dezelfde periode. In het regulier onderwijs kregen kinderen twee lessen per dag, in de experimentele conditie was dat één les per dag. Daarnaast was de tijd tussen de voortoets en natoets in de controle groep 1,5 tot 3 keer zo groot als in de experimentele conditie. Onbedoeld is zelfs de flexibiliteit van de game bewezen: in pilot II speelden kinderen geen vijf dagen per week (de gemiddelde frequentie van spelen van 2–3 dagen per week), maar hebben ze toch hun tests scores significant verbeterd. Dit laat zien dat kinderen een paar leersessies per week, of zelfs af en toe een hele week, kunnen overslaan zonder dat dit hun leerresultaten negatief beïnvloedt. Dit betekent dat deze game gebruikt kan worden om meer kinderen in afgelegen dorpen in Soedan toegang tot onderwijs te geven.
Tegelijkertijd draagt dit onderzoek ook op een andere manier bij aan een oplossing voor de wereldwijde onderwijs crisis. Bij het ontwerp van de game heeft opschaling steeds centraal gestaan, wat betekent dat veel van het ontwerp van de game en van het ontwerp proces hergebruikt kan worden op het moment dat opgeschaald wordt naar een nieuwe context. Omdat de game specifiek voor de Soedanese context ontwikkeld is, zullen de context randvoorwaarden waarschijnlijk aangepast moeten worden voor een nieuwe context. Dit leidt tot veranderingen in het verhaal, de plaatjes, de kleuren en de taal. Omdat de game uit componenten bestaat, is het eenvoudig om dit te veranderen. Curriculum randvoorwaarden leiden alleen tot aanpassingen in de game als het rekencurriculum in de nieuwe context andere leerdoelen bevat. Veranderingen hiervan worden ook ondersteund door de structuur van de game: mini–games kunnen weggehaald of toegevoegd worden en de volgorde ervan kan veranderd worden zonder een compleet nieuwe game te ontwikkelen.

Hoe verder

In de tussentijd is de rekengame aangepast voor Libanon en Jordanië, ook voor de Syrische vluchtelingen in die landen. Er zijn inmiddels pilots gestart om de effectiviteit meten. Gebruik makend van een soortgelijk ontwikkelproces, is daarnaast ook een game ontwikkeld waarmee kinderen zelfstandig kunnen leren lezen (voor *grade* 1, 2 en 3). Twee versies hiervan, voor Soedan en voor Jordanië, worden in pilots getest. Hoewel de games vooralsnog in het Arabisch ontwikkeld zijn, is het de bedoeling om op korte termijn meer talen toe te voegen. Tegen 2020 hoopt het Can't Wait to Learn programma 170.000 kinderen bereikt te hebben in gemarginaliseerde groepen in meerdere landen.

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66. Kolovou, A. (2011). Mathematical problem solving in primary school.
65. Meijer, M. R. (2011). Macro–meso–micro thinking with structure–property relations for chemistry. An explorative design–based study.

64. Kortland, J., & Klaassen, C. J. W. M. (2010). *Designing theory–based teaching-learning sequences for science. Proceedings of the symposium in honour of Piet Lijnse at the time of his retirement as professor of Physics Didactics at Utrecht University.*
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57. Buijs, K. (2008). *Leren vermenigvuldigen met meercijferige getallen.*
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32. Van den Heuvel–Panhuizen, M., & Vermeer, H. J. (1999). *Verschillen tussen meisjes en jongens bij het vak rekenen – wiskunde op de basisschool – Eindrapport MOOJ–onderzoek.*
31. Beeftink, C. (2000). *Met het oog op integratie – Een studie over integratie van leerstof uit de natuurwetenschappelijke vakken in de tweede fase van het voortgezet onderwijs.*
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12. Zuidema, J., & Van der Gaag, L. (1993). *De volgende opgave van de computer.*
11. Gravemeijer, K., Van den Heuvel–Panhuizen, M., Van Donselaar, G., Ruesink, N., Streefland, L., Vermeulen, W., Te Woerd, E., & Van der Ploeg, D. (1993). *Methoden in het reken–wiskundeonderwijs, een rijke context voor vergelijkend onderzoek.*
10. Van der Valk, A. E. (1992). *Ontwikkeling in Energieonderwijs.*
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